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Tank mix application of selected herbicides and insecticides for weed and insect control in transplanted rice

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ABSTRACT

Post-emergence application of two insecticide molecules chloropyriphos 200 g/ha, fipronil 50 g/ha and three herbicide molecules chlorimuron-ethyl + metsulfuron-methyl at 4 g/ha, bispyribac-sodium at 25 g/ha, cyhalofop-butyl + penoxsulam at 135 g/ha were tested alone as well as in combination with an untreated control against grass, sedge, broad-leaf weed and stem borer for their compatibility during winter seasons 2015-16 and 2016-17. Tank mix application of cyhalofop-butyl + penoxsulam + fipronil (135 + 50 g/ha) recorded lowest incidence of dead heart (0.59%), white ear (3.53%), total weed density (8 no./m^2) and weed biomass (3.5 g/m^2) and enhanced weed control efficiency (84.6%), grain yield (5.23 t/ha), net returns (` 40.44 x10^3/ha) and benefit : cost ratio (2.02). Dead heart percentage was less (0.59 to 1.55%) in sole fipronil and its combination with different herbicide than that of chloropyriphos (0.92 to 1.92%). There was no difference in grain yield of rice in treatments, which received application of cyhalofop-butyl + penoxsulam alone and with fipronil indicating the compatibility of herbicide with insecticide.

Key words: Herbicide and insecticide mixture, Tank mix application, Transplanted rice, Weeds

Rice is grown primarily by manual transplanting of seedlings in puddle soil. Weed infestation along with insect pests are two major biotic stresses, which occurs simultaneously and damage rice crop under field conditions. Higher weed infestation is a major constraint in water deficient transplanted rice ecosystems. Post-emergence application of herbicide was found effective in controlling weeds in transplanted rice (Tripathy *et al*. 2016). Chlorimuron-ethyl + metsulfuron-methyl, bispyribac-sodium and cyhalofop-butyl + penoxsulam are new generation post-emergence broad spectrum herbicides introduced for control of all types of weeds in transplanted rice. Similarly chloropyriphos and fipronil are popularly used to control the incidence of major pest. Sequential application of herbicides and insecticides are labour consuming and sometimes less effective. Therefore combined application of herbicide and insecticide as tank mixture may save time and labour.

Change in physical and chemical properties in combinations could lead to enhancement or reduction in the efficacy of either of the two compounds. Knowledge of combined application of various chemicals can be helpful in the formulation and adoption of a sound and cost effective pest control. It can also help to exploit the synergistic and antagonistic interactions between various pesticides for an effective eradication of pest problems. Instead of sequential application of herbicide, insecticide, fungicide and fertilizer, it is advantageous to tank mix suitable agrochemicals to control weeds as well as other pest co-existing in the crop to save labour, time and increase input use efficiency. However, these chemicals should be compatible with each other. Individual effects of insecticides were studied widely but very little information is available for combined effects of pesticides (Singh 2000). Interactions between different group of pesticides (fungicides, insecticides and herbicides) can lead to better management of pest and diseases of rice (Prakash *et al.* 2013, Karthikeyan 2015). Keeping this in view, this trial was laid out to evaluate the compatibility of selected insecticides and herbicides as tank mix.

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MATERIALS AND METHODS

Field experiment was conducted at Regional Research and Technology Transfer Station, Chiplima, Odisha, during winter seasons 2015-16 and 2016-17. 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 268.0, 13.4 and 132.0 kg/ha, respectively. Thirty 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 half dose of N and K_2O were applied as basal and remaining N and K_2O were 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. Pre-emergence application of pretilachlor 750 g/ha was given to all the treatments. The experiment consisted of 12 treatments including sole and combined application of two insecticides and three herbicide molecules along with an untreated control (**Table 1**). The sprays were made at 20 DAT with a knapsack sprayer fitted with flood jet nozzle. The observations were made a week after spraying on per cent tiller damage (dead heart) at vegetative stage and white ear at reproductive stage for yellow stem borer (*Scirpophaga incertulas* Walker) and incidence of weeds. The grain yield was recorded in t/ha and the experiments were laid out using completely randomized block design (RBD). The treatments were replicated thrice.

For weight assessment, samples were kept at low temperature to minimize loss through respiration and then put to air circulating ovens at 85 ^{0}C for 16 hours (Klingman 1971). Weeds were separated into three broad classes of grass, sedge and broad-leaf before drying.

As a lab study, emulsion stability test was conducted. Recommended spray concentration of herbicide insecticide 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). The data were statistically analyzed in RBD as per Gomez and Gomez (2010).

RESULTS AND DISCUSSION

Laboratory study

No sediment at the bottom or floating creamy material at surface was found in any of the combinations. Hence it confirms that the herbicides like chlorimuron-ethyl + metsufuron-methyl or bispyribac-sodium or cyhalofop-butyl + penoxsulam can be used in combination with insecticides like chloropyriphos or fipronil.

Effect on stem borer

Dead heart percentage was less (1.55 to 1.92%) in sole insecticide treated plot than sole herbicide treated plots. Fipronil was more effective than that of chloropyriphos for control of stem borer in rice (**Table 1**). The incidence of dead hearts and white ear

Table 1. Effect of treatments on dead heart, white ear and crop injury in rice (mean data of 2 years)

Treatment	Stem borer		Crop injury	
	(DH %) 50 DAT	(WE %) harvest	(5 DAA)	(15 DAA
Chloropyriphos (200 g/ha) 20 EC 20 DAT	1.71(1.92)	2.52 (5.37)	1.0	1.0
Fipronil (50 g/ha) 80 WG 20 DAT	1.59 (1.55)	2.16 (3.70)	1.0	1.0
Chlorimuron-ethyl + metsulfuron-methyl (Almix) ready mix (4 g/ha) 20 WP20 DAT	2.81 (6.92)	2.81 (6.92)	1.0	1.0
Bispyribac -sodium (25 g/ha) 10 SC 20 DAT	2.76 (6.67)	2.76 (6.67)	1.2	1.0
Cyhalofop-butyl + penoxsulam (Vivaya) ready mix (135 g/ha) 6.1 OD 20 DAT	2.73 (6.47)	2.73 (6.47)	1.3	1.0
Chloropyriphos + chlorimuron-ethyl + metsulfuron-methyl (200 + 4 g/ha) 20 DAT	1.48 (1.21)	2.38 (4.70)	1.2	1.0
Chloropyriphos + bispyribac-sodium (200 + 25 g/ha) 20 DAT	1.38 (0.92)	2.32 (4.40)	1.3	1.0
Chloropyriphos + cyhalofop-butyl + penoxsulam (200 + 135 g/ha) 20 DAT	1.43 (1.07)	2.39 (4.73)	1.4	1.0
Fipronil + chlorimuron-ethyl + metsulfuron-methyl (50 + 4 g/ha) 20 DAT	1.42 (1.04)	2.25 (4.07)	1.3	1.0
Fipronil + bispyribac -sodium (50 + 25 g/ha) 20 DAT	1.34 (0.82)	2.15 (3.63)	1.4	1.0
Fipronil + cyhalofop-butyl + penoxsulam (50 + 135 g/ha) 20 DAT	1.25 (0.59)	2.12 (3.53)	1.4	1.0
Control (weedy check)	2.97 (7.87)	2.97 (7.87)	1.0	1.0
LSD (P=0.05)	0.99	0.47	1.01	-

Figures in parentheses represent the original values, which were subjected to square root transformation ($\sqrt{x+1}$) before analysis, DH- dead heart, WE – white ear, DAT- days after transplanting, DAA – days after application, Crop injury is measured on a scale 1-10, 1= no crop injury and 10 = complete crop destruction were also low in all other combinations of insecticides and herbicides over sole application of either of them and over control. Among combined application, fipronil + cyhalofop-butyl + penoxsulam suffered less due to dead heart (0.59%) and white ear (3.53%) damage caused by stem borer followed by fipronil + bispyribac-sodium (0.82 and 3.53%) and fipronil + chlorimuron + metsulfuron (1.07 and 3.63%), respectively. Tank mixing of insecticides with herbicides did not reduce the efficiency of the insecticide against stem borer. Hence, they are compatible with each other for tank mix spray application to control rice pest. These are in conformity with the findings of Deepa and Jayakumar (2008).

Crop injury

The visual toxicity ratings were used to quantify the crop tolerance to the herbicide. In qualitative assessment, the plants in control (weedy check) were used as reference. Chlorimuron + metsulfuron, bispyribac-sodium, cyhalofop + penoxsulam applied alone or in combination with insecticides chloropyriphos or fipronil did not show any crop injury symptoms (**Table 1**). None of the treatments had any toxicity on the rice crop in terms of crop stand, crop growth, yellowing, necrosis, scorching, epinasty and hyponasty. Similar results were reported by Deepa and Jayakumar (2008) for control of weed and insect in rice.

Effect on weeds

The major weed flora in the experimental field comprised of grasses *Echinochloa crusgalli* (L.), *Echinochloa colona* (L.), *Digitaria sanguinalis* (L.) Scop., *Panicum repens* (L.), *Leptochloa chinensis* (L.) *Paspalum distichum* (L.); sedges *Cyperus difformis* (L.), *Fimbristylis miliacea* (L.) Vahal; Scirpus juncoides and broad-leaved weeds (BLW) *Ludwigia paraviflora* (L.), *Ammania baccifera* (L.), *Eclipta prostrata* (L.), *Eclipta alba* (L.), *Lippa nodiflora* Nich, *Marsilea quadrifolium* (L.), *Sphenoclea zeylanica* Gaertn., *Commelina benghalensis* (L.). The composition of grasses, sedges and broad-leaved weeds in weedy check plot was 25.4, 50.9 and 23.5%, respectively. Emergence of sedges and broad-leaved weeds were noticed earlier as compared to grasses.

At 50 DAT, the densities of all the weeds were influenced significantly due to various combinations of herbicides with insecticides. Compatible mixture of cyhalofop + penoxsulam with fipronil or chloropyriphos was found more effective to control the density of grass, sedges and broad-leaf weeds than chlorimuron-ethyl + metsulfuron-methyl with fipronil or chloropyriphos. All the herbicidal treatments were able to reduce the density of weed as compared to weedy check (**Table 2**).

Weed control efficiency (WCE) of herbicides and insecticides tank mixture were superior to their

Table 2. Effect of treatments on weed density, biomass and weed control efficiency (WCE) at 40 days after transplanting in rice (mean data of 2 years)

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				WCE (%)
	Grass	Sedge	BLW	Total	Grass	Sedge	BLW	Total	
Chloropyriphos (200 g/ha) 20 EC 20 DAT	3.9(14)	4.8(23)	3.4(11)	7.0(48)	2.8(6.7)	3.3(9.9)	2.3(4.2)	4.7(20.7)	9.2
Fipronil (50 g/ha) 80 WG 20 DAT	3.5(11)	5.2(26)	3.4(11)	7.1(49)	2.5(5.4)	3.5(11.6)	2.2(4.1)	4.7(21.0)	7.8
Chlorimuron-ethyl + metsulfuron-methyl (Almix) ready mix (4 g/ha) 20 WP20 DAT	2.5(5)	3.2(10)	1.9(3)	4.3(18)	1.9(2.6)	2.2(4.2)	1.4(1.0)	3.0(7.8)	65.8
Bispyribac -sodium (25 g/ha) 10 SC 20 DAT	2.2(4)	2.9(8)	1.9(3)	3.9(14)	1.7(1.9)	2.1(3.4)	1.4(1.0)	2.7(6.2)	72.8
Cyhalofop-butyl + penoxsulam (Vivaya) ready mix (135 g/ha) 6.1 OD 20 DAT	1.9(3)	2.5(5)	1.8(2)	3.4(11)	1.5(1.4)	1.8(2.2)	1.4(0.9)	2.4(4.6)	79.8
Chloropyriphos + chlorimuron-ethyl + metsulfuron-methyl (200 + 4 g/ha) 20 DAT	3.5(11)	3.3(10)	1.9(3)	5.0(24)	2.5(5.4)	2.3(4.2)	1.4(1.0)	3.4(10.7)	53.1
Chloropyriphos + bispyribac-sodium (200 + 25 g/ha) 20 DAT	3.4(11)	2.9(7)	1.6(1)	4.5(19)	2.5(5.1)	2.0(3.1)	1.2(0.5)	3.1(8.8)	61.4
Chloropyriphos + cyhalofop-butyl + penoxsulam (200 + 135 g/ha) 20 DAT	2.8(9)	2.6(6)	1.8(2)	4.3(17)	2.1(4.2)	1.9(2.7)	1.4(0.9)	3.0(7.8)	65.7
Fipronil + chlorimuron-ethyl + metsulfuron-methyl (50 + 4 g/ha) 20 DAT	3.0(9)	2.4(5)	1.9(3)	4.2(17)	2.2(4.2)	1.8(2.3)	1.4(1.1)	2.9(7.6)	66.7
Fipronil + bispyribac -sodium (50 + 25 g/ha) 20 DAT	2.1(3)	2.4(5)	1.8(2)	3.4(10)	1.6(1.6)	1.7(2.1)	1.4(0.8)	2.3(4.5)	80.2
Fipronil + cyhalofop-butyl + penoxsulam (50 + 135 g/ha) 20 DAT	1.8(2)	2.3(4)	1.4(1)	3.0(8)	1.5(1.2)	1.7(1.9)	1.2(0.4)	2.1(3.5)	84.6
Control (weedy check)	3.7(13)	5.2(26)	3.5(12)	7.2(51)	2.8(6.8)	3.5(11.5)	2.3(4.5)	4.9(22.8)	0.0
LSD (p=0.05)	0.9	0.8	0.8	0.7	0.6	0.5	0.4	0.4	

Figures in parentheses represent the original values and are subjected to square root transformation ($\sqrt{x+1}$) before analysis, BLW – Broad leaf weeds, WCE – Weed control efficiency sole application. The WCE with respect to grass, sedge and broad-leaved weeds was the highest (84.6%) with application of cyhalofop-butyl + penoxsulam with fipronil followed by the same insecticide with bispyribac-sodium (80.2%). The higher WCE in these treatments might be due to better crop stand resulting in smothering of weeds leading to lower weed growth and dry matter accumulation as compared to other treatments. The results are in conformity with the findings of Singh *et al.* (2015), who observed the synergistic effect of tank mix application of penoxsulam + cyhalofop-butyl (150 g/ha) along with chloropyriphos (125 g/ha) for weed control in rice. The lowest WCE (7.8 to 9.2%) was recorded in only insecticide treated plots.

Effect on crop

Effective tillers/m^2 (442), grains/panicle (137), panicle length (23.8 cm) and test weight (23.7 g) were the highest with fipronil + cyhalofop-butyl + penoxsulam and were superior to weedy check (**Table 3**). The complex weed flora comprised of grasses, sedges and broad-leaf weeds showed reduction of 28.5% in grain yield in the weedy check compared to this treatment (5.23 t/ha). Sole application of chlorimuron + metsulfuron, bispyribac-sodium, cyhalofop + penoxsulam recorded lower grain yield as compared to their tank mix application with chloropyriphos or fipronil. The lowest yield (3.91 t/ha) was with the application of chlorimuron + metsulfuron with chloropyriphos at 4 + 200 g/ha. This differential response might be due to difference in nature of weeds, herbicides, insecticides or environmental conditions (Chhokar *et al.* 2013).

Mixed application of fipronil with chlorimuron + metsulfuron, bispyribac-sodium, cyhalofop + penoxsulam resulted in significantly higher yield than their sole application due to better control of all grasses, sedges and broad-leaf weeds. Application of chlorimuron + metsulfuron, bispyribac-sodium, cyhalofop + penoxsulam alone increased yield by 4.3, 13.0 and 19.3% and resulted in an average increase of 9.8, 24.1 and 28.4%, respectively with fipronil as compared to weedy check. Chlorimuron + metsulfuron, bispyribac-sodium, cyhalofop + penoxsulam were compatible with fipronil and chloropyriphos, as their mode of action is different in the plant. All the three herbicides inhibit the plant enzyme acetolactate synthase (ALS), which is essential for the synthesis of branched chain amino acids. Inhibition of amino acid production subsequently inhibits cell division. Insecticide chloropyriphos inhibits breakdown of acetyl choline, a neurotransmitter and fipronil block gaba-gated chloride channel of stem borer.

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

Treatment	Tillers/ m^2	Panicle length (cm)	Grains/ panicle	Test weight (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
Chloropyriphos (200 g/ha) 20 EC 20 DAT	351	22.6	99	22.8	3.94	5.1	59.63	35.77	23.86	1.67
Fipronil (50 g/ha) 80 WG 20 DAT	372	22.9	102	23.2	3.95	5.5	60.09	36.74	23.35	1.64
Chlorimuron-ethyl + metsulfuron-methyl (Almix) ready mix (4 g/ha) 20 WP20 DAT	380	23.4	104	23.5	3.91	6.1	60.01	36.02	23.99	1.66
Bispyribac -sodium (25 g/ha) 10 SC 20 DAT	405	23.5	106	23.6	4.30	6.1	65.51	37.16	28.35	1.76
Cyhalofop-butyl + penoxsulam (Vivaya) ready mix (135 g/ha) 6.1 OD 20 DAT	408	23.6	112	23.5	4.64	6.3	70.46	37.90	32.56	1.86
Chloropyriphos + chlorimuron-ethyl + metsulfuron-methyl (200 + 4 g/ha) 20 DAT	388	23.7	110	23.6	3.97	5.8	60.62	36.69	23.93	1.65
Chloropyriphos + bispyribac-sodium (200 + 25 g/ha) 20 DAT	418	23.7	129	23.6	4.80	6.6	72.96	37.66	35.30	1.94
Chloropyriphos + cyhalofop-butyl + penoxsulam (200 + 135 g/ha) 20 DAT	438	22.5	131	23.4	4.84	7.0	73.84	37.83	36.01	1.95
Fipronil + chlorimuron-ethyl + metsulfuron-methyl (50 + 4 g/ha) 20 DAT	390	23.3	110	23.5	4.15	6.4	63.63	38.80	24.84	1.64
Fipronil + bispyribac -sodium (50 + 25 g/ha) 20 DAT	440	23.8	137	23.6	4.93	7.2	75.27	38.57	36.70	1.95
Fipronil + cyhalofop-butyl + penoxsulam (50 + 135 g/ha) 20 DAT	442	23.8	137	23.7	5.23	7.8	79.98	39.54	40.44	2.02
Control (weedy check)	349	20.8	93	23.2	3.74	5.0	56.73	35.10	21.63	1.61
LSD (p=0.05)	106.58	NS	48.75	NS	0.66	1.85				

Input price (`/kg): Rice seed, 14.10; straw, 8; urea, 5.52; di-ammonium phosphate, 24.45; muriate of potash, 17.44; chloropyriphos 20 EC, ` 270/L; fipronil 80 WG, ` 40/2 g; chlorimuron + metsulfuron 20 WP, ` 207/8 g, bispyribac-sodium 10 EC ` 660/100 ml, cyhalofop-butyl + penoxsulam, ` 1200/L.

Rice yield was 4.64 t/ha following application with cyhalofop + penoxsulam applied alone and a similar yield of 5.23 t/ha when tank-mixed with fipronil (**Table 3**). No significant difference in yield between herbicide + insecticide mixtures and herbicide alone indicate compatibility of insecticide with herbicide. Miller *et al*. (2010) reported no reduction in seed cotton yield following post-emergence application of insecticides with glyphosate.

Economics

All the herbicides and insecticides alone or in tank mix application recorded higher monetary returns than their sole application and weedy check (**Table 3**). Among the chemical weed control treatments, cyhalofop-butyl + penoxsulam + fipronil gave the maximum net returns (40.44 x 10^3 `/ha) and benefit: cost ratio (2.02) followed by same insecticide with bispyribac-sodium (36.70 x $10^3$ `/ha and 1.95, respectively) owing to low cost and high grain yield as compared to other post-emergence herbicides and insecticides.

It can be concluded that fipronil or chloropyriphos can be safely tank mixed with chlorimuron + metsulfuron or bispyribac-sodium or cyhalofop + penoxsulam, as no crop injury has been observed. Fipronil and cyhalofop + penoxsulam mixtures offer farmers the ability to integrate pest management strategies and limit application costs without sacrificing crop yield.

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Long term application of herbicides on soil microbial demography in rice - rice cropping sequence of North-East India

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ABSTRACT

Field study was carried out to determine the long term effect of herbicide application on soil microbial community in rice- rice cropping sequence in acid soil of North-East India. Treatment comprised of absolute control with one hand weeding, butachlor + 2,4-D with 100% NPK through chemical fertilizer, butachlor + 2,4-D with 75% NPK through chemical fertilizer and 25% through organic source, butachlor + 2,4-D rotated with pretilachlor with 100% NPK through chemical fertilizer and butachlor + 2,4-D rotated with pretilachlor with 75% NPK through chemical fertilizer 25% through organic source. Result revealed that, after 14 years of continuous use of herbicide and organic input along with recommended dose of fertilizer application demonstrated significant increase in the activity of acid phosphatase. The effect of herbicide application was more prominent with sole chemical fertilizer than with organic manure for 25% N fertilizer replacement. Dehydrogenase activity in soil was increased following herbicide application up to 14 days after that it again decreased more prominent with addition of organic manure than with chemical fertilizer. No characteristic trend of urease activity was observed after application of herbicide. Significant inhibition of respiration was observed after application of herbicide up to 14 days followed by gradual recovery afterwards. Microbial biomass carbon in soil was significantly enhanced by application of organic manure for 25% N fertilizer substitution. Under rice-rice cropping system, application of herbicide showed temporary decline in microbial population and enzyme activities up to 14 days. Application of organic manure for 25% N fertilizer substitution significantly enhanced the microbial population and enzyme activities as compared to sole application of chemical fertilizers. Further application of butachlor rotated with pretilachlor resulted in higher microbial population as well as enzyme activities.

Key words: Demography, Herbicide, Microbial community, Rice-Rice sequence, Soil enzyme, Soil respiration

Weed management is an ever-present challenge to crop production. Weeds have the potential to reduce resources that would otherwise provide nourishment to growing crops or interfere with planting or harvesting operations. Due to negative impacts of weed in crop production, it should be aimed at reducing its populations usually through mechanical disturbance or chemical applications. Since weed management through mechanical and cultural methods is not feasible due to morphological similarity between the crop and weeds and scarcity of labour in the peak period of transplanting, weed management through herbicide practices is more promising for farmers. Butachlor and pretilachlor, member of the chloroacetanilide group of herbicides, are used for the selective control of annual weeds in rice fields. Both are most commonly used herbicides to control a wide range of annual grass and broad-leaf weeds. However application of such chemicals may exert an effect upon the soil microbes (Wardle and Parkinson1990) and their biological activities. An unintended consequence of the application of herbicides is that it may lead to significant changes in the soil microbial population and their activities thereby influencing the microbial ecological balance in the soil (Saeki and Toyota 2004) and affecting the productivity of soils. For optimizing and sustaining natural resources, the soil microbial population play an important role in carbon stock, nutrient cycling, organic matter decomposition which in turn affect soil fertility and plant growth.

Application of herbicides may affect the non-target organism including soil microorganisms is the major concern with the use of xenobiotic compounds in rice ecosystem (Latha and Gopal 2010). A large portion of these chemicals accumulates in the top layer soil where most of the microbiological activities occur. As a result, there is a loss in microbial biodiversity and that can affect the functional stability of the soil microbial community and soil health. Many soil enzymes can be used as indicators of soil quality

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for sustainable management because they are sensitive to ecological stress and land management (Benedetti and Dilly 2006). Evidence of the stimulation effect of herbicides on soil biochemical properties has been earlier reported (Garcia-Ruiz *et al*. 2008), even if herbicides are not designed to directly interact with soil enzymes. Long term use of herbicide with or without organic matter may alter the soil organic carbon, which ultimately affect the soil health. Microbes like bacteria, fungi, algae, protozoa and some nematodes have significant role in sustaining soil and crop productivity. Various soil microbial processes, enzymatic activities are affected by the time and application of herbicide. In cognizance with the above, a study was carried out to determine the long term effect of herbicide application on soil microbial community in rice-rice cropping sequence.

MATERIALS AND METHODS

The study area was located at 26°44'N and 94°12'E and at an altitude of 91.0 m above mean sea level. The climatic condition of the site is sub-tropical having humid summer and cold winter with total annual rainfall 2124 mm. The soil of the experimental site was sandy clay loam in texture. The experiment was laid down in randomized block design (RBD) replicated thrice with five treatment combinations *viz*. absolute control with one hand weeding, butachlor + 2,4-D with 100% NPK through chemical fertilizer, butachlor + 2,4-D with 75% NPK through chemical fertilizer, 25% through organic source, butachlor + 2,4-D rotated with pretilachlor with 100% NPK through chemical fertilizer and butachlor + 2,4-D rotated with pretilachlor with 75% NPK through chemical fertilizer, 25% through organic source. The plot of each treatment was 100 sq m in size.

Field trials were carried out for 14 years (2001-2015) with two rice crops in rice-rice cropping sequence during winter and summer season. Two sources of nitrogen (N) *viz*. inorganic to supply 100% N and organic (FYM) to supply 25% N were used as per the treatment. Weed management treatments include hand weeding, pre-emergence, herbicides in combination and pre emergence herbicides in rotation. Crop varieties used in the sequence were '*Ranjit (TTB 101-17)*' and '*Luit*'. Recommended dose of fertilizer *i.e.*, 40:20:20 and 60:20:40 N: P_2O_5: K_2O for autumn and winter rice, respectively were applied as per-recommended practice. The organic manure was applied to each crop in the respective treatment to substitute 25% of N fertilizer. During 2001 to 2005, FYM was used and there after vermicompost 2 t/ha (total N 1.4-1.5%, P 1.0-1.1% and K 1.5-1.8%) is being used as organic manure for partial substitution of N-fertilizer. However, the amount of P and K supplied through organic manure was not adjusted and recommended doses were applied through mineral fertilizers. Observations were made on soil biological properties at the end of the 26th and 27th rice crop (winter – autumn rice). (two crops in a year)

The classical serial dilution technique was used for enumeration of *Azotobacter* and PSB by spread plate technique on Burks media and Pikovskaya's solid media, respectively. Rhizosphere soil sample of 1g was suspended in 9 ml water blank, followed by serially diluted up to 10^4 and 10^5. Aliquots of 100 µl of 10^4 and 10^5 dilutions were spread over the solidified media in triplicates and plates were incubated at 30±2°C for phosphate solubulizing bacteria (PSB) while nitrogen fixing bacteria (NFB) plates were incubated at 35±2 °C for 3 days. The microbial population were estimated as colony forming unit (cfu) per gram soil on dry weight basis and transformed to log cfu/g.

Microbial biomass carbon (MBC) was determined by chloroform fumigation extraction technique following the method of Vance *et al*. (1987). Field moist soil (25 g) was fumigated with ethanol free chloroform at 25 °C for 24 hours. After fumigation, chloroform vapours were removed by repeated evacuation. The soil samples were then extracted with 100 ml 0.5M K_2SO_4 (1:4 soil: K_2SO_4). Controls were prepared by extracting soils without fumigation. The soil suspension was filtered through Whatman No 42 filter paper. Dehydrogenase (DH) activity was determined by the reduction of triphenyltetrazolium chloride (TTC) to triphenyl-formazan (TPF). Briefly, field moist soil (1g) was treated with one ml of 3% TTC, and then incubated at 28°C for 24 hours. To account for any abiotic TTC reductions, sterile controls consisted of autoclaved soil (121°C, 20 min. on three consecutive days) were used. Spectrophotometer blanks for both autoclaved and non-autoclaved treatments consisted of soil and TTC replaced with millipore water. The optical density at 485 nm was compared to that of triphenylformazan standards. DH activity was expressed on dry weight as ìg TPF/g dry soil /24hr. Phosphomonoesterase (PMEase) activities involve the use of an artificial substrate, *p*-nitrophenyl phosphate (*p*-NPP). The product of phospho-monoesterase activity, *p*-nitrophenol, a chromophore under alkaline conditions were detected colorimetrically following the method of Tabatabi and

Bremner (1969) and expressed as ìg *p*-nitrophenol/g dry soil/hr. Urease activity in soil was estimated by incubating the soil sample with (hydroxymethyl) aminomethane (THAM) buffer, Urea solution and toluene at $37^{o}C$ for two hours with 2.5M KCl solution containing a Urease inhibitor (Ag_2SO_4) and steam distilled with MgO.

The initial values were for *Azotobacter* count 18.0 $x10^4$cfu gm, PSB population 16.0$x10^4$cfu gm, dehydrogenase activity 110.6 µg TPFg soil 7 days, phosphomonusterase activity 270.86 µg p-nitrophenol g soil h, urease activity 210.72 µg NH_4 g soil 2h, soil respiration 1.65 µg CO_2 –C g dw hr, microbial biomass carbon 365.5 µg g soil .

The technique of analysis of variance was used in RBD for statistical analysis of data obtained from various treatment studies. For statistical significance the difference between the treatment means was tested with DMRT test.

RESULTS AND DISCUSSION

Azotobacter and PSB population

The *Azotobacter* and PSB populations in soil with rotational application of pre-emergence herbicide *i.e.* butachlor in autumn rice and pretilachlor in winter rice showed relatively higher values compared to one that was continuously subject to butachlor application (**Table 1**). This might be due to the fact that butachlor is known to have more inhibitory effect to microbial population and soil enzyme activities than pretilachlor (Latha and Gopal 2010). Significant variation in *Azotobacter* population were recorded in different treatments. The population count of *Azotobacter* were significantly higher in farmers practice with one hand weeding in each crop and with the combination of herbicide and organic manure for partial N fertilizer substitution. Moreover, a higher *Azotobacter* and PSB populations in soil was observed during autumn season over the winter season. On the contrary, highest inhibition recorded with the sole application of chemical fertilizer. Inhibitory effects of butachlor and pretilachlor on population of nitrogen fixing bacteria in rice rhizosphere had been reported (Barman *et al.* 2009) and confirm to the observation of the present study. *Azotobacter* population decreased sharply up to 14 days after application of herbicide after which it showed an increasing trend. Highest inhibition recorded with the sole application of chemical fertilizer. The significant reduction in the population of *Azotobacter* in herbicide treated plots may be ascribed to the negative effect of herbicides on *Azotobacter* (Barman *et al.* 2009). Similar trend was observed with the PSB population. Most of the herbicides exhibited detrimental influence on soil microflora upto 15 days after application which was recovered later on. Balasubramanian and Sankaran (2001) also reported initial suppression of soil microflora on herbicide application in different soils. The toxic effect of herbicides normally appears immediately after the application when their

Table 1. Population dynamics of *Azotobacter* and PSB in soil during autumn and winter rice as affected by herbicide application in rice-rice sequence (cfu x 10^4/g)

Treatment	Autumn					Winter				
	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA
Azotobacter										
Farmers practice (one hand weeding)	25.00^{a}	28.00^{a}	25.33^{a}	27.00^{a}	25.33^{a}	17.66^{a}	22.67^{a}	19.00^{a}	18.00^{a}	20.00^{a}
Butachlor + 2,4-D (100% NPK TCF)	13.67^{c}	9.67^{d}	10.67^{c}	12.67^{d}	14.67^{c}	12.33^{c}	8.33^{c}	8.67^{d}	11.67^{d}	14.00^{d}
Butachlor + 2,4-D (75% NPK TCF 25% TOS)	18.33^{b}	14.00^{b}	15.00^{b}	17.67^{c}	20.67^{b}	14.67^{bc}	9.67^{c}	9.67^{b}	12.67^{c}	17.33^{b}
Butachlor + 2,4-D rotated with pretilachlor (100% NPK TCF)	14.67^{c}	11.67^{c}	10.33^{c}	13.00^{d}	17.67^{c}	13.00^{bc}	9.00^{c}	9.33^{c}	11.67^{cd}	15.00^{d}
Butachlor + 2,4-D rotated with pretilachlor (75% NPK TCF, 25% TOS)	19.00^{b}	14.33^{b}	15.67^{b}	19.00^{b}	23.00^{ab}	15.00^{b}	10.00^{b}	11.67^{b}	16.00^{b}	17.67^{c}
PSB										
Farmers' practice (one hand weeding)	20.67^{a}	21.33^{a}	19.67^{a}	19.00^{a}	22.00^{a}	15.00^{a}	17.00^{a}	14.00^{a}	16.00^{a}	17.33^{a}
Butachlor + 2,4-D (100% NPK TCF)	10.33^{d}	6.33^{c}	7.00^{d}	11.00^{e}	13.33^{e}	7.33^{d}	4.33^{d}	3.67^{d}	7.33^{e}	10.00^{e}
Butachlor + 2,4-D (75% NPK TCF 25% TOS)	13.00^{c}	9.67^{b}	8.67^{c}	12.67^{c}	17.67^{c}	10.00^{c}	7.67^{b}	8.33^{b}	11.33^{c}	14.00^{c}
Butachlor + 2,4-D rotated with pretilachlor (100% NPK TCF)	11.00^{d}	7.00^{bc}	7.33^{d}	11.67^{d}	15.67^{d}	8.33^{d}	6.00^{c}	5.67^{c}	9.67^{d}	12.33^{d}
Butachlor + 2,4-D rotated with pretilachlor (75% NPK TCF , 25% TOS)	14.67^{b}	11.67^{b}	11.33^{b}	15.00^{b}	20.00^{b}	12.00^{b}	8.00^{b}	9.33^{b}	13.00^{b}	15.67^{b}

Values with same letters are not statistically significant, DAA- Days after application; TCF - Through chemical fertilizer; TOS - Through organic source concentration in soil is highest. Later on, microorganisms take part in degradation process and herbicide concentration in soil and their toxic effects decrease (Radivojevic *et al.* 2004).

Soil enzymes

Organic acids produced during decomposition of organic manure tend to reduce soil reaction, which enhanced the enzyme activity (Reddy and Reddy 2009). Recovery of enzyme activities after the initial inhibition associated with the increased availability of nutrients due to the degradation of herbicides was reported by Ismail *et al.* (1998). Significant increased in dehydrogenase activity was recorded in flooded rice soils treated with herbicide with or without organic manure (**Table 2**). Significant increase in dehydrogenase activity with application of butachlor was recorded highest being at 14 days after application and that decreased gradually. The result is in accordance with the result of Vandana *et al.* (2012). Addition of organic manure for partial substitution of N fertilizer significantly increased dehydrogenase activity in soils than application of inorganics alone because of substitution of organic sources increased the availability of substrate for dehydrogenase activity (Chaudhury *et al.* 2005). Dehydrogenase activity is known to have strong correlation with organic carbon content and thus addition of organic manure resulted in more soil dehydrogenase activity in the study (Madejon *et al.* 2007). The anaerobic microorganisms could effectively degrade butachlor in paddy soil. Since dehydrogenase is mostly produced by anaerobic microorganisms under anaerobic condition, such as sulphate-reducing bacteria, this might have led to increase in dehydrogenase activity. Tejada and Gonzalez (2009) reported that the increased in dehydrogenase activity in submerged soil attributed to the increase in the anaerobic microbial population and shift from aerobic to anaerobic microbes ones after a soil is flooded. The applied organic sources were able to provide sufficient nutrition for proliferation for microbes and their activities in terms of soil dehydrogenase activity. A balanced amount of NPK and organic manures will increase the enzyme activity (Joa 2010).

Phosphatases are often measured because of their importance in phosphorus cycles (Aon and Colaneri 2001). Apart from being good indicators of soil fertility, phosphatase enzyme plays a key role in the soil system (Dick *et al.* 2000). PMEase is an enzyme of agronomic value because it hydrolyses compounds of organic P and transforms them into inorganic P. The activity of acid phosphatase in soil is significantly affected by herbicide application compared to farmers practice with one hand weeding. Application of herbicide resulted in inhibition of acid phosphatase activity and increased after 14 days of application of herbicide. The PMEase activity was highest in control plots that received only one hand weeding at 40 days after transplanting (DAT) and decreased in soil with application of herbicide with or without organic matter (**Table 3**). The result was in accordance with Wang *et al.* (2008). The increased acid phosphatase activity in organic manure treatments might be due to the added quantity of organic matter, which in turn increased organic carbon and nitrogen (Kadlag *et al.* 2008).

The activity of urease as influenced by the herbicide treatments (**Table 4**) recorded higher value with nutrient application as compared to control. It was observed that the significantly higher urease activity levels in herbicide treatments than the control for all the periods. Vandana *et al.* (2012) also reported that application of butachlor did not change the urease activity despite an initial increase during first ninety days after application. Among the herbicide treated soil, increase in urease activity with organic manure addition may be due to the positive effect of organic

Table 2. Activity of dehydrogenase enzyme in soil during autumn and winter rice as affected by herbicide application in rice-rice sequence (µg TPF g/dry soil/7 days)

Treatment	Autumn					Winter				
	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA
Farmers practice (one hand weeding)	118.3^{e}	123.1^{e}	128.4^{e}	125.8^{d}	121.8^{d}	108.5^{e}	115.1^{e}	103.8^{e}	106.7^{d}	110.6^{c}
Butachlor + 2,4-D (100% NPK TCF)	133.7^{d}	138.8^{d}	144.5^{d}	134.7^{c}	127.8^{c}	126.7^{d}	131.0^{d}	136.0^{d}	124.4^{c}	119.5^{b}
Butachlor + 2,4-D (75% NPK TCF 25% TOS)	142.7^{b}	149.7^{b}	152.5^{b}	139.7^{b}	135.8^{b}	136.5^{b}	143.6^{b}	147.2^{b}	134.8^{b}	128.7^{a}
Butachlor + 2,4-D rotated with pretilachlor (100% NPK TCF)	137.5^{c}	144.5^{c}	147.4^{c}	135.7^{c}	128.6^{c}	129.7^{c}	134.1^{c}	138.7^{c}	125.7^{c}	120.7^{b}
Butachlor + 2,4-D rotated with pretilachlor (75% NPK TCF , 25% TOS)	145.7^{a}	154.5^{a}	156.7^{a}	143.7^{a}	139.7^{a}	140.7^{a}	147.6^{a}	151.1^{a}	138.5^{a}	130.2^{a}

Values with same letters are not statistically significant, DAA- Days after application; TCF - Through chemical fertilizer; TOS - Through organic source manure in soil. Urease being a urea degrading enzyme, and does not mediate the degrading pathway of the herbicides and probably therefore remained unaffected by the herbicides. It appears that the herbicides were inert to urease producing microbes and so as to the urease activity. Mineral fertilization resulted in the lowest urease activity presumably by the small amounts of organic residues left in the soil (Balezentiene and Kilimas 2009). Though in general, application of chemical fertilizers stimulated the growth and multiplication of microorganisms, increased dosage was found to inhibit the survival of microbe due to osmotic stress created by fertilizers (Bharathi *et al.* 2011). A significant increase in soil enzyme activity of urease (78 ìg of NH_4^+/ g/ day), in unfertilized control plot was followed by 75% of RDF of NPK at 30 DAS. There is further reduction in enzyme activity when150% of RDF of NPK was applied due to the negative impact of higher dose of chemical fertilizers alone on survival of microorganisms.

Butachlor application on respiration showed a temporary inhibition within the earlier period (14 Days) after treatment and followed by a recovery during the later period in paddy soil (**Table 5**). The results are in conformity with the findings of Barman *et al.* (2009). The decline in the microbial population following herbicide application might have inhibited the respiration. It was observed that application of organic manure reduced the inhibition than application of sole chemical fertilizers. The higher enzyme activity in herbicide applied plots with organic manure addition may be ascribed to the significantly higher microbial population and activity compared to the plots with only chemical fertilizers (Bohme *et al.* 2005). The positive effect of organic manure addition may be ascribed to the significantly higher microbial population and activity compared to the plots with only chemical fertilizers. (Gu *et al.* 2009) or supply of substrates such as carbohydrates and amino acids (Bohme *et al.* 2005), which provide important sources of nutrients for microorganisms in the rhizosphere.

The microbial biomass of microorganisms is one of the important properties of ecological studies, which can be related to parameters describing microbial activity and soil health (Bolter *et al.*, 2006). The rising MBC accretion, established *Azospirillum* and PSB populations were extensively correlated with the PMEase activity signifying that compost and

Table 3. Activity of phosphatase enzyme in soil during autumn and winter rice as affected by herbicide application in rice-rice sequence (µg p-nitrophenol/g/dry soil/h)

Treatment	Autumn					Winter				
	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA
Farmers practice (one hand weeding)	288.2^{a}	285.6^{a}	290.4^{a}	287.6^{a}	294.7^{a}	245.8^{a}	242.3^{a}	249.9^{a}	250.7^{a}	246.8^{a}
Butachlor + 2,4-D (100% NPK TCF)	255.7^{e}	248.2^{e}	242.6^{e}	259.7^{e}	267.0^{e}	202.5^{e}	190.5^{d}	188.2^{d}	206.0^{e}	219.7^{d}
Butachlor + 2,4-D (75% NPK TCF 25% TOS)	265.0^{c}	255.3^{c}	252.3^{c}	268.7^{c}	275.7^{c}	210.4^{c}	204.5^{c}	202.0^{c}	222.3^{c}	234.4^{b}
Butachlor + 2,4-D rotated with pretilachlor (100% NPK TCF)	258.5^{d}	250.5^{d}	245.6^{d}	262.5^{d}	269.4^{d}	204.6^{d}	187.7^{e}	189.1^{d}	210.7^{d}	225.5^{c}
Butachlor + 2,4-D rotated with pretilachlor (75% NPK TCF , 25% TOS)	269.3^{b}	258.4^{b}	256.7^{b}	272.5^{b}	280.6^{b}	212.2^{b}	210.4^{b}	205.6^{b}	225.0^{b}	237.6^{b}

Values with same letters are not statistically significant, DAA - Days after application; TCF - Through chemical fertilizer; TOS - Through organic source

Table 4. Activity of urease enzyme in soil during autumn and winter rice as affected by herbicide application in rice-rice sequence (µg NH_4 g/soil/2h)

Treatment	Autumn					Winter				
	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA
Farmers practice (one hand weeding)	270.73^{e}	276.77^{e}	288.48^{d}	295.76^{c}	281.55^{d}	234.55^{d}	243.76^{d}	225.39^{e}	242.76^{c}	251.72^{e}
Butachlor + 2,4-D (100% NPK TCF)	285.54^{c}	292.62^{c}	268.50^{e}	278.58^{d}	267.59^{e}	226.70^{e}	255.87^{c}	267.76^{c}	236.71^{d}	247.80^{d}
Butachlor + 2,4-D (75% NPK TCF 25% TOS)	315.40^{a}	329.39^{a}	340.49^{a}	311.43^{b}	303.46^{b}	290.63^{a}	281.89^{b}	296.75^{a}	276.69^{b}	287.75^{a}
Butachlor + 2,4-D rotated with pretilachlor (100% NPK TCF)	279.04^{d}	287.64^{d}	294.79^{c}	265.76^{e}	292.43^{c}	242.79^{c}	230.57^{e}	254.61^{d}	229.61^{e}	265.64^{c}
Butachlor + 2,4-D rotated with pretilachlor (75% NPK TCF , 25% TOS)	309.65^{b}	301.62^{b}	317.03^{b}	331.65^{a}	336.82^{a}	280.83^{b}	289.50^{a}	280.62^{b}	295.83^{a}	281.50^{b}

Values with same letters are not statistically significant, DAA - Days after application; TCF - Through chemical fertilizer; TOS - Through organic source

Table 5. Soil respiration during autumn and winter rice as affected by herbicide application in rice –rice sequence (µg CO_2 –C g/dw/hr)

Treatment	Autumn					Winter				
	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA
Farmers practice (one hand weeding)	1.83[a]	1.75[a]	1.82[a]	1.74[a]	1.76[a]	1.56[a]	1.43[a]	1.65[a]	1.49[a]	1.47[a]
Butachlor + 2,4-D (100% NPK TCF)	1.17[e]	1.11[e]	1.08[e]	1.22[e]	1.33[d]	0.98[e]	0.89[e]	0.87[e]	1.06[e]	1.16[e]
Butachlor + 2,4-D (75% NPK TCF 25% TOS)	1.42[c]	1.33[c]	1.25[b]	1.56[c]	1.67[b]	1.25[c]	1.16[c]	1.13[c]	1.32[c]	1.34[c]
Butachlor + 2,4-D rotated with pretilachlor (100% NPK TCF)	1.27[d]	1.18[d]	1.15[d]	1.32[d]	1.41[c]	1.07[d]	0.97[d]	0.96[d]	1.23[d]	1.25[d]
Butachlor + 2,4-D rotated with pretilachlor (75% NPK TCF, 25% TOS)	1.58[b]	1.50[b]	1.22[c]	1.65[b]	1.76[a]	1.34[b]	1.27[b]	1.24[b]	1.38[b]	1.43[b]

Values with same letters are not statistically significant, DAA - Days after application; TCF - Through chemical fertilizer; TOS - Through organic source

Table 6. Microbial biomass carbon in soil during autumn and winter rice as affected by herbicide application in rice–rice sequence (µg/g)

Treatment	Autumn					Winter				
	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA	0 DAA	7 DAA	14 DAA	30 DAA	60 DAA
Farmers practice (one hand weeding)	387.34[c]	382.39[c]	419.42[c]	399.61[c]	410.41[c]	374.51[c]	367.35[c]	358.79[c]	355.19[c]	375.15[c]
Butachlor + 2,4-D (100% NPK TCF)	332.66[e]	319.49[e]	313.61[e]	330.26[e]	339.76[e]	299.57[e]	280.67[e]	270.57[e]	289.44[e]	304.21[e]
Butachlor + 2,4-D (75% NPK TCF 25% TOS)	452.59[b]	442.33[b]	439.39[b]	459.41[b]	461.32[b]	430.61[b]	425.29[b]	405.34[b]	412.86[b]	429.34[b]
Butachlor + 2,4-D rotated with pretilachlor (100% NPK TCF)	365.47[d]	359.21[d]	350.47[d]	368.53[d]	379.38[d]	337.62[d]	328.63[d]	318.45[d]	340.38[d]	322.49[d]
Butachlor + 2,4-D rotated with pretilachlor (75% NPK TCF, 25% TOS)	498.43[a]	479.58[a]	478.43[a]	486.49[a]	506.79[a]	468.48[a]	463.47[a]	444.25[a]	449.53[a]	458.19[a]

Values with same letters are not statistically significant, DAA - Days after application; TCF - Through chemical fertilizer; TOS - Through organic source

enriched compost plays an important role in protecting and maintaining soil enzymes in their active forms (Saha *et al.* 2008). The effect of butachlor on MBC was found to be highest on 14th day (**Table 6**). Increase in MBC in some herbicide treated soil may be due to the fact that some of the herbicides acting as the source of nutrients (Cook and Hutter 1981) in which case they significantly affect microbial growth and multiplication. However, the effect of herbicides is usually short-term and minor, when compared with natural, spatial and temporal variation in soil microbial biomass. The decrease in MBC may be due to the adsorption of small amount of pesticides on organic matter that mask the effects of these agrochemicals on soil microbial biomass, and subsequently led to hydrolysis of microbial cells (Jayamadhuri and Rangaswamy 2005). Herbicides affect various soil microbial processes (Johen and Drew 1977), inhibit decomposition (Grossbard and Wingfield 1978), which depends upon the type and rate of application that can alter the microbial biomass quantitatively and qualitatively in both short-term and long-term (Anderson and Armstrong 1981).

Microbial population in the rhizosphere soil of transplanted *Kharif* rice decreased after herbicide application but, there was no long term adverse effect on the microbial population of the soil. Butachlor 1.5 kg/ha and pretilachlor 0.75 kg/ha are harmful to the given soil in terms of total microbial activity, however addition of easily degradable source of organic carbon with recommended dose of fertilizer to the soil prior to butachlor and pretilachlor application could nullify this adverse impact on soil microorganisms as well as on physico-chemical properties of soil.

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Methods of seeding and cultivars effect on weed dynamics in direct-seeded rice under rainfed upland conditions of Nagaland

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ABSTRACT

Field experiments were conducted during *Kharif* season of 2009 and 2010 to study the effect of methods of seeding and rice cultivars on dynamics of weeds in direct-seeded rice under rainfed upland conditions of Nagaland. Two seeding methods *viz.,* line seeding and broadcasting and four local direct-seeded rice cultivars, *viz.* '*Kezie*', '*Chongloiman*', '*Leikhumo*' and '*Kotsala*' were evaluated under the trial in split-plot design. A total of 29 weed species were recorded, out of which *Digitaria setigera* Roth ex Roem. & Schult, *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* Linn., *Borreria articularis* (L. f.) F. N. Will., *Ipomoea triloba* L. and *Mimosa pudica* L. were the dominant weed species. The line sowing was found superior over broadcasting in recording lower density, biomass and relative weed growth rate of grass, sedge and broad-leaf weeds. It also recorded significantly higher grain yield of rice. Among the cultivars ,'*Chongloiman'* and '*Kezie'* were at par with each other and recorded significantly lower density and biomass of associated grass, sedge and broad-leaved weeds. The highest grain yield during both the years was recorded by the cultivar *'Chongloiman'* which was at par with '*Kezie*'.

Key words: Cultivars, Direct-seeded rice, Sowing methods, Weed dynamics

Upland rainfed rice in Nagaland occupies an area of 94700 hectare, with a production of 181820 t while transplanted rice culture (TRC)/wet rice culture (WRC) covers an area of 94780 ha, with a production of 247820 t (DES 2014). One of the most important production constraints responsible for the production gap is the high weed pressure faced by upland direct-seeded rice. Direct-seeded rice germinates together with weeds, eliminating the 'head start' of transplanted seedlings thereby subjecting it to higher weed pressure (Rao *et al*. 2017). Chemical and manual weeding are the most popular methods among farmers, however problems of environmental pollution, rapid developing herbicide resistant weed ecotypes and cost effectiveness associated with these methods are causes for serious concern. Moreover weed populations tend to vary between environments, which makes it impossible for a single method to provide effective weed control. Therefore, it is imperative to test and develop alternative cultural weed management options such as competitive crop cultivars and sowing methods along with judicious use of direct weed control methods so as to evolve low cost, effective and eco-friendly practice for sustainable weed management. Cultivars within a crop species vary considerably in their competitiveness with weeds. Morphological and physiological traits of a strongly competitive crop will enable it to capture resources from a weed and utilize them more efficiently (Lemerle *et al.* 2001, Ramesh *et al.* 2017). The use of competitive crop cultivars may therefore be considered as an important component for integrated weed management (Ramesh *et al.* 2017). Achieving a uniform/optimum crop stand is yet another important requirement, which ensures optimum crop growth and gives the crop a competitive edge over the weeds. Hence, selection of proper sowing method is necessary to ensure crop emergence, crop stand, reduced weed growth and ultimately higher crop yield. Therefore, the present investigation was undertaken with the objective to study the effect of methods of seeding and rice cultivars on dynamics of weeds in direct-seeded rice under rainfed upland conditions of Nagaland.

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MATERIALS AND METHODS

The investigation was carried out at the experimental farm of NU, SASRD, Medziphema, Nagaland, located at an altitude of 310 m above mean sea level, during the *Kharif* season of 2009 and 2010. The soil of the experimental site was clayey loam, well drained and acidic in reaction with low available nitrogen, medium available phosphorous and available potassium and high organic carbon content. The experiment was laid out in a split-plot design with three replications. Treatments consisted of two sowing methods, *viz.* line sowing and broadcasting and four local rice cultivars, *viz.* '*Kezie*', '*Chongloiman*', '*Leikhumo*' and '*Kotsala*'. Seeds 50 kg/ha at the rate of were sown in furrows at a spacing of 20 cm x 10 cm under line sowing whereas, 100 kg/ ha of seeds were broadcasted over the seedbed under broadcast method. All agronomic and cultural practices were kept standard and uniform for all the treatments. Observations on weed growth parameters were recorded at 15, 30, 45, 60 and 90 days after seeding (DAS) and at harvest. Weeds were sampled using quadrats, measuring 0.5 x 0.5 m^2. Species dominance was determined through manual counting of the different species within each quadrat. The data recorded on weed density were subjected to square root transformation before analysis. Observation on crop yield was also recorded during both the years.

RESULTS AND DISCUSSION

Effect of sowing methods on weed growth attributes

Line sowing of the crop was superior over broadcasting in reducing density, biomass and relative weed growth rate of grasses, sedges and broad-leaved weeds (**Table 1** and **2**). In dry- seeded crop, weed competition is very severe from the beginning the crop and weed seeds germinate simultaneously and weeds, being more vigorous, smother the crop. Line sowing of the crop resulted in early and uniform crop emergence and establishment, which may have given the crop a competitive edge over the weeds and better access to soil nutrients and water thereby reducing weed growth and biomass. Line sowing facilitates uniform depth of sowing resulting in uniform crop stand (Reddy and Reddy 2010). Spatially uniform crop stand establishment under line sowing results in supplementary advantage for weed control by minimizing competition within the crop population early in the growing season (Olsen and Weiner 2007), maximizing the total shade cast by the crop (Weiner *et al.* 2001) and also by providing greater selectivity between the crop and weed during weeding operations. Under broadcasting, uneven crop stand and slow emergence of the crop might have given a competitive edge to the weeds resulting in higher weed growth and competition. In broadcasting method, seeds fall at different depths resulting in uneven crop stand. Moreover, spacing available for the individual plants also varied considerably, which resulted in excess competition within the crop at certain areas and no competition at all in some areas of the field (Reddy and Reddy 2010).

Effect of cultivars on weed growth attributes

Cultivars were found to record significant differences in weed density, biomass and relative weed growth rate (**Table 1** and **2**). '*Kezie*' and '*Chongloiman*' were at par and recorded significantly lower density and biomass of grasses, sedges and broad-leaved weeds over '*Leikhumo*' which recorded the highest density and biomass of grasses, sedges and broad-leaved weeds throughout the crop season. Cultivars '*Kezie*' and '*Chongloiman*' were associated with traits like rapid tillering and increased plant height respectively early in the cropping season leading to early canopy establishment, ground cover and crop biomass accumulation and these attributes may have resulted in better weed suppression and lower weed growth. The ideal plant type that can strongly compete against weeds has shoots that spread and cover the ground rapidly during early vegetative stage (Zhao 2006). Characteristics commonly identified to make crops more competitive against weeds include rapid germination, early above ground growth, rapid canopy establishment (Lemerle *et al.* 2001), high tillering capacity (Saito *et al.* 2010), taller plants (Hucl 1998) and greater biomass accumulation early in the cropping period (Saito *et al.* 2010).

Early canopy establishment by the cultivars '*Kezie*' and '*Chongloiman*' might also have resulted in better photosynthetic photon flux density interception enhancing competitiveness of the rice cultivars. Crops with vigorous growth that reduce the quality and quantity of light beneath the crop canopy are the most competitive (Buhler 2002). Relative weed growth rate recorded at 30 to 60 DAS was found to be significantly lower for '*Kezie*' and '*Chongloiman*', which were at par. '*Leikhumo*' and '*Kotsala*' were also at par and recorded significantly higher relative growth rate of weeds. This may be attributed to significantly lower weed biomass recorded by '*Kezie*' and '*Chongloiman*' compared to '*Leikhumo*' and '*Kotsala*'.

Effect of sowing methods and cultivars on crop yield

Significantly higher grain yields were recorded under line sowing as compared to broadcasting during both the years (**Table 1**). Comparatively superior weed suppression and reduced weed growth exhibited under line sowing as compared to broadcasting, facilitated higher uptake of nutrients by the crop resulting in better crop growth and yield attributes. Higher uptake of nutrients by the rice crop helps to achieve higher source-sink capacity, which positively reflects in higher grain yield of rice (Choudhary 1989). Vijayakumar *et al*. (2006) also reported that higher nutrient availability subsequently results in better source to sink conversion. Lower grain yield recorded under broadcasting can be attributed to the increased nutrient removal by the weeds due to high weed competition associated with the treatment. Broadcasting produced the lowest number of effective tillers/hill, total filled grains/ panicle, 1000-grain weight and grain yield (Roy *et al.* 2009). Significant differences in grain yield were also recorded among the different cultivars (**Table 1**). During both the years '*Chongloiman*' was found to record significantly higher grain yield over '*Leikhumo'* and '*Kotsala'*, which were at par. '*Kezie*' was at par with '*Chongloiman'* and '*Kotsala'* and recorded significantly higher grain yield over the cultivar '*Leikhumo'*. The cultivars '*Chongloiman'* and'*Kezie'* exhibited superior weed suppression and reduced weed growth during the vegetative stage of the crop which facilitated efficient utilization of the various growth resources leading to luxuriant crop growth and better expression of yield attributes and grain yield. The morphology and growth rate of a cultivar can have a significant effect on both the crop and weed development. The morphological and physiological traits of a strongly competitive crop will enable it to capture resources from a weed and utilize resources more efficiently (Lemerle *et al.* 2001).

Weeds

In the present experiment, 29 weed species were identified out of which broad-leaved weeds, grasses and sedges comprised 20, 7 and 2 species. The weed flora and growth pattern of most dominant weed species belonging to each category of weeds are have been given below:

Grasses: Grass species recorded from the experimental field were *Cynodon dactylon* (L.) Pers., *Digitaria setigera* Roth ex Roem. and Schult., *Echinochloa colona* (L.) Link, *Imperata cylindrica* (L.) P. Beauv., *Eleusine indica* (L.) Gaertn., *Paspalum distichum* L. and *Setaria pumila* (Poir.) Roem. & Schult. Among the grassy weeds recorded, *Digitaria setigera* was observed to be the most dominant species throughout the crop season. The emergence, growth pattern and population density of the weed species as affected by sowing methods and cultivars are discussed below.

Digitaria setigera: The grassy weed was observed in the experimental field at 15 DAS and reached peak emergence at 90 DAS. The weed showed a slow growth during the early part of the crop growth with a faster growth during the later stages of the crop growth. The slow initial growth of the weed may be due to low temperature while, progressive increase in temperature during the later stages coupled with wider adaptability might have resulted in the faster growth of the weeds at later stages. Longchar (2000) also reported the dominance of *Digitaria setigera* in upland rice fields of Nagaland. Sowing methods exhibited considerable variations in the population density of the weed. At the peak period of emergence, broadcasting was found to record higher population of the grassy weed (47 and 42 plants/m^2 during 2009 and 2010 respectively) whereas, lower populations (33 plants/m^2 each during 2009 and 2010) were recorded under line sowing. Considerable variation in the population of this grassy weed was also recorded among the four cultivars. Maximum population (40 and 36 plants/m^2 during 2009 and 2010, respectively) at peak period of emergence was recorded by '*Leikhumo'* during both the years whereas, '*Chongloiman'* recorded the lowest population of 33

Table 1. Effect of seeding methods and cultivars on density of weeds

Treatment	Density of different weed categories (no./m^2)					
	Grasses		Sedges		Broad-leaved weeds	
	2009	2010	2009	2010	2009	2010
Sowing methods						
Broadcasting	4.45(19.3)	4.18(17.0)	2.39(5.2)	2.27(4.6)	21.14(446.4)	20.26(410.0)
Line sowing	3.68(13.0)	3.43(11.3)	2.00(3.5)	1.91(3.1)	17.46(304.3)	16.33(266.2)
LSD (p=0.05)	0.76	0.73	0.37	0.31	3.65	3.80
Cultivars						
Leikhumo	4.54(20.1)	4.26(17.6)	2.45(5.5)	2.31(4.8)	21.65(468.2)	20.76(430.5)
Kotsala	4.17(16.9)	3.94(15.0)	2.21(4.4)	2.13(4.0)	19.91(395.9)	18.97(359.4)
Kezie	3.84(14.2)	3.57(12.2)	2.11(3.9)	1.98(3.4)	18.08(326.4)	17.01(288.8)
Chongloiman	3.72(13.3)	3.45(11.4)	2.01(3.5)	1.93(3.2)	17.56(307.8)	16.45(270.1)
LSD (p=0.05)	0.47	0.52	0.25	0.22	2.35	2.52

Figures in parentheses represent original values and 29 plants/m^2 during 2009 and 2010, respectively followed by '*Kezie'* (35 and 31 plants/m^2 during 2009 and 2010, respectively).

Sedges: The sedge species observed in the experimental field were *Cyperus iria* L. and *Cyperus rotundus* Linn. of which the later was found to be more dominant. Emergence, growth pattern and population density of the weed species are discussed below.

***Cyperus rotundus* Linn.**: The sedge species was observed to emerge at initial stage of the crop (15 DAS), attaining its peak at mid stage of the crop (60 DAS) and declining towards harvest of the crop. Dutta (1993) also reported dominance of sedges at 60 DAS to harvest in direct sown rainfed summer rice. Better adaptability and favourable microclimate conditions created by the influence of temperature, moisture and soil type under the crop canopy might have resulted in pre-dominance of the weed. Whereas, smothering effect of the rice canopy and the more competitive broad-leaf species may have resulted in reduced population of the weed species during the later stages of the crop. Predominance of *C. rotundus* in upland rice field of Nagaland was also reported by Longchar (2000). At the peak period of emergence, maximum population of the weed (26 and 24 plants/m^2 during 2009 and 2010, respectively) was recorded under broadcasting whereas, lower populations (20 and 18 plants/m^2 during 2009 and 2010, respectively) were recorded under line sowing during both the years (**Table 2**). Among the cultivars, highest population at peak period of emergence (22 and 20 plants/m^2 during 2009 and 2010, respectively) was recorded by '*Leikhumo*' during both the years whereas, the lowest population of the sedge (17 and 15 plants/m^2 during 2009 and 2010, respectively) was recorded by '*Chongloiman'* followed by 'Kezie' (18 and 16 plants/m^2 (**Table 2**) during 2009 and 2010, respectively).

Broad-leaf weeds: Broad-leaf weed species recorded from the experimental field were *Ageratum conyzoides* L., *Amaranthus viridis* L., *Borreria articularis* (L. f.) F. N. Will., *Cassia tora* L., *Cleome rutidosperma* DC., *Corchorus aestuans* L., *Commelina benghalensis* L., *Cuphea balsamina, Emilia sonchifolia* (L.) DC., *Eryngium foetidum* L., *Hedyotis auricularia* L., *Ipomoea triloba* L., *Ludwigia linifolia* Poir., *Melochia corchorifolia* L., *Mimosa pudica* L., *Mollugo pentaphylla* L., *Scoparia dulcis* L., *Solanum khasianum* C.B. Clarke., *Synedrella nodiflora* (L.) Gaertn., *Triumfetta rhomboids* Jacq. Among the broad-leaf species *Borreria articularis* (L.f.) F.N. Will. was found to be the most dominant species. The emergence, growth pattern and population density of the weed species as affected by sowing methods and cultivars are discussed below.

Borreria articularis: The broad-leaf weed was observed in the experimental field at 15 DAS attaining maximum population at mid stage (60 DAS) of the crop and declining slightly towards harvest. Behera and Jena (1997) also reported dominance of broad-leaf weeds at mid stages of crop growth in direct sown rice. In the present investigation, broadleaf weed species in general were found to be most dominant recording considerably higher weed density and dry weight throughout the crop season as compared to the grassy weeds and sedges. Early germination of the broad-leaf weed with vigorous early growth due to better competitive ability might have resulted in smothering of the other grassy weeds and sedges. At the peak period of emergence, broadcasting method was found to record higher population of the weed during both the years (694 and 623 plants/m^2 during 2009 and 2010, respectively)

Table 2. Effect of seeding methods and cultivars on weed growth and rice yield

Treatment	Weed biomass (g/m^2)		Relative weed growth rate 30-60 DAS (g/g/day)		Grain yield (t/ha)	
	2009	2010	2009	2010	2009	2010
Sowing methods						
Broadcasting	155.7	148.5	0.0190	0.0179	2.05	2.17
Line Sowing	132.0	123.7	0.0136	0.0116	2.85	3.00
LSD (p=0.05)	16.50	15.05	0.0029	0.0028	0.59	0.42
Cultivars						
Leikhumo	153.2	146.5	0.0176	0.0166	2.20	2.37
Kotsala	146.5	138.4	0.0176	0.0164	2.36	2.53
Kezie	139.5	131.4	0.0152	0.0133	2.50	2.61
Chongloiman	136.4	128.1	0.0148	0.0127	2.75	2.83
LSD (p=0.05)	10.98	10.62	0.0019	0.0018	0.28	0.24

whereas, line sowing recorded lower populations of the weed (479 and 455 plants/m^2 during 2009 and 2010, respectively). Variations in the population of the weed were also recorded among the four cultivars. During both the years at the peak period of emergence, '*Leikhumo*' was found to record the highest population of the weed (638 and 598 plants/m^2 during 2009 and 2010, respectively) whereas, the lowest population was recorded by '*Chongloiman*' (447 and 387 plants/m^2 during 2009 and 2010, respectively) followed by '*Kezie*' (486 and 426 plants/m^2) and '*Kotsala*' (585 and 549 plants/m^2) during 2009 and 2010, respectively.

Line sowing of the cultivars '*Chongloiman*' and '*Kezie*' was found to record significantly lower weed growth and higher grain yield of rice during both the years. Among the three categories of weeds recorded, broad-leaf weed species were found to be most dominant and recorded considerably higher weed density and biomass throughout the crop season as compared to the grasses and sedges. Sowing methods and cultivars were found to influence weed density and biomass. Further research in this area is needed to develop sustainable integrated weed management approaches with emphasis on indirect methods of control in order to alleviate the issues of low production and productivity of direct-seeded upland rice while addressing the issues of environmental pollution and food security.

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Quantification of flufenacet residues in soil and wheat grain

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ABSTRACT

The terminal residues of flufenacet were quantified in soil and wheat grains. Flufenacet was applied at 250 and 300 g/ha on 21 and 35 days after the sowing of wheat at the Research Farm of Punjab Agricultural University, Ludhiana. Matrix solid phase dispersion (MSPD) method was used for the extraction of flufenacet from soil and grain samples. The herbicide residues were quantified using High Performance Liquid Chromatography (HPLC) equipped with UV-Vis detector and were confirmed with gas chromatographic tandem mass spectrometry (GC-MS/MS). The average recoveries of flufenacet extracted from the matrix ranged from 80.9 to 93.0% and 88.0 to 96.2% when quantified using HPLC and GC-MS/MS, respectively with relative standard deviation less than 10%. Both HPLC and GC-MS/MS offer high reproducibility, however GC-MS/MS was more sensitive having limit of detection (LOD) and limit of quantification (LOQ) as 0.001 and 0.003 μg/g, respectively. Terminal residues of flufenacet in the soil and wheat grain samples were below the detectable limit. Thus, the use of flufenacet in wheat under sub-tropical humid conditions could be considered safe.

Key words: Flufenacet, GC-MS/MS, HPLC, MSPD, Residue, Soil, Wheat grain

India has world's largest cultivated area (30.23 million ha) under wheat and ranks third in production (93.50 million tonnes) after European Union and China, with a productivity of 3.09 t/ ha (DES 2017). Wheat is an important food grain crop in Punjab. It is grown on 3.51 million hectare, with an average annual production of 16.07 million tonnes and productivity of 4.58 t/ha (POP 2017).

Weeds are the major biotic constraint in wheat production, causing grain yield losses from 10 to 80% depending on the weed species and the weed density (Ladha *et al.* 2000, Timsina and Connor 2001). Among grassy weeds *P. minor* Retz. is of major concern in irrigated wheat under rice-wheat system in India (Singh *et al.* 1995, Chhokar *et al.* 2006). Sequential selection pressure exerted by the extensive use of herbicides (*viz.* isoproturon, clodinafop and sulfosulfuron) has led to the evolution of multiple herbicide resistant biotypes of *P. minor* (Chhokar and Sharma 2008). Continuous application of the same herbicide over a long period of time can result in resistance along with residue buildup in soil, which may harm the succeeding crops. So, there is a challenge to develop new herbicides with alternative modes of action which can be used in rotation with the existing herbicides. Flufenacet (4'-fluoro-*N*-isopropyl-2-[5-(trifluoromethyl)-1,3,4-thiadiazol-2 yloxy]acetanilide), is a new oxyacetanilide herbicide. It has been found effective for the control of a wide range of annual grasses in maize, wheat, rice, soybeans, cotton, sunflower, groundnut, tomato and potato (Deege *et al.* 1995, Forster *et al.* 1997, Michel 1998). It is applied pre or early post-emergence and acts as a seedling growth inhibitor by disrupting the biosynthesis of very-long-chain fatty acids in plants with inhibition of cell division and meristematic activity (Senseman 2007).

Flufenacet can cause endocrine disruption, methemoglobinemia and multi-organ effects in blood, kidney, spleen and heart (Christenson 1996), allergic skin reaction and eye irritation. It has been found to affect the fertility in aves and cause delays in the growth and development of aquatic organisms (USEPA 2011). It is a biodegradable compound, but undergoes slow degradation in the environment and in waste water treatment plants (Cheminova 2014). Hence, the residue estimation of this herbicide in soil and edible part of the crop is very essential to determine the duration of herbicide activity in soil and its effect on crop.

Determination of the herbicide residues is a challenging task as low maximum residue limits (MRLs) are imposed by regulatory agencies (Codex Alimentarius Commission 2005, European Union On-line 2005, Korea Food and Drug Administration 2005). Due to the low level of herbicides that may be found in soil/crop, the analytical methods used to

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monitor the herbicide levels in soil, water and food products should be able to identify and quantify the herbicide residues at very low levels (Saieva *et al*. 2004, Taylor *et al*. 2002). There are numerous reports on the efficacy of flufenacet against various weeds in cereal crops, but very few reports are available in literature on the methods of its analysis and its environmental fate in agro ecosystems. Rouchaud *et al*. (1999), Gupta *et al*. (2001) and Gupta and Gajbhiye (2002) performed residue analysis of flufenacet using gas-liquid chromatography (GLC), gas chromatography (GC) and chromatography–selected ion monitoring–mass spectroscopy (GC-MS-SIM). Since the persistence of herbicides is correlated not only with the climatic conditions but also with the management practices and soil physico-chemistry (Ampong-Nyarko and Datta 1991), the behavior of flufenacet in subtropical humid agroclimatic conditions of Punjab needs to be scrutinized. Keeping these points in view the present study was done in order to develop a novel, simple and sensitive MSPD (Matrix Solid Phase Dispersion) method for the efficient extraction of flufenacet and its determination using High Performance Liquid Chromatography (HPLC) followed by confirmation and quantification with GC-MS tandem mass spectrometery (GC-MS/MS).

MATERIALS AND METHODS

Chemicals

The analytical-grade flufenacet (99.1±5% purity) was supplied by Bayer India Ltd. Methanol, water HPLC grade and all other chemicals used in extraction were purchased from Finar Chemicals, Mumbai, India. Only redistilled solvents were used in the study.

Preparation of standards

A stock solution of flufenacet (1000 µg/ml) was prepared by dissolving 10 mg of analytical-grade herbicide in 10 ml of methanol HPLC grade and was stored at - 4 °C. Working standard solutions (0.001, 0.01, 0.1, 0.5, 1, 5, 10 µg/ml) were prepared by dilution with methanol HPLC grade.

Experimental field

A field experiment was conducted at Punjab Agricultural University, Ludhiana (30º 54‘ N latitude and 75º 48‘ E longitude, at a height of 247 meters above the mean sea level), Punjab, India during winter season of 2013-14 and 2014-15. The experimental soil was loamy sand having organic carbon (0.38%), pH (7.90) and EC (0.19 mmhos/cm). Weekly weather data during the cropping season of 2013-14 and 2014-15 is given in **Figure 1**. Wheat variety (*HD-2967*) was seeded on 15 November 2013 and 2014 and the crop was raised following the recommended package of practices. Herbicides were applied using knapsack sprayer fitted with flat fan nozzle which was calibrated to deliver 375 L of spray solution/ha. Soil (0-20 cm) and grain samples for residue analysis were collected at harvest from the experimental plots, which were sprayed with flufenacet 250 and 300 g/ha at 21 and 35 days after sowing (DAS) and also from unsprayed control plots. Four soil cores were taken randomly from each plot using the soil auger, excluding the outer 20 cm fringes of the plots. The soil from all cores within a plot was pooled, air dried under shade, powdered and sieved through a 2 mm sieve. The wheat grain samples collected at harvest were cleaned and crushed using mechanical blender.

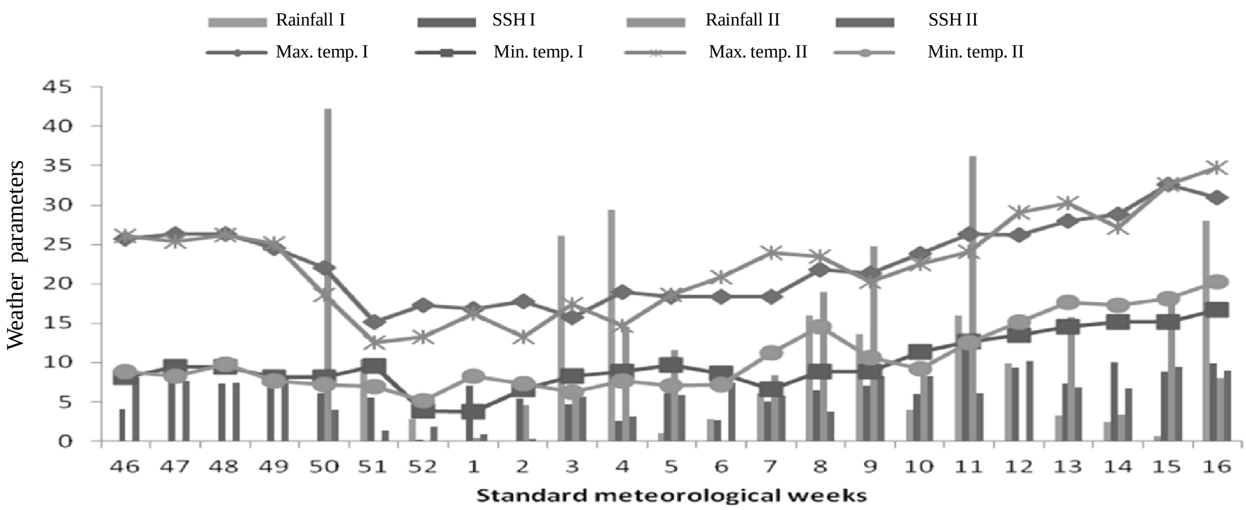


Figure 1. Weather data of 2013-14 (I), 2014-15 (II) during the cropping season at Ludhiana

Herbicide residue analysis

Extraction of flufenacet was done using matrix solid phase dispersion (MSPD). The soil/grain samples were blended with 5 g of florisil (60-200 mesh, HIMEDIA) activated at 200°C for 8 hours. A glass column (50 cm) was plugged with cotton on its lower end. To this column 2 g sodium sulphate, 1.0 g of charcoal and the blend were transferred in succession. The analyte was eluted with acetone:hexane (45 ml) (8:2) and the extract was collected and the solvent was evaporated to dryness using rotary vacuum evaporator at 40^{o}C. The samples were reconstituted in 2 ml methanol and analyzed by HPLC and GC-MS/MS.

Instrument and operating conditions

Gas chromatography: Chromatographic analysis of flufenacet was carried out using GC-MS/MS (Agilent 7890 A series) at CCS Haryana Agricultural University, Hisar. Operating conditions included the use of a HP-5 column (30 m x 0.32 mm i.d. × 0.25 µm film thickness). Helium at the flow rate of 1 ml/min was used as the carrier gas. Injections (2 µl) were made in the pulse split less mode. The samples were analyzed using the following oven temperature programme: an initial oven temperature of 70°C held for 2 minutes (min) with a ramp of 25°C per min up to 150°C, then a ramp of 15°C per min up to 200°C and finally a ramp of 8°C per min up to 280°C and held for 2 min. Detector: Mass 7000 GC-MS/MS; detector parameters were: source temperature, 230°C; emission current, 35 mA; energy, – 70 eV; repeller voltage, 11 V; ion body, 12 V; extractor, –7.2 V; ion focus, –7.4 V; quadrupole one (MS^1) temperature, 150°C; quadrupole two (MS^2) temperature, 150°C. The retention time under the present experimental condition was found to be 18.44 min.

High performance liquid chromatography: Water HPLC system with 20 ìl injection loop and UV/Vis detector was used. The separation of flufenacet was performed using reverse phase symmetry C18 (5.0 ìm, 4.6 mm × 250 mm column at 210 nm. The mobile phase consisted of methanol: water (80: 20) at the flow rate of 1 ml/min. Under these operating conditions, the retention time of flufenacet was found to be 4.08 min.

Standardization of method

Since the quantitative determination of flufenacet in a given soil or plant sample is directly dependent on the evaluation and interpretation of data, a reliable method is required which is reproducible and can be applicable to different samples. The method was fully validated according to the analytical method recommendations described in the SANCO guidelines in terms of linearity, precision (repeatability and reproducibility) and accuracy (SANCO 2013).

RESULTS AND DISCUSSION

Optimization of matrix solid phase dispersion (MSPD)

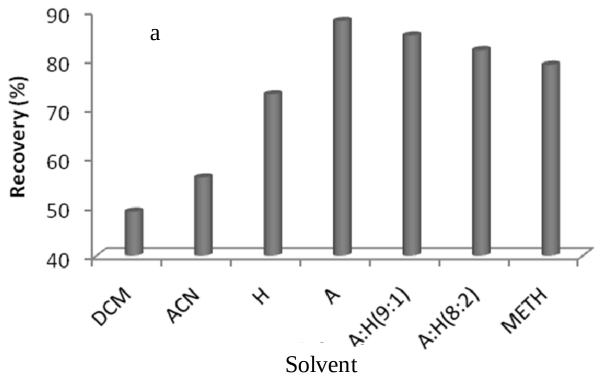
Preliminary experiments were carried out to select the optimum conditions for extraction of flufenacet using MSPD. In MSPD, type and volume of elution solvent is important for the efficient extraction of herbicide from sorbent. Several solvents such as acetone, hexane, acetone: hexane (9:1), acetone: hexane (8:2), acetonitrile, methanol and dichloromethane were evaluated as elution solvents for extraction of flufenacet from spiked soil and wheat grain samples (fortified at 0.01, 0.05, 0.5 and 0.1 µg/g). The percentage recoveries varied from 49 ± 4.01% to 88 ± 5.29% (**Figure 2a**). Use of acetone gave the highest recovery, but the co-elution of matrix co-extracts gave undesirable peaks close to retention time of target analyte in HPLC chromatograms and the results were not interpretable. Based on the results of percent recovery and HPLC chromatograms, acetone: hexane (8:2) was selected as the eluting solvent.

The optimization of elution volume was performed with acetone:hexane (8:2) as elution solvent. The results showed that the recovery of the target compound increased till an increase in volume of elution solvent up to 45 ml and thereafter, equilibrium was attained with further increase in volume (**Figure 2b**).

Method validation

Linearity: The linearity of the method was evaluated from the calibration curve using standard solutions over the concentrations ranging from 0.001 to 10 µg/ml using HPLC and GC-MS/MS. The response was found to be linear in the range of 0.003 to 10 and 0.001-10 µg/ml in case of HPLC and GC-MS/MS, respectively, with the co-efficient of determination (R^2) > 0.99.

Limit of detection and quantification: The limit of detection (LOD) and limit of quantification (LOQ) were determined based on signal-to-noise ratio (S/N) of 3:1 and 10:1, respectively (Sahoo *et al.* 2013). The LOD and LOQ in this study were calculated as 0.003 and 0.01 µg/g, respectively, in case of HPLC and 0.001 and 0.003 µg/g, respectively, in case of GC-MS/MS.



DCM- Dichloromethane, ACN- Acetonitrile, H- Hexane, A-Acetone, METH-Methanol

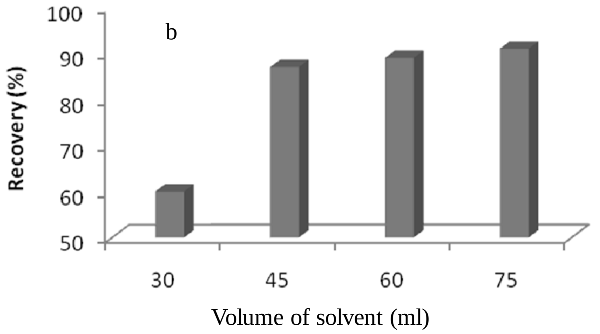


Figure 2 a and b. Effect of different elution solvent types and their volume on flufenacet recovery in MSPD

Accuracy and precision: The accuracy of the analytical method was estimated in terms of percent recoveries. The mean recoveries for the three replicates of spiked samples at different fortification levels (0.01, 0.05, 0.5 and 0.1 µg/g) ranged from 82 ± 4.3 to 96 ± 3.4% in soil, and 80 ± 2.7 to 93 ± 2.6% in wheat grains. The precision values expressed as relative standard deviation (RSD) were <10% irrespective of sample type and spiking levels indicating good reproducibility of the method **(Table 1)**.

Residues of flufenacet under field conditions

No quantifiable amount of residues of flufenacet was detected in the soil and grain samples at harvest by HPLC at both the application rates in 2013-14 and 2014-15 **(Table 3)**. The maximum residue limit (MRL) of flufenacet for wheat grain has been set as 0.05 µg/g by EFSA. Under the present experimental conditions, the residues in wheat grain at harvest were below the MRL set by EFSA (EFSA 2012). Therefore, it could be considered nontoxic to food and environment. Though the proposed method was carefully designed and no interference of matrix peak was observed in the samples and residues were well below the MRL, still the confirmatory test plays essential part in quantification of residues in trace quantities. In the present study confirmatory method was developed using GC-MS/MS to identify and detect the flufenacet residues. Based on the LOD it was observed that GC-MS/MS was at least 3 fold more sensitive than HPLC/UV and could be used as alternative instrument for detection of flufenacet residues. The confirmation and quantification of flufenacet was achieved by developing a programming in SCAN, product ion and finally multiple reaction monitoring (MRM). Characteristic ions with relatively high intensity and strong anti-turbulence were selected as monitoring and quantitative ions (**Table 2** and **Figure 3**).

Analysis of soil and wheat grain samples using GC-MS/MS showed that residues were below 0.003 µg/g in 2013-14 and 2014-15 (**Table 3**). It revealed that none of the flufenacet application rates or timings could cause the herbicide to persist in detectable

Table 1. Average recovery of flufenacet from fortified soil and wheat grains

Matrix	Level of fortification (µg/g)	Recovery (%) HPLC	Recovery (%) GC-MS/MS
Soil	1	93.4±6.1	96.2±3.5
	0.5	91.8±5.5	94.7±4.6
	0.05	88.3±6.5	93.6±4.3
	0.01	82.6±4.3	92.8±2.1
Grain	1	92.5±1.7	93.1±3.4
	0.5	91.7±2.3	93.5±2.4
	0.05	85.3±7.2	90.9±2.0
	0.01	80.9±2.7	88.0±3.0

Each value is mean±SD of three replicates

Table 2. Programming parameters for MRM

Compound	Molecular mass	Precursor ion (m/z)	Collision energy	Monitoring ions (m/z) and relative abundance (in bracket)
Flufenacet	363	151 211	10 4	95 (50694.4), 136.1 (69036.4) 123.1 (17976.9)

Table 3. Flufenacet residues in soil and wheat grains at harvest

Flufenacet: Dose of application	Flufenacet: Time of application	Matrix	Residues (µg/g) HPLC	Residues (µg/g) GC-MS/MS
250 g/ha	21 DAS	Soil	<0.01	<0.003
250 g/ha	21 DAS	Grain	<0.01	<0.003
250 g/ha	35 DAS	Soil	<0.01	<0.003
250 g/ha	35 DAS	Grain	<0.01	<0.003
300 g/ha	21 DAS	Soil	<0.01	<0.003
300 g/ha	21 DAS	Grain	<0.01	<0.003
300 g/ha	35 DAS	Soil	<0.01	<0.003
300 g/ha	35 DAS	Grain	<0.01	<0.003

DAS-Days after sowing

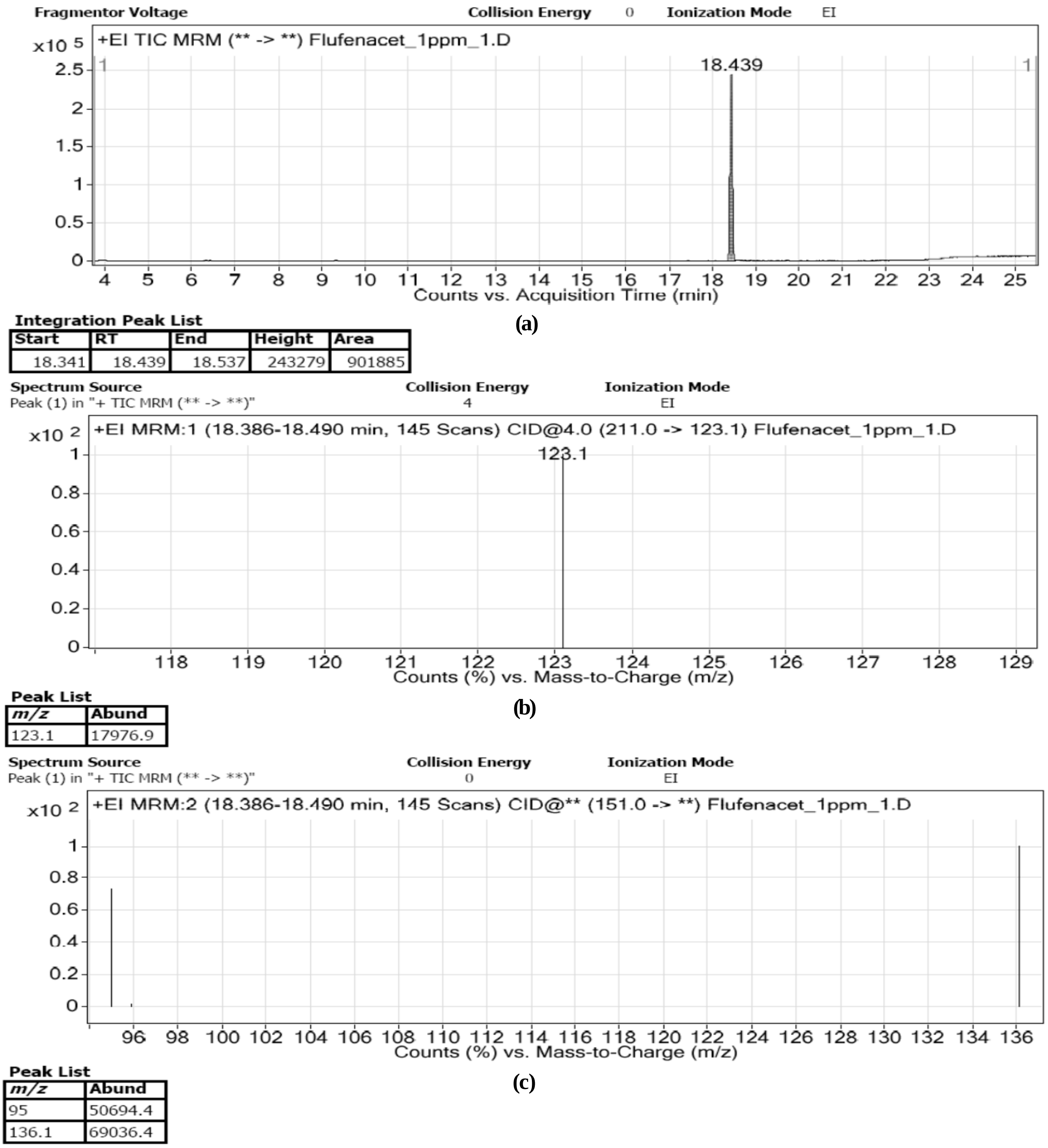


Figure 3. (a) User chromatogram of flufenacet; (b, c) Mass spectrums of flufenacet at different collision energies scanned in MRM

concentrations in the soil till harvest, thus confirming the rotational safety of flufenacet to succeeding crops, as well as the safety of wheat grains from the consumption point of view. This may be attributed to the dissipation of flufenacet, due to longer time duration between the herbicide application and harvest. These results are in conformity with the studies conducted by Gupta *et al*. (2001) and Rouchaud *et al.* (1999).

MSPD method has a good analytical performance in terms of accuracy, precision, selectivity, sensitivity and rapidity and could be used for the detection and quantification of flufenacet residues in soil and wheat grain. Both HPLC and GC-MS/MS offer high reproducibility, but GC-MS/MS was more sensitive for quantification of flufenacet residues. As the residue of flufenacet applied at 250 and 300 g/ha at 21 and 35 DAS were below 0.001 µg/g, flufenacet application at those doses and time could be considered as an option for controlling *P. minor* in wheat under subtropical conditions of Punjab.

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Evaluation of herbicide combinations for controlling complex weed flora in wheat

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ABSTRACT

A field experiment was conducted during the *Rabi* seasons of 2014-15 and 2015-16 on a silty clay loam soil at Palampur. *Avena ludoviciana* (36.3%), *Phalaris minor* (27.5%), *Lolium temulentum* (13.9%), *Anagallis arvensis* (10%) and *Coronopus didymus* (6.9) were the major weeds. Herbicide combinations (pendimethalin 1.0 kg/ha + metribuzin 175 g/ha, pendimethalin 1.0 kg/ha *fb* sulfosulfuron 18 g/ha, sulfosulfuron 20 g/ha + metsulfuron 4 g/ha, pinoxaden 60 g/ha + metsulfuron 4 g/ha, clodinafop 60 g/ha + metsulfuron 4 g/ha, isoproturon 1.0 kg/ha + 2,4-D 0.5 kg/ha) were superior to sole application of herbicides (pendimethalin 1.25 kg/ha, sulfosulfuron 25 g/ha, metribuzin 210 g/ha and clodinafop 60 g/ha) in reducing weed count and dry weight and increasing plant height, number of tillers, crop dry matter, yield attributes and yield of wheat. Clodinafop + metsulfuron, pinoxaden + metsulfuron and pendimethalin *fb* metsulfuron being better than other combinations gave 28.6, 22.5 and 23.1% higher grain yield of wheat over hand weeding twice. Weeds reduced the grain yield by 51.9%. With unit increase in weed count per m^2, the wheat grain yield was decreased by 13.3 kg/ha. The cost of weed control under herbicidal treatments was 9.0-28.9% of that under hand weeding lowest being under metribuzin and highest under pendimethalin *fb* sulfosulfuron. Clodinafop + metsulfuron gave the highest net returns due to weed control and marginal benefit: cost ratio (MBCR). Clodinafop + metsulfuron resulted in highest weed control efficiency (WCE), weed control index (WCI), crop resistance index (CRI), treatment efficiency index, crop intensity index and weed index. Weed management index, agronomic management index and integrated weed management index were highest under sulfosulfuron followed by clodinafop + metsulfuron. Based on overall impact index clodinafop + metsulfuron, pinoxaden + metsulfuron, sulfosulfuron + metsulfuron, pendimethalin *fb* sulfosulfuron and pendimethalin + metribuzin were recommended for effective weed management in wheat under mid hill conditions of Himachal Pradesh.

Key words: Herbicide combinations, Wheat, Weeds, Threshold, Impact assessment, Economics

Wheat is the most important staple food contributing 30-35% to total food-grain basket of the country (Singh *et al.* 2013). Weed infestation is the major biotic constraint for higher productivity. Herbicidal control of weeds is preferred because of its better efficiency, lower cost and lesser time involvement. Effective weed control depends on the proper selection of herbicides depending on the type of weed flora infesting the crop, optimum dose and time using proper application technology (Kumar *et al.* 2009). Wheat is infested with plurispecific weed flora as it is grown under diverse agroclimatic conditions. But the major challenge offered is by grass weeds especially *Phalaris*, *Avena* and *Lolium*. Generally post-emergence herbicides are adopted by the growers (Kumar *et al.* 2011a&b, 2012a), which are mainly applied 7-10 days after first irrigation. Pre-emergence application of pendimethalin provides selective weed control in wheat (Kumar *et al.* 2005). The continuous use of a single herbicide leads to resistance in weeds. Herbicides effective against isoproturon resistance biotypes of *P. minor* are sulfosulfuron, clodinafop, pendimethalin, mesosulfuron + iodosulfuron and pinoxaden. Sulfosulfuron, mesosulfuron + iodosulfuron and pendimethalin are effective against both grass and non-grass weeds, whereas, clodinafop and pinoxaden are specific to grasses. However, sulfosulfuron and pendimethalin are not effective against *Rumex dentatus* and *Avena ludoviciana*, respectively. For control of broadleaved weeds in wheat, three major herbicides used are metsulfuron, 2,4-D and carfentrazone. For the control of complex weed flora and to provide season-long weed control, combination of herbicides are needed. Therefore, the combination approach either as tank- mixed or as double nock (one herbicide after the other) takes care of the mixed populations of the weeds associated with wheat. Tank-mix combinations or ready

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mixtures are advantageous over sequential application due to saving in application timing and cost. Keeping above facts in mind, different herbicide combinations were evaluated against complex weed flora in wheat.

MATERIALS AND METHODS

A field trial was conducted during the *Rabi* seasons of 2014-15 and 2015-16 on a silty clay loam soil at Palampur (32^o62 N latitude, 76^o32 E longitude and 1290.8 m altitude). The site (Palampur) lies in sub-temperate humid zone of Himachal Pradesh (NARP zone II), which is characterized by mild summers and severe winters. The area experiences occasional snowfall during winter. The average total annual rainfall received at the centre is around 2693.4 mm, out of which 74.4% is received during monsoon period (June to Sept.), 17.3% during December to March and 8.3% during October-November. The soil of the experimental site was silty clay loam in texture, acidic (pH 5.6) in reaction and medium in available N (333 kg/ha), P (9.6 kg/ha) and K (221 kg/ha). Thirteen weed control treatments were tested in randomized block design with three replications (**Table 1**). Wheat variety '*HPW-236*' was sown at 100 kg/ha on 12 November 2014 and 04 November 2015 keeping row to row spacing of 22.5 cm. The crop was fertilized with 120 kg N, 60 kg P_2O_5 and 30 kg K_2O/ha through urea, single super phosphate and muriate of potash, respectively. The required quantity of half N and whole P_2O_5 and K_2O was drilled at sowing. The remaining half N was broadcasted in two equal splits at tillering and flag-leaf stages. Herbicides as per treatment were applied with backpack power sprayer using 600 litre water/ha.

Weed count and dry weight were recorded at two spots using a quadrate of 50 x 50 cm. Yields were harvested from net plot (4.5 x 3.6 m) on 8 May 2015 and 5 May 2016. The data obtained were subjected to statistical analysis by analysis of variance (ANOVA) to test the significance of the overall differences among the treatments by the "F" test and conclusion was drawn at 5% probability.

The economic threshold (=economic injury levels), the weed density at which the cost of treatment equals the economic benefit obtained from that treatment, was calculated after Uygur & Mennan (1995) as well as those given by Stone and Pedigo (1972) as below:

Uygur and Mennan:

$$Y= [\{(100/He*Hc)+A_C\}/(Gp*Yg)]*100$$

where, Y is percent yield losses at a different weed density; He, herbicide efficiency; Hc, herbicide cost; Ac, application cost of herbicide; Gp, grain price and Ywf, yield of weed free.

Stone and Pedigo:

Economic threshold = Gain threshold/Regression coefficient

where, gain threshold = cost of weed control (Hc+Ac)/price of produce (Gp), and regression coefficient (b) is the outcome of simple linear relationship between yield (Y) and weed density/ biomass (x), Y = a + bx.

The different impact indices were worked out after Rana and Kumar (2014).

'Overall impact index' was determined, by calculating firstly the 'unit value' where the value under a particular treatment of a parameter was divided by the respective arithmetic mean of treatments for that parameter as given below:

$$U_{ij} = \frac{V_{ij}}{AM_j}$$

where Uij is the unit value for ith treatment corresponding to jth parameter, Vij is the actual measured value for ith treatment and jth parameter and AMj is the arithmetic mean value for jth parameter.

The overall impact index was calculated as an average of unit values (Uij) of all the parameters under consideration:

$$OI_i = \frac{1}{N}\sum_{i=1}^{N} U_{ij}$$

where OIi is the overall impact index for ith treatment and N is the number of parameters used in deriving overall impact index.

RESULTS AND DISCUSSION

Effect on weeds

In the unweeded check, *Avena ludoviciana* (36.3%), *Phalaris minor* (27.5%), *Lolium temulentum* (13.9%), *Anagallis arvensis* (10.0%) and *Coronopus didymus* (6.9%) were the main weeds. *Vicia sativa* (10.2%) had infestations during 2014-15 only.

Weed control treatments gave significant suppression of *A. ludoviciana* over weedy check (**Table 1**). The control of *A. ludoviciana* with pinoxaden alone (Kumar *et al.* 2013) and with metsulfuron-methyl (Katara *et al.* 2012), sulfosulfuron (Kumar and Rana 2013) alone and with metsulfuron, metribizin (Kumar *et al.* 2013), isoproturon (Kumar *et al.* 2013) and clodinafop alone

(Kumar *et al.* 2012a) and with metsulfuron or 2,4-D (Kumar *et al.* 2012a, 2013) has been reported. Herbicide combinations, *viz*. pendimethalin + metribuzin, pendimethalin followed by (*fb*) sulfosulfuron, sulfosulfuron + metsulfuron, penoxaden + metsulfuron and clodinafop + metsulfuron were as good as hand weeding twice in reducing its count and dry weight. Similarly these herbicide combinations had better efficacy against *P. minor* than sole application of herbicides. Superiority of clodinafop + metsulfuron against *P. minor* over clodinafop or metsulfuron-methyl alone has been documented (Kumar *et al.* 2011a). All weed control treatments were significantly superior to weedy check in reducing the count and dry weight of *L. temulentum*. The effectiveness of sulfosulfuron, metribuzin, pinoxaden, clodinafop and isoproturon (Kumat *et al.* 2011, 2013a&b) and combinations based on these herbicides (Kumar *et al.* 2011, 2013a&b, Rana *et al.* 2016) against *L. temulentum* has been documented. The combinations, *viz*. pendimethalin + metribuzin, pendimethalin *fb* sulfosulfuron, sulfosulfuron + metsulfuron, pinoxaden + metsulfuron were superior to sole application of herbicides for season-long control of *Lolium*. Count and dry weight of *A. arvensis* were also significantly lower under weed control treatments over the weedy check. Counts and dry weight of *Vicia* sp were also significantly lower under weed control treatments than weedy check. Combinations in general were superior to sole application of herbicides.

Effect on crop

All the weed control treatments were significantly superior to weedy check in increasing plant height, tillers and dry matter accumulation (**Table 2**). The new herbicide combinations, *viz*. pendimethalin + metribuzin, pendimethalin *fb* sulfosulfuron, sulfosulfuron + metsulfuron and penoxaden + metsulfuron were as good as clodinafop + metsulfuron.

Better growth due to control of weeds had its significant effect on yield performance of wheat. Post-emergence application of clodinafop 60 g/ha + metsulfuron 4 g/ha being at par with pinoxaden 60 g/ha + metsulfuron 4 g/ha and pendimethalin 1.0 kg/ ha *fb* metsulfuron 2 g/ha gave significantly higher

Table 1. Effect of treatments on count (no./m^2) and dry weight (g/m^2) of weeds at maximum population and dry matter stage (90-120 DAS) in wheat (data transformed to square root transformation)

Treatment	Dose (g/ha)	Time (DAS)	*A. ludoviciana* 2014-15	*A. ludoviciana* 2015-16	*P. minor* 2014-15	*P. minor* 2015-16	*L. temulentum* 2014-15	*L. temulentum* 2015-16	*A. arvensis* 2014-15	*A. arvensis* 2015-16	*V. sativa* 2014-15
Count											
Pendemethalin	1250	Pre	4.7(21.6)	4.4(18.6)	4.0(15.2)	3.9(14.3)	2.8(7.1)	2.2(4.0)	2.7(6.6)	2.5(5.2)	2.7(6.2)
Sulfosulfuron	25	Post	5.5(28.9)	5.4(27.8)	4.6(20.4)	4.5(19.6)	3.2(9.5)	2.9(7.3)	3.1(8.8)	2.9(7.5)	3.1(8.3)
Metribuzin	210	Pre	4.6(20.4)	4.7(21.4)	3.9(14.4)	3.7(13.0)	2.8(6.7)	2.3(4.3)	2.7(6.2)	2.5(5.4)	2.6(5.9)
Clodinafop	60	Post	5.2(26.6)	5.1(24.7)	4.4(18.7)	4.1(16.0)	3.1(8.8)	2.7(6.5)	3.0(8.1)	2.9(7.6)	2.9(7.6)
Pendimethalin + metribuzin	1000+175	Pre	3.6(12.3)	3.9(13.9)	3.1(8.7)	3.1(8.5)	2.2(4.1)	1.9(2.5)	2.2(3.7)	2.0(2.9)	2.1(3.5)
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	3.3(10.0)	3.6(11.8)	2.8(7.1)	2.9(7.5)	2.1(3.3)	1.7(2.0)	2.0(3.1)	1.9(2.8)	2.0(2.9)
Sulfosulfuron + metsulfuron	20+4	Post	3.3(10.1)	3.5(11.3)	2.8(7.1)	2.8(7.0)	2.1(3.3)	1.8(2.4)	2.0(3.1)	2.0(2.9)	2.0(2.9)
Pinoxaden + metsulfuron	60+4	Post	3.1(8.7)	3.2(9.5)	2.7(6.1)	2.7(6.1)	2.0(2.9)	1.8(2.1)	1.9(2.6)	1.9(2.5)	1.9(2.5)
Mesosulfuron + iodosulfuron	12+2.4	Post	4.3(17.3)	4.4(18.4)	3.6(12.2)	3.2(9.5)	2.6(5.7)	2.0(2.9)	2.5(5.3)	2.4(4.6)	2.4(5.0)
Clodinafop + metsulfuron	60+4	Post	2.9(7.4)	3.0(8.0)	2.5(5.2)	2.2(3.9)	1.9(2.4)	1.7(1.8)	1.8(2.2)	1.6(1.5)	1.8(2.1)
Isoproturon + 2,4-D	1000+500	Post	5.2(26.0)	5.0(24.0)	4.4(18.3)	3.8(13.7)	3.1(8.6)	2.7(6.5)	3.0(7.9)	2.4(4.6)	2.9(7.5)
Hand weeding	-	30 & 60	3.6(11.8)	2.7(6.5)	3.1(8.3)	3.2(9.0)	2.2(3.9)	1.9(2.5)	2.1(3.6)	2.0(3.2)	2.1(3.4)
Weedy check	-	-	8.2(66.8)	8.1(63.9)	6.9(47.1)	7.3(52.1)	4.8(22.0)	5.4(28.1)	4.6(20.3)	4.1(15.7)	4.5(19.2)
LSD (p=0.05)			2.9	2.6	2.0	1.4	1.0	0.5	0.9	0.6	0.8
Dry weight											
Pendemethalin	1250	Pre	5.2(25.6)	4.9(23.2)	4.4(18.3)	3.9(14.3)	3.0 (8.0)	1.7 (1.8)	2.8 (7.0)	2.0 (2.9)	2.7 (6.2)
Sulfosulfuron	25	Post	6.7(43.9)	6.4(40.1)	5.7(31.3)	5.6(30.3)	3.8(13.8)	1.7 (1.8)	3.6(11.9)	1.9(2.5)	3.4(10.6)
Metribuzin	210	Pre	4.9(22.6)	5.2(26.5)	4.1(16.2)	3.9(14.2)	2.9 (7.1)	1.6 (1.7)	2.7 (6.1)	1.8 (2.2)	2.5 (5.5)
Clodinafop	60	Post	5.3(26.9)	5.5(29.6)	4.5(19.2)	4.3(17.5)	3.1 (8.4)	1.6 (1.5)	2.9 (7.3)	1.9 (2.8)	2.7 (6.5)
Pendimethalin + metribuzin	1000+175	Pre	4.2(16.4)	4.5(18.9)	3.6(11.7)	3.6(12.0)	2.5 (5.1)	1.4 (1.1)	2.3 (4.4)	17 (1.9)	2.2 (4.0)
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	3.8(13.6)	4.1(15.7)	3.3(9.7)	3.5(11.0)	2.3 (4.3)	1.4 (1.0)	2.2 (3.7)	1.7 (2.0)	2.1 (3.3)
Sulfosulfuron + metsulfuron	20+4	Post	3.9(14.3)	4.0(15.0)	3.4(10.2)	3.3(10.0)	2.3 (4.5)	1.5 (1.3)	2.2 (3.9)	1.8 (2.4)	2.1 (3.5)
Pinoxaden + metsulfuron	60+4	Post	3.7(12.9)	3.8(13.7)	3.2 (9.2)	3.2(9.1)	2.2 (4.0)	1.4 (1.0)	2.1 (3.5)	1.5 (1.2)	2.0 (3.1)
Mesosulfuron + iodosulfuron	12+2.4	Post	4.5(19.2)	4.5(19.0)	3.8(13.7)	3.9(13.9)	2.7 (6.1)	1.4 (1.0)	2.5 (5.2)	2.0(3.0)	2.4 (4.7)
Clodinafop + metsulfuron	60+4	Post	3.5(10.9)	3.1(8.9)	3.0 (7.8)	2.8(6.8)	2.1 (3.5)	1.4 (0.9)	2.0 (3.0)	1.3 (2.8)	1.9 (2.7)
Isoproturon + 2,4-D	1000+500	Post	5.9(33.3)	5.7(31.6)	5.0(23.8)	5.1(25.4)	3.4(10.4)	1.6(1.6)	3.2 (9.0)	2.9 (7.5)	3.0 (8.1)
Hand weeding	-	30 & 60	4.4(18.0)	4.2(16.5)	3.7(12.9)	3.5(11.3)	2.6 (5.7)	1.3 (0.8)	2.4 (4.9)	2.2(3.9)	2.3 (4.4)
Weedy check	-	-	9.1(81.9)	8.6(79.2)	7.7(58.5)	7.8(60.3)	5.2(25.7)	4.6(20.1)	4.8(22.2)	4.4(18.5)	4.6(19.9)
LSD (p=0.05)			2.4	2.0	1.7	0.2	0.7	0.2	0.6	0.4	0.6

Data in parentheses are the means of original values grain and straw yield of wheat. These treatments gave 98-108% higher grain yield of wheat over weedy check and 23-28% over farmers practice of hand weeding twice. Weeds in weedy check reduced the yield by 51.9%.

Wheat grain yield was found to be negatively associated with total weed count (r = -0.885**) and total weed dry weight (r = -0.887**) and was positively associated with crop height (r = 0.974**), number of tillers (r = 0.979**), crop dry matter (r = 0.966**), spikelets/spike (r= 0.976**), spike length (0.981**), spikes/m^2 (0.942**), grains/spike (r= 0.939**) and 100- seed weight (r = 0.930**). The increase in yield attributes and yield due to effective control of weeds with herbicides alone, in combination and hand weeding has been documented (Katara *et al.* 2012, Kumar and Rana 2013, Rana *et al.* 2016). The linear relationship between weed count and dry weight (x) and yield (Y) of wheat is given here as under:

Weed count

Y = 4299 – 13.3x (R^2= 0.782).......................(1)

Weed dry weight

Y = 4337 – 11.5x (R^2= 0.787)........................(2)

Equations 1 and 2 explain 78.2 and 78.7% of the variation in wheat grain yield due to count and dry weight of weeds, respectively. With unit increase in weed count per m^2, the wheat grain yield reduced by 13.3 kg/ha. Similarly with every unit increase in weed weight, the wheat grain yield decreased by 11.5 kg/ ha.

Economic threshold

The economic threshold levels of weeds at the current prices of treatment application and the crop production on the basis of weed infestation in wheat (**Table 3**). The economic threshold levels in terms of count (no./m^2) and dry weight (g/m^2) with the weed management practices studied varied between 7.6 – 84.7/m^2 and 8.8-97.9 g/m^2 when determined after Stone and Pedigo and 3.0 to 28.9/m^2 and 2.9 – 28.9 g/ m^2, respectively, after Uygur and Mennan. The former method determined higher values of economic thresholds than the later, but the trends were similar under both the methods of determination. It is indicated that any increase in cost of weed control would lead to higher values of economic threshold, whereas an increase in price of crop produce would result in low economic threshold. Hand weeding had higher values of economic threshold than the herbicidal treatments due to higher wages. Herbicidal treatments had lower application cost and thus had lower values of economic threshold.

Economics

The cost of weed control under herbicidal treatments varied from 9.0 to 28.9% of that under hand weeding treatment lowest being under pre-emergence metribuzin 210 g/ha and highest under pre-emergence pendimethalin *fb* sulfosulfuron (**Table 3**). Gross returns due to weed control were highest under clodinafop + metsulfuron followed by pinoxaden + metsulfuron, pendimethalin *fb* sulfosulfuron, sulfosulfuron + metsulfuron and pendimethalin + metribuzin. All treatments except sulfosulfuron were superior to hand weeding twice in increasing net returns due to weed control. These were highest under clodinafop + metsulfuron followed by penoxaden + metsulfuron, sulfosulfuron + metsulfuron, pendimethalin *fb* sulfosulfuron and pendimethalin + metribuzin. Due to low cost of application, all herbicidal treatments were superior to

Table 2. Effect of treatments on growth, yield attributes and yield of wheat

Treatment	Dose (g/ha)	Time (DAS)	Emergence count (no./m^2)	Plant height (cm)	Tillers (no./m^2)	Crop dry matter (g/m^2)	Spikes (no./m^2)		Grains /spike		Grain weight/ spike (g)		Grain yield (t/ha)		Straw yield (t/ha)	
			2014-15	2014-15	2014-15	2014-15	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendemethalin	1250	Pre	43.3	98.5	183.6	963.5	172.0	193.0	46.1	45.6	2.4	2.3	2.99	3.75	5.67	5.39
Sulfosulfuron	25	Post	44.2	94.3	169.8	906.9	157.8	188.1	44.3	41.0	2.2	2.1	2.52	3.31	4.37	4.85
Metribuzin	210	Pre	45.3	99.4	186.7	974.1	174.7	194.0	47.5	46.3	2.5	2.4	3.31	3.43	6.62	5.06
Clodinafop	60	Post	43.5	96.9	174.7	955.7	163.1	185.0	46.4	46.0	2.4	2.5	2.82	3.96	5.23	5.54
Pendimethalin metribuzin	1000+175	Pre	44.7	103.4	195.6	1042.9	182.2	177.0	50.5	49.0	2.8	2.7	3.82	3.75	7.46	5.46
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	46.2	104.1	210.2	1107.6	198.7	199.5	51.9	51.3	2.9	2.7	4.19	4.03	7.79	6.05
Sulfosulfuron + metsulfuron	20+4	Post	45.3	104.0	203.6	1072.9	192.0	200.0	50.5	48.6	2.8	27	4.10	4.12	7.50	6.15
Pinoxaden + metsulfuron	60+4	Post	46.2	105.9	216.9	1197.0	205.3	210.5	51.7	50.0	3.0	3.1	4.17	4.49	7.83	6.66
Mesosulfuron + iodosulfuron	12+2.4	Post	44.3	102.5	200.9	1020.3	188.9	198.1	50.0	50.0	2.7	2.6	3.61	3.75	6.50	6.32
Clodinafop + metsulfuron	60+4	Post	47.5	107.4	222.2	1274.8	210.2	212.0	52.6	51.0	3.1	3.2	4.38	4.87	8.40	6.85
Isoproturon + 2,4-D	1000+500	Post	44.0	96.8	167.6	952.5	156.9	186.0	45.5	45.0	2.3	2.4	2.64	3.59	4.64	6.09
Hand weeding	-	30 & 60	44.3	101.2	193.3	1009.4	181.3	189.0	49.2	46.3	2.7	2.5	3.40	3.94	6.53	6.33
Weedy check	-	-	42.5	92.1	133.3	808.0	121.3	133.0	38.2	31.0	1.6	1.7	2.11	2.36	4.17	4.02
LSD (p=0.05)	-	-	0.3	2.9	28.0	62.9	21.3	9.6	1.4	1.8	0.2	0.06	0.38	0.36	0.70	0.60

hand weeding twice in terms of marginal benefit cost ratio (MBCR). The highest MBCR was obtained under clodinafop + metsulfuron, sulfosulfuron + metsulfuron, metribuzin and pinoxaden + metsulfuron.

Impact assessment

Weed control efficiency (WCE) and weed control index (WCI) were significantly and positively associated with grain yield of wheat. Clodinafop + metsulfuron resulted in highest WCE and WCI followed by pinoxaden + metsulfuron, sulfosulfuron + metsulfuron, and pendimethalin *fb* sulfosulfuron (**Table 4**). Weed flora was of diverse nature with added phenotypic plasticity and competitive ability even after their survival after a treatment. That is why weed persistence index (WPI) was more in treatments where better control was achieved. Hand weeding had the highest WPI followed by clodinafop + metuslfuron, sulfosulfuron, and pinoxaden + metsulfuron. Crop competitive ability relative to those of weeds is shown by crop resistance index (CRI). The highest CRI and treatment/herbicide efficiency index (HEI) was worked out for clodinafop + metsulfuron followed by pinoxaden + metsulfuron, pendimethalin *fb* sulfosulfuron and sulfosulfuron + metsulfuron. WMI, AMI and IWMI were highest under sulfosulfuron followed by clodinafop +

Table 3. Economics of weed control and economic threshold of weeds

Treatment	Dose (g/ha)	Time	Gt	Et (S&P)		Et (U&M)		CWC	GR	GRwc	NRwc	MBCR
				Count	Weight	Count	Weight					
Pendemethalin	1250	Pre	260	19.6	22.6	8.8	8.6	4162	81548	25343	21180	5.1
Sulfosulfuron	25	Post	118	8.9	10.3	3.9	4.3	1889	69702	13496	11607	6.1
Metribuzin	210	Pre	101	7.6	8.8	3.0	2.9	1622	83120	26915	25293	15.6
Clodinafop	60	Post	142	10.7	12.4	4.8	4.5	2274	81185	24979	22705	10.0
Pendimethalin + metribuzin	1000+175	Pre	250	18.8	21.7	7.4	7.6	3997	92847	36642	32645	8.2
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	326	24.5	28.3	9.2	9.4	5209	100368	44162	38953	7.5
Sulfosulfuron + metsulfuron	20+4	Post	132	10.0	11.5	3.7	3.7	2117	99856	43651	41533	19.6
Pinoxaden + metsulfuron	60+4	Post	209	15.7	18.2	5.9	6.0	3347	105489	49283	45936	13.7
Mesosulfuron + iodosulfuron	12+2.4	Post	157	11.8	13.6	4.8	4.7	2511	90938	34733	32222	12.8
Clodinafop + metsulfuron	60+4	Post	166	12.5	14.5	4.6	4.6	2664	112085	55880	53216	20.0
Isoproturon + 2,4-D	1000+500	Post	156	11.7	13.6	5.2	5.5	2496	76667	20462	17966	7.2
Hand weeding	-	30 & 60	1126	84.7	97.9	28.9	28.9	18020	90902	34696	16676	0.9
Weedy check	-	-	0	0.0	0.0	-	-	0	56206	0	0	0.0
LSD (p=0.05)	-	-										

Gt, gain threshold; Et, Economic threshold; Et (S&P), economic threshold after Stone and Pedigo; Et (U&M), Economic threshold after Uyger & Mennan; GR, Gross return (INR/ha); GRwc, Gross return over weedy check (INR/ha); CWC, cost of weed control (INR/ha); NRwc, Net return over weedy check; MBCR, marginal benefit cost ratio

Table 4. Impact assessment indices

Treatment	Dose (kg/ha)	Time (DAS)	WCE	WCI	WPI	CRI	WMI	AMI	IWMI	HEI	WI	Win	Cin	OIi
Pendemethalin	1250	Pre	70.5	72.0	0.95	5.01	2.10	1.10	1.60	1.81	8.3	22.5	77.5	0.83
Sulfosulfuron	25	Post	58.9	51.4	1.18	2.45	2.54	1.54	2.04	0.63	20.6	30.0	70.0	0.63
Metribuzin	210	Pre	70.9	73.3	0.92	5.45	2.06	1.06	1.56	1.91	8.2	22.1	77.9	0.98
Clodinafop	60	Post	62.9	68.7	0.84	4.43	2.21	1.21	1.71	1.66	7.6	27.7	72.3	0.85
Pendimethalin + metribuzin	1000+175	Pre	82.0	80.2	1.10	8.16	2.11	1.11	1.61	3.50	-3.1	15.3	84.7	1.09
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	84.9	83.1	1.12	10.34	2.21	1.21	1.71	4.99	-11.9	12.0	88.0	1.22
Sulfosulfuron + metsulfuron	20+4	Post	85.1	83.0	1.14	10.15	2.22	1.22	1.72	4.93	-11.9	12.1	87.9	1.36
Pinoxaden + metsulfuron	60+4	Post	87.2	85.0	1.17	12.22	2.28	1.28	1.78	6.27	-17.9	10.0	90.0	1.42
Mesosulfuron + iodosulfuron	12+2.4	Post	75.8	77.4	0.93	7.06	2.13	1.13	1.63	2.87	-0.2	18.4	81.6	1.07
Clodinafop + metsulfuron	60+4	Post	89.7	87.7	1.19	15.77	2.36	1.36	1.86	8.72	-25.9	8.1	91.9	1.68
Isoproturon + 2,4-D	1000+500	Post	65.0	60.8	1.12	3.42	2.30	1.30	1.80	1.01	15.2	26.9	73.1	0.74
Hand weeding	-	30 & 60	84.3	79.5	1.30	7.79	2.07	1.07	1.57	3.14	0.0	13.3	86.7	0.92
Weedy check	-	-	0.0	0.0	1.00	1.00				0.00	39.2	58.6	41.4	0.22
LSD (P=0.05)	-	-												

WCE, weed control efficiency (%); WPI, Weed persistence index; CRI, Crop resistance index; WMI, Weed management index; AMI, Agronomic management index; IWMI, Integrated Weed management index; HEI, Treatment/Herbicide efficiency index; WI, weed index; Win, Weed intensity; Cin, Crop intensity; OIi, overall impact index metsulfuron, isoproturon + metsulfuron, penoxaden + metsulfuron, sulfosulfuron + 2,4-D and clodinafop. Weed index was lowest under clodinafop + metsulfuron followed by pinoxaden + metsulfuron, sulfosulfuron + metsulfuron, pendimethalin + metsulfuron and pendimethalin + metribuzin. The other treatments had positive values of WI indicating lower yield relative to hand weeding twice. Weed intensity was the lowest and crop intensity was the highest under clodinafop + metsulfuron followed by penoxaden + metsulfuron, pendimethalin *fb* sulfosulfuron, sulfosulfuron + metuslfuron and hand weeding twice. Grain yield of wheat was positively associated with CRI (r= 0.965**), TEI (r= 0.941**) and crop intensity (r= 0.931**). To have a valid inference from the present investigation an overall impact index was worked out by taking into consideration growth, yield attributes, yield and economics as well as different impact indices together. **Table 4** showing higher values of OIi for all herbicidal combinations than the threshold value of 1. The other treatments had values of OIi lower than the threshold value.

It can be inferred that clodinafop + metsulfuron, penoxaden + metsulfuron, sulfosulfuron + metsulfuron, pendimethalin *fb* sulfosulfuron and pendimethalin + metribuzin may be preferred against sole application of herbicides for effective weed management in wheat under mid hills condition of Himachal Pradesh.

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Bio-efficacy of different herbicides in greengram under irrigated condition of middle Gujarat

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ABSTRACT

A systemic field study on bioefficacy of different herbicides in greengram (*Vigna radiata* L.) under irrigated condition of Gujarat and its residual effect on succeeding mustard crop was conducted during *Kharif* 2014 and 2015 at AAU, Anand. Among the tested options, hand hoeing at 20 and 40 days after sowing (DAS) and pre-emergence (PE) application of imazethapyr + pendimethalin ready mix (RM) at 1000 g/ha proved their supremacy in achieving highest seed yield (1.45 and 1.43 t/ha) with highest B:C of 2.91 & 2.88, respectively. These treatments provided season long control of weeds with the weed control efficiency (WCE) of 93% and 89%, respectively. Moreover, post-emergence (PoE) application of imazethapyr 70 and 80 g/ha or imazethapyr + imazamox ready mix (RM) 80 g/ha provided excellent WCE of more than 85%, but posed their negative impact on symbiotic parameters such as nodule number, plant dry weight and secured lower net return. Treatment receiving pre-emergence application of imazethapyr 80 g/ha was only found superior to achieve all profits with low input cost but did not control weeds effectively. Additionally, imazethapyr and its ready mix combination irrespective of dose did not show any residual effect to succeeding mustard crop.

Key words: Bio-efficacy, Dose-response, Herbicide combination, Integrated weed management

Greengram (*Vigna radiata* L.) is the most important and extensively cultivated legume crop grown during the *Kharif* season in India. It is cultivated on 3.44 million hectares with the production of 17.2 million tonnes in arid and semi-arid regions of India. Major constrains to the production of greengram are use of low genetic yield potential varieties, weed growth during the critical period, pre harvest sprouting and yellow vein mosaic virus incidence. Among these, weed infestation, particularly at early crop growth stages, poses a considerable threat to achieving the expected yields. Critical period of crop-weed competition in greengram is about 20-40 days after sowing (Saraswat and Mishra 1993). Life cycle of most of weeds coincide with that of crop they invade thus, ensuring mixing of their seed with those of the crops (Mahroof *et al*. 2009). Use of herbicide at critical stages plays a significant role in maintaining the productivity by decreasing weed interferences. Weeds in greengram have been reported to offer serious competition and cause yield reduction to the extent of 49% (Parkash *et al*. 1988) while Verma *et al*. (2015) reported that up to 96.5% yield reduction was observed depending on weed type and crop weed competition.

Greengram is a short duration crop requires initial control of weeds for crop establishment. The initial 70-80% of crop growth is generally achieved during initial 20-40 days of crop. Hence, pre-emergence herbicides presume great important during the initial growth period. The application of pre-emergence herbicide suppress the weed emergence hence, provide favorable environment to grow under weed free condition. The weed emerged during critical growth period also require indispensable attention to control weed flush, which can be controlled either by the use of post-emergence herbicides or hand weeding or inter culture operations. So that all growth stages can be covered to achieve higher yield outcome within time frame.

The most commonly and effective herbicides for controlling weeds in greengram are quizalofop-p-ethyl, pendimethalin, imazethapyr, imazamox, oxyfluorfen (Chhodavadia *et al*. 2013 and Kaur *et al*. 2016). The combination of pre- and post-emergence herbicide or some ready-mix formulations available in the market help to manage complex weed flora and reduced crop-weed competition. Hence, the present investigation was undertaken to determine the efficacy of different pre- and post-emergence herbicides applied as alone and ready mix in conjunction with mechanical method (hand hoeing) in greengram. The succeeding mustard crop was taken as test crop in the same set of treatment to assess residual effects of applied herbicides in greengram on growth and yield parameters of succeeding mustard crop.

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MATERIALS AND METHODS

The present studies were conducted at research farm of AICRP- Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand during the *Kharif* and *Rabi* seasons of 2014 and 2015 under irrigated condition. The soil of the experimental site had loamy sand in textured with the pH and electrical conductivity (EC) of 8.1 and 0.29 dS/m, respectively. The organic carbon, available nitrogen, phosphorus and potassium of the soil ranged from 0.42% (low), 233.8 (low), 13.8 (medium) and 270.5 (medium) kg/ha, respectively. The experiment was comprised of twelve treatments comprising alone and combinations of different pre-emergence (PE) and post-emergence (PoE) herbicides *viz.* imazethapyr 70 g/ha PE, imazethapyr 80 g/ha PE, imazethapyr 70 g/ha PoE, imazethapyr 80 g/ha PoE, imazethapyr + imazamox ready mix (RM) 70 g/ha PE, imazethapyr + imazamox ready mix (RM) 80 g/ha PE, imazethapyr + imazamox ready mix (RM) 70 g/ha PoE, imazethapyr + imazamox ready mix (RM) 80 g/ha PoE, pendimethalin 1000 g/ha PE, imazethapyr + pendimethalin ready mix (RM) 1000 g/ha PE, hoeing 20 and 40 DAS and weedy check. The field experiment was laid out in randomized block design and replicated thrice.

Greengram cultivar '*Meha*' was sown at the rate of 20 kg/ha on August, 17 and July, 17 and harvested on November, 15 and October, 11 during the 2014 and 2015, respectively keeping 45 cm row spacing. The dose of nitrogen and phosphorous fertilizers was supplied through urea and di-ammonium phosphate (DAP) at 20 and 40 kg/ha, respectively. The PE herbicides were applied to soil on next day of sowing, while PoE herbicides spray was done at 15-20 days after sowing (DAS) (3-4 leaf stage of weeds) based on soil moisture condition by knapsack sprayer fitted with flat-fan nozzle using 500 litres/ha water. All the recommended package of practices was followed to grow greengram and mustard crop. Observations of weed density and weed dry biomass were recorded at 40 DAS by using one meter square size quadrate. The crop plant dry biomass was also recorded by uprooting five plants from each replication. Weed control efficiency (WCE) and weed index (WI) were calculated with the standard formula.

The weed index signifies loss of seed yield percent by the presence of weeds and its competition. This is used to assess the efficacy of herbicide. Lesser the weed index better is the efficiency of herbicides and vice versa. Weed control efficacy signifies herbicide use efficacy to control weeds effectively.

Phytotoxic effect of herbicides on crop in terms of yellowing, wilting, necrosis epinasty and hyponasty were recorded at 7 and 14 days after herbicide application (DAHA). Crop yield and yield parameters were recorded at maturity. Mustard crop cultivar '*GM 2'* was sown in second fortnight of November after harvest of greengram without disturbing soil in same layout of preceding greengram. Plant dry biomass and plant height of mustard were recorded at 60 DAS. Seed and stalk yield of mustard were recorded at harvest to quantify the residual effect of herbicides used in preceding greengram crop.

RESULTS AND DISCUSSION

Weed flora

The predominant weeds recorded in the experimental site among the monocot weeds were *Eleusine indica, Commelina benghalensis, Cyprus iria, Eragrostis major, Dactyloctenium aegyptium, Digitaria sanguinalis,* and among dicot weeds were *Digera arvensis, Phyllanthus niruri, Euphorbia hirta, Oldenlandia umbellate* and *Boerhavia diffusa.* The incidences of monocoat weeds were predominated (74.6%) followed by broad-leaved (25.4%) during the experimentation of greengram crop. *Eleusine indica* (30.7%) and *Digera arvensis* (6.79%) were found more dominant weed species among the grassy and broad-leaved weeds, respectively.

Effects on weeds

All the herbicidal treatments convincingly suppressed weed growth of monocot, dicot and total weeds and found superior over weedy check (**Table 1**). Weed density and weed dry biomass recorded at 40 DAS were significantly influenced by weed management practices except for monocot weed dry biomass. Among the herbicides applied alone, application of pendimethalin 1000 g/ha as pre-emergence application resulted in the lowest density of monocot and total weeds, while the lowest density of dicot weeds was recorded with post-emergence application of imazethapyr 80 g/ha. The combination of imazethapyr + pendimethalin (RM 1000 g/ha PE) proved its supremacy over all other treatments to control monocot (4.74 weeds/m^2) and total weeds (5.62 weeds/m^2) and imazethapyr + imazamox (RM) 80 g/ha PoE (1.44 weeds/m^2) found superior to control dicot weeds over weedy check for each category. Singh *et al.* (2016) also reported the same trend of result in black gram. Kushwah and Vyas (2006) reported that imazethapyr applied at 75 g/ha was effective against both monocot and dicot weeds and was at par with one hand weeding carried out at

20 DAS, however, it was more effective against grassy weeds. The better performance of combination of herbicides might be due to synergistic effect between the two herbicides reducing the population as well as dry biomass accumulation of different weed species. All the premix herbicides were found to be superior over individual weed control treatments. This might be due to the combined effect of both herbicides in checking the weed growth successfully (Mansoori *et al.* 2015).

Further, it was noticed that the minimum weed dry biomass of monocot (3.74 g/m^2) and total weeds (4.30 g/m^2) was observed in imazethapyr + pendimethalin (RM) 1000 g/ha PE treatment, whereas, imazethapyr + imazamox (RM) 80 g/ha recorded the lowest dicot weed dry biomass (1.09 g/m^2). Hand hoeing at 20 and 40 DAS was also found comparable with combination of imazethapyr + pendimethalin at 1000 g/ha in reducing the dry matter accumulation of weeds.

Weed index and weed control efficiency are generally driven based on abundance of weed species present in the field. Hand hoeing at 20 and 40 days after sowing recorded 93 per cent weed control and nullify yield lose of greengram due to crop weed competition. Among various herbicide application, the highest weed control efficiency (89%) and the lowest weed index (1%) was obtained under imazethapyr + pendimethalin (RM) applied at 1000 g/ha PE. Weedy check recorded with the highest weed index (44%) due to absolute crop-weed competition. The highest weed control efficiency in ready mix of imazethapyr + pendimethalin applied at 1000 g/ha PE was recorded due to synergistic impact of herbicides to control grassy weeds which led to less dry biomass accumulation by weeds.

Effect on yield attributes and yield

The result revealed that plant stand (no./m^2) at 15 DAS and dry biomass of *Rhizobium* root nodule (mg/plant) at 35 DAS was not influenced significantly but differed significantly in plant height (cm) at 60 DAS and plant dry biomass (g/plant) at 30 and 60 DAS (**Table 2**). The combination of imazethapyr + imazamox (RM) 70 g/ha PE recorded the highest number of plants /m^2 after 15 DAS. The highest biomass of *Rhizobium* root nodules were recorded under weedy check followed by hand hoeing at 20 and 40 DAS. The results of Brahmbhatt (2014) revealed that dry weight of *Rhizobium* nodules in blackgram plant recorded at 45 DAS was significantly higher under IC + HW carried out at 20 and 40 DAS than application of imazethapyr at 100 g/ha as PoE but was found at par with post emergence application of imazethapyr at 75 g/ha. Gonzalez *et al.* (1996) also reported that the number of nodules/plant was affected by application of imazethapyr.

Plant height at 60 DAS and plant dry biomass (g/plant) at 30 and 60 DAS differed significantly with different herbicide treatments. The highest plant dry biomass at 30 and 60 DAS was recorded under application of imazethapyr at 70 g/ha PE due to effective control of weeds and least effect on crop growth which reduced crop-weed competition at initial stage effectively.

All the herbicide treatments produced significantly higher seed yield ranged from 0.98 to 1.43 t/ha in comparison to weedy check (0.81 t/ha) except under imazethapyr + imazamox (RM) 80 g/ha PoE (**Table 2**). Hand hoeing at 20 and 40 DAS achieved the highest seed yield (1.45 t/ha) followed by imazethapyr + pendimethalin (RM) at 1000 g/ha PE, imazethapyr 80 g/ha PE and least under weedy

Table 1. Observation of weed parameters under different weed management treatment and impact of herbicide on crop and weeds

Treatment	Weed density (No./ m^2) at 40 DAS			Weed dry biomass (g/m^2) at 40 DAS			WCE (%)	Weed Index (%)
	Monocot	Dicot	Total	Monocot	Dicot	Total		
Imazethapyr 70 g/ha PE	8.92^{ab} (158)	3.49^{bcd} (24.3)	9.59^{b} (91.2)	6.61 (45.2)	2.42^{b} (5.12)	7.04^{bc} (50.3)	71	10
Imazethapyr 80 g/ha PE	7.89^{abcd} (128)	3.52^{bcd} (27.0)	8.81^{bc} (77.4)	6.59 (46.2)	2.09^{b} (3.42)	6.87^{bc} (49.7)	71	3
Imazethapyr 70 g/ha PoE	7.77^{abcd} (121)	3.84^{ab} (32.8)	8.78^{bc} (76.8)	4.54 (21.1)	1.98^{b} (2.98)	4.86^{bc} (24.0)	86	9
Imazethapyr 80 g/ha PoE	7.54^{bcd} (113)	3.19^{bcd} (20.8)	8.21^{bcde} (66.7)	4.90 (23.4)	1.87^{b} (2.54)	5.22^{bc} (25.9)	85	12
Imazethapyr + imazamox 70 g/ha PE	8.16^{abc} (133)	2.59^{bcd} (12.1)	8.52^{bcd} (72.3)	8.20 (70.1)	2.31^{b} (5.13)	8.47^{b} (75.2)	57	7
Imazethapyr + imazamox 80 g/ha PE	7.53^{bcd} (114)	2.51^{bcd} (11.1)	7.90^{bcde} (62.4)	6.76 (50.7)	1.60^{b} (1.71)	6.88^{bc} (52.3)	70	6
Imazethapyr + imazamox 70 g/ha PoE	6.84^{bcd} (93.5)	1.46^{cd} (3.00)	6.96^{cdef} (48.0)	5.84 (33.4)	1.14^{b} (0.35)	5.86^{bc} (33.7)	81	19
Imazethapyr + imazamox 80 g/ha PoE	6.39^{cde} (81)	1.44^{d} (3.00)	6.52^{ef} (41.8)	4.52 (21.7)	1.09^{b} (0.20)	4.54^{bc} (21.9)	87	32
Pendimethalin 1000 g/ha PE	5.82^{de} (70.5)	3.56^{bcd} (23.6)	6.80^{def} (46.6)	6.23 (38.4)	3.94^{b} (17.3)	7.38^{bc} (55.6)	68	10
Imazethapyr + pendimethalin 1000 g/ha PE	4.74^{e} (47.3)	3.12^{bcd} (17.8)	5.62^{f} (32.5)	3.74 (14.6)	2.31^{b} (4.77)	4.30^{bc} (19.3)	89	1
Hoeing at 20 and 40 DAS	4.48^{e} (39.3)	3.19^{bcd} (16.8)	5.43^{f} (28.9)	2.89 (7.70)	2.11^{b} (3.65)	3.48^{c} (11.4)	93	0
Weedy check	9.9^{a} (209)	5.98^{a} (71.0)	11.7^{a} (140)	10.1 (105)	7.77^{a} (67.8)	13.2^{a} (173)	0	44
LSD (p=0.05)	1.93	1.88	1.78.	NS	2.99	3.81	-	-

Note: Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values. Treatment means with the letter/letters in common are not significant by Duncan's New Multiple Range Test at 5% level of significance.

check. Alone adoptability of two hand hoeing (20 and 40 DAS) found comparable with imazethapyr + pendimethalin (RM) applied at 1000 g/ha PE. Among the different pre-mix herbicides, maximum seed yield was recorded with the application of imazethapyr + pendimethalin (RM) at 1000 g/ha PE which was at par with all other RM combinations except with imazethapyr + imazamox (RM) 80 g/ha PoE. Seed yield under this treatment was negatively associated with total weed density and weed dry biomass and positively associated with plants (no./m^2), pods/plant and seeds/pod. Rao *et al.* (2010) also reported that application of pendimethalin alone or combinations of imazethapyr + pendimethalin found better in reduction of dry matter accumulation of weeds with maximum seed yield. Among alone application of herbicide, higher seed yield (1.40 t/ha) was recorded with the application of imazethapyr at 80 g/ha PE, which showed 72.8% increment in yield over weedy check. Out of chemical treatments imazethapyr + imazamox (RM) 80 g/ha PoE accounted 32% yield reduction in seed yield in comparison with hand hoeing at 20 and 40 DAS. The reduction in yield in the seed yield in treatment was accounted due to phytotoxic effect of herbicide on greengram. Haulm yield followed the similar on trend of green yield.

Phytotoxic effects on greengram

The phytotoxicity score of the applied herbicides on greengram crop indicated that application of imazethapyr 80 g/ha PoE and imazethapyr + imazamox (RM) 70 and 80 g/ha PoE caused phytotoxicity in crop up to two weeks but after that crop fully recovered from the ill effect of herbicides. However, this slight impact of phytotoxicity in initial growth period of greengram resulted in yield reduction to the tune of 11.7, 18.6 and 32.4% in these three treatments, respectively.

Economics

Hand hoeing at 20 and 40 DAS achieved the highest seed yield, gross income, net return, and reduced weed dry biomass and weed density followed by imazethapyr + pendimethalin (RM) applied at 1000 g/ha PE (**Table 2**). Treatment imazethapyr 80 g/ha as pre-emergence was only comparable to achieve all profits with low input cost. Ali *et al.* (2011) recorded that among the other weed control treatments application of imazethapyr 100 g/ha as post-emergence recorded maximum net return of ` 50,472/ha. The B:C ratio also reported highest under hand hoeing at 20 and 40 DAS treatment followed by imazethapyr at 80 g/ha PE, imazethapyr + pendimethalin (RM) applied at 1000 g/ha PE and lowest under imazethapyr + imazamox (RM) 80 g/ha PoE. Tamang *et al.* (2015) also observed maximum net returns and benefit: cost ratio obtained from pendimethalin + imazethapyr 1000 g/ha.

From the results of field experiments, it is concluded that hand hoeing at 20 and 40 DAS achieved best results but in paucity of labour, pre-emergence application of imazethapyr + pendimethalin (RM) at 1000 g/ha or imazethapyr 80 g/ha PE was found suitable alternate for managing complex weed flora and obtaining higher seed yield, net return and return per rupee invested for *Kharif* greengram in alluvial soil of middle Gujarat.

Table 2. Influence of different weed management practices on growth parameters of greengram

Treatment	Plant stand at 15 DAS (no./m)	Plant height at 60 DAS (cm)	Root nodule Dry biomass 35 DAS (mg/plant)	Plant dry biomass at (g/plant)		Seed yield (t/ha)	Haulm yield (t/ha)	B: C ratio
				30 DAS	60 DAS			
Imazethapyr 70 g/ha PE	9.85	72.6^{bc}	55.9	4.29^{a}	29.2^{a}	1.30^{a}	2.11^{abc}	2.72
Imazethapyr 80 g/ha PE	10.4	72.5^{bc}	52.1	4.12^{abc}	26.7^{abcd}	1.40^{a}	2.19^{ab}	2.90
Imazethapyr 70 g/ha PoE	10.4	66.7^{cd}	56.6	3.47^{bcd}	25.1^{abcd}	1.33^{a}	2.07^{abc}	2.77
Imazethapyr 80 g/ha PoE	10.4	65.2^{d}	56.2	3.37^{cde}	23.8^{bcd}	1.28^{a}	2.01^{bc}	2.66
Imazethapyr + imazamox 70 g/ha PE	10.3	73.7^{abc}	60.3	4.18^{ab}	27.2^{abc}	1.35^{a}	2.18^{ab}	2.79
Imazethapyr + imazamox 80 g/ha PE	10.3	74.7^{ab}	58.3	3.98^{abc}	28.1^{ab}	1.36^{a}	2.21^{ab}	2.78
Imazethapyr + imazamox 70 g/ha PoE	10.6	64.8^{d}	51.7	2.76^{de}	23.4^{cd}	1.18^{a}	2.02^{abc}	2.43
Imazethapyr + imazamox 80 g/ha PoE	10.5	62.9^{d}	50.9	2.72^{e}	22.7^{de}	0.98^{bc}	1.81^{c}	2.02
Pendimethalin 1000 g/ha PE	10.2	72.5^{bc}	56.7	3.94^{abc}	26.6^{abcd}	1.31^{a}	2.04^{abc}	2.71
Imazethapyr + pendimethalin 1000 g/ha PE	10.2	74.3^{ab}	57.0	3.55^{abc}	27.5^{abc}	1.43^{a}	2.38^{a}	2.88
Hoeing at 20 and 40 DAS	10.3	72.3^{bc}	62.0	4.12^{abc}	26.9^{abcd}	1.45^{a}	2.29^{ab}	2.91
Weedy check	9.8	80.3^{a}	66.4	3.71^{abc}	19.3^{e}	0.81^{c}	1.22^{d}	1.84
LSD (p=0.05)	NS	6.55	NS	0.70	3.82	0.27	0.34	-

Note: Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values. Treatment means with the letter/letters in common are not significant by Duncan's New Multiple Range Test at 5% level of significance.

Table 3. Influence of different weed management practices of preceding greengram crop on growth of succeeding mustard crop

Treatment	Plant population at 15 DAS (no./m)	Plant height at 60 DAS (cm)	Plant dry biomass at 60 DAS (g/plant)	Seed yield (t/ha)	Stalk yield (t/ha)
Imazethapyr 70 g/ha PE	9.00	165	41.4	1.55	5.68
Imazethapyr 80 g/ha PE	9.05	167	40.7	1.61	5.88
Imazethapyr 70 g/ha PoE	8.82	168	41.8	1.68	6.08
Imazethapyr 80 g/ha PoE	8.72	167	43.4	1.72	6.09
Imazethapyr + imazamox 70 g/ha PE	8.90	165	41.6	1.60	5.84
Imazethapyr + imazamox 80 g/ha PE	8.65	164	41.3	1.58	5.85
Imazethapyr + imazamox 70 g/ha PoE	9.05	164	43.1	1.61	6.10
Imazethapyr + imazamox 80 g/ha PoE	8.95	165	41.2	1.55	5.79
Pendimethalin 1000 g/ha PE	8.92	167	42.9	1.61	5.66
Imazethapyr + pendimethalin 1000 g/ha PE	9.00	167	42.8	1.66	6.20
Hoeing at 20 and 40 DAS	9.25	162	42.5	1.55	6.09
Weedy check	9.27	167	39.9	1.57	6.00

Residual effect of herbicides on mustard

No any residual effect of applied herbicides in greengram was visible on succeeding mustard crop in plant stand, plant height, plant dry biomass, seed and stalk yield and exhibited no significant differences in these parameters (**Table 3**).

The present investigation observed that weeds in greengram caused 44% reduction in seed yield. As per the findings of this study, it was inferred that hand hoeing at 20 and 40 days after sowing or pre-emergence application of imazethapyr + pendimethalin (RM) at 1000 g/ha proved their supremacy in achieving higher seed yield, net monetary, gross monetary returns with no phytotoxic effect on greengram. No residual effect of any herbicide applied in greengram was observed on succeeding mustard crop.

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Weed management in blackgram and its residual effect on succeeding mustard crop

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ABSTRACT

The investigation was undertaken at Birsa Agricultural University, Ranchi during *Kharif*, 2014 and 2015. The experiment was laid out in randomized block design with sixteen treatments replicated thrice. The treatments comprised of pre- and post-emergence of imazathepyr 50, 70 and 80 g/ha; pre- and post-emergence of ready mix imazethapyr 35% + imazamox 35% (Odyssey) 50, 70 and 80 g/ha; pre-emergence (PE) of pendimethalin 1000 g/ha, ready mix imazethapyr 2% + pendimethalin 30% (Vallor) 1000 g/ha, hoeing twice and weedy check. Post-emergence (PoE) of imazethapyr 35% + imazamox 35% 70 g/ha similar to PE of imazethapyre 80 g/ha, imazethapyr 35% + imazamox 35% 70 g/ha, imazethapyr 35% + imazamox 35% 80 g/ha, pendimethalin 1000 g/ha and PoE of imazethapyr 80 g/ha, imazethapyr 35% + imazamox 35% 50 g/ha recorded 69.86 and 126.72% significantly higher seed (1.12 t/ha) and straw yield (2.33 t/ha) respectively, 168.63% higher net return (` 24,126/-) and 192.41% higher B:C ratio (2.31) compared to weedy check owing to 87.29 and 86.08% weed control efficiency.

Key words: Blackgram, Imazethapyr, Phytotoxicity, Ready mix, Weed management

Pulse crops are very slow in growth at seedling stage. In addition, they do not have much canopy in terms of branching and leaf size during initial growth to stand up to weed competition. One of the major causes for poor yields in pulses is attributed to the luxurious growth of weeds in these crops and failure to control them in time. Weed infestation in black gram may reduce yield up to an extent of 45 to 60%. With the identification of short-statured, compact and early-maturing varieties, the weed problem has become more acute. The most commonly employed method is weeding through physical methods which include both manual and mechanical operations. Manual weeding is also cumbersome and uneconomical to practice (Sasikala *et al.* 2014).

Use of herbicides under such conditions is advantageous as the operation is not only economical but also provides timely protection. Some important considerations have to be borne in mind while using the herbicides for weed control; the herbicides besides being selective on a particular crop should not leave residues in the soil to affect the succeeding crops in rotation. In the case of pulses an additional important point to be kept in view is that these herbicides should not be harmful to the soil micro flora that build up soil fertility and to the nodule-inducing organisms which fix atmospheric nitrogen. Although pre-emergence use of pendimethalin at 1.0 kg/ha has been found effective to control weeds in blackgram but a residual herbicide is needed to control second flush of weeds emerging after rains. Imazethapyr and its ready mix combination with imazamox, new herbicides of imidazolinone group have been found promising to control weeds in blackgram. Imazethapyr being highly persistent in soil may cause residual toxicity in succeeding crops (Hollaway *et al*. 2006). Keeping these in view, herbicides imazethapyr alone or in combination with imazamox and pendimethalin as pre-mixture were tested under pre and post-emergence conditions.

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MATERIALS AND METHODS

A field experiment was conducted in agronomical farm of Birsa Agricultural University, Ranchi during *Kharif*, 2014 and 2015 to find out the effect of weed control methods on weed dynamics and productivity of blackgram and succeeding mustard and also system productivity of blackgram and mustard cropping system. The treatments comprised of pre- and post-emergence application of imazathepyr 50, 70 and 80 g/ha; pre- and post-emergence application of ready mix imazethapyr 35% + imazamox 35% (Odyssey) 50, 70 and 80 g/ha; PE application of pendimethalin 1000 g/ha, ready mix imazethapyr 2%+ pendimethalin 30% (Valor) 1000 g/ha, hoeing twice at 25 and 50 DAS and weedy check. All herbicides were sprayed using knapsack sprayer fitted with flat fan nozzle with 600 L water/ha. The experiment was laid out in a randomized block design with three replications. The experimental soil was sandy loam in texture with pH 5.6. The soil was poor in nitrogen (189 kg/ha), medium in phosphorus (21.0 kg/ha) and potash (155 kg/ha). The organic carbon was 4.30 g/kg soil. Cultural practices recommended for blackgram and mustard was adopted during crop growth period.

Weed density was counted at 30, and 60 DAS. Yield and yield attributes were recorded at harvest. To evaluate bioefficacy of herbicide against grassy, broad-leaf and sedges the weeds were removed at 30, and 60 DAS. The blackgram crop variety '*T9*' was sown on 16th and 3rd July 2014 and 2015 and was harvested on 22nd and 12th September, 2014 and 2015 respectively. The succeeding mustard crop variety '*Shivani*' was sown on 29th October and 2nd November, 2014 and 2015 and harvested on 10th and 28th February, 2015 and 2016 respectively. The phytotoxic effect on blackgram was assessed by visual observations of crop injury at 10 scales.

RESULTS AND DISCUSSION

Weed density

Post-emergence application of imazethapyr 35% + imazamox 35% 80 g/ha was most effective in reducing grassy weeds at 30 and 60 DAS while imazethapyr 2% + pendimethalin 30% 1000 g/ha was effective against broad-leave weeds at 30 DAS and PoE of imazethapyr 70 g/ha against sedges at 30 and 60 DAS (**Table 1**).

Weed dry-matter

Among different herbicides, application of imazethapyr + pendimethalin 1000 g/ha was most effective in reducing weed dry matter of total weeds at 30 and 60 DAS. However at 30 DAS, it was similar to all herbicides except PoE of imazethapyr irrespective of doses and PoE of imazethapyr + imazamox 50 g/ha, as well as PE of imazethapyr 50 g/ha and pendimethalin 1000 g/ha. Among different categories of weeds PE of imazethapyr + imazamox 80 g/ha was most effective in reducing dry matter of grassy and sedges weeds at 30 DAS and also broad-leaved weeds at 60 DAS (**Table 2**).

Phytotoxicity and weed control efficiency in blackgram

Post-emergence imazethapyr and ready mix imazethapyr and imazamox irrespective of doses showed mean weed control efficiency of 66.53 and 66.77% and 82.65 and 78.93%, respectively at 30 and 60 DAS but at the same time showed slight phytotoxicity in black gram plants at 15 days after application of herbicides in the form of stunted growth of plants which mitigated after some time. Kumar *et al*. (2015) have also observed post-emergence use of imazethapyr + imazamox at 60-80 g/ha, which exhibited 78-83% control of weeds with slight crop suppression in form of chlorosis, leaf crinkling and stunting, which mitigated within 15 days after spray (**Table 3**).

Table 1. Weed density (no./m^2) as influenced by imazathepyre and its ready mix in blackgram (pooled of 2014and 2015)

Treatment	Weed density (no./m^2)							
	30 DAS			60 DAS			30 DAS	60 DAS
	Grassy	BLW	Sedges	Grassy	BLW	Sedges	Total	Total
Imazethapyr 50 g/ha PE	13.47 (182)	17.05 (291)	6.04 (38)	12.65 (160)	19.12 (366)	6.07 (37)	20.91 (438)	23.71 (563)
Imazethapyr 70 g/ha PE	9.99 (126)	13.28 (254)	3.80 (22)	11.06 (135)	16.78 (329)	5.20 (34)	15.94 (340)	20.76 (498)
Imazethapyr 80 g/ha PE	11.24 (99)	15.94 (176)	4.77 (14)	11.62 (122)	18.03 (282)	5.85 (27)	18.44 (255)	22.25 (431)
Imazethapyr 50 g/ha PoE	12.53 (158)	15.77 (249)	6.66 (44)	11.07 (122)	15.51 (240)	4.48 (20)	20.05 (405)	19.55 (382)
Imazethapyr 70 g/ha PoE	7.86 (109)	11.36 (169)	2.29 (13)	8.84 (97)	12.83 (239)	1.79 (12)	19.75 (359)	15.70 (348)
Imazethapyr 80 g/ha PoE	10.44 (62)	12.97 (130)	3.71 (6)	9.86 (78)	15.26 (166)	3.52 (3)	18.96 (395)	18.51 (248)
Imazethapyr + imazamox 50 g/ha PE	13.31 (178)	16.14 (261)	5.74 (33)	10.87 (119)	17.70 (315)	5.26 (27)	19.45 (378)	21.40 (461)
Imazethapyr + imazamox 70 g/ha PE	10.91 (119)	15.50 (245)	4.72 (22)	10.28 (106)	14.13 (200)	4.11 (17)	16.08 (261)	17.93 (323)
Imazethapyr + imazamox 80 g/ha PE	8.74 (77)	12.84 (164)	3.18 (10)	9.21 (85)	12.20 (150)	2.49 (6)	12.85 (166)	15.50 (240)
Imazethapyr + imazamox 50 g/ha PoE	10.94 (122)	16.84 (283)	5.12 (27)	12.07 (145)	16.74 (281)	4.18 (17)	20.07 (403)	21.05 (444)
Imazethapyr + imazamox 70 g/ha PoE	5.92 (35)	10.51 (111)	3.95 (15)	8.17 (66)	14.22 (202)	3.68 (13)	14.45 (209)	16.80 (282)
Imazethapyr + imazamox 80 g/ha PoE	3.73 (15)	9.40 (90)	2.85 (10)	5.73 (34)	11.30 (131)	2.11 (4)	10.04 (102)	12.83 (168)
Pendimethalin 1000 g/ha PE	4.60 (21)	10.14 (103)	5.46 (30)	5.32 (28)	7.28 (55)	4.86 (23)	10.57 (112)	10.29 (106)
Imazethapyr 2% + pendimethalin 30% 1000 g/ha	5.14 (26)	5.71 (33)	4.00 (16)	4.97 (26)	12.84 (168)	3.91 (15)	12.57 (160)	14.41 (209)
Hoeing twice	3.80 (14)	8.82 (78)	4.19 (17)	5.45 (30)	9.78 (99)	2.46 (6)	37.87 (1441)	11.53 (134)
Weedy check	15.83 (251)	14.60 (215)	11.77 (140)	9.99 (99)	15.16 (230)	10.11 (102)	35.50 (1265)	20.77 (431)
LSD (p=0.05)	2.22	2.88	2.46	2.06	3.76	1.69	3.53	3.34

Values in parentheses are original. Data transformed to square root transformation

Table 2. Weed dry-matter as influenced by imazathapyr and its ready mix in blackgram (pooled of 2014 and 2015)

Treatment	Weed dry matter (g/m^2) 30 DAS Grassy	30 DAS BLW	30 DAS Sedges	60 DAS Grassy	60 DAS BLW	60 DAS Sedges	30 DAS Total	60 DAS Total
Imazethapyr 50 g/ha PE	5.03 (24.9)	3.08 (9.0)	1.78 (2.73)	5.69 (32.9)	2.64 (6.51)	0.71 (0.00)	6.09 (36.7)	6.26 (39.4)
Imazethapyr 70 g/ha PE	3.06 (13.8)	2.19 (7.5)	0.88 (0.40)	3.74 (17.6)	2.17 (5.01)	0.73 (0.00)	3.74 (21.7)	4.28 (22.6)
Imazethapyr 80 g/ha PE	3.77 (9.0)	2.83 (4.4)	0.95 (0.28)	4.16 (14.0)	2.34 (4.21)	0.71 (0.03)	4.71 (13.7)	4.74 (18.2)
Imazethapyr 50 g/ha PoE	6.52 (42.0)	3.51 (11.9)	2.47 (5.61)	7.48 (58.4)	3.96 (15.8)	0.86 (0.27)	7.74 (59.5)	8.52 (74.5)
Imazethapyr 70 g/ha PoE	3.29 (24.4)	2.97 (11.1)	1.12 (0.90)	6.04 (56.9)	2.41 (8.68)	0.81 (0.07)	4.48 (36.4)	6.48 (65.6)
Imazethapyr 80 g/ha PoE	4.97 (10.6)	3.37 (8.3)	1.18 (0.93)	7.57 (36.4)	2.99 (5.37)	0.75 (0.17)	6.08 (19.8)	8.12 (41.9)
Imazethapyr + imazamox 50 g/ha PE	4.24 (17.7)	2.30 (4.8)	1.18 (0.90)	5.41 (29.1)	2.43 (5.56)	0.79 (0.13)	4.86 (23.4)	5.93 (34.8)
Imazethapyr + imazamox 70 g/ha PE	2.96 (8.3)	2.08 (4.1)	0.76 (0.08)	3.59 (12.6)	2.12 (4.12)	0.71 (0.01)	3.57 (12.5)	4.12 (16.7)
Imazethapyr + imazamox 80 g/ha PE	2.15 (4.6)	2.01 (3.8)	0.74 (0.05)	2.79 (7.6)	1.99 (3.57)	0.75 (0.07)	2.88 (8.5)	3.41 (11.2)
Imazethapyr + imazamox 50 g/ha PoE	4.58 (21.1)	2.94 (8.2)	1.67 (2.30)	6.88 (47.5)	3.47 (11.6)	2.39 (5.26)	5.64 (31.6)	8.01 (64.3)
Imazethapyr + imazamox 70 g/ha PoE	2.47 (5.6)	2.85 (7.6)	1.60 (2.08)	3.57 (12.6)	3.04 (8.81)	2.31 (4.83)	3.98 (15.3)	5.16 (26.3)
Imazethapyr + imazamox 80 g/ha PoE	2.30 (4.9)	2.69 (6.9)	1.44 (1.60)	3.15 (10.7)	2.89 (7.84)	1.77 (2.65)	3.70 (13.4)	4.58 (21.2)
Pendimethalin 1000 g/ha PE	3.28 (10.6)	2.52 (6.3)	4.01 (15.7)	3.75 (13.7)	2.53 (5.91)	2.73 (7.21)	5.69 (32.6)	5.23 (26.9)
Imazethapyr 2% + pendimethalin 30% 1000 g/ha	2.31 (5.6)	1.07 (0.8)	0.83 (0.20)	1.78 (3.2)	2.50 (6.29)	0.98 (0.58)	2.47 (6.6)	3.09 (10.1)
Hoeing twice	2.62 (7.5)	2.37 (5.2)	0.84 (0.21)	1.91 (3.7)	2.03 (3.64)	0.78 (0.13)	3.57 (12.9)	2.80 (7.51)
Weedy check	5.93 (36.9)	4.03 (16.1)	4.17 (16.9)	10.63 (118.9)	4.25 (18.4)	2.93 (8.14)	8.28 (69.9)	11.86 (145.4)
LSD (p=0.05)	1.67	1.01	0.53	2.91	1.26	0.51	1.60	2.60

Values in parentheses are original. Data transformed to square root transformation

Table 3. Effect of weed control methods on economics of blackgram production (pool of 2014 and 2015)

Treatment	WCE% 30 DAS	WCE% 60 DAS	Phytotoxicity 15 days after application of herbicides	Yield (t/ha) Seed	Yield (t/ha) Straw	Gross return ($x10^3$ /ha)	Net return ($x10^3$ /ha)	B:C ratio
Imazethapyr 50 g/ha PE	63.72	77.29	0	0.92	1.32	28.55	18.15	1.74
Imazethapyr 70 g/ha PE	75.57	85.78	0	0.94	1.48	29.05	18.64	1.79
Imazethapyr 80 g/ha PE	86.89	84.88	0	1.07	2.17	33.23	22.80	2.19
Imazethapyr 50 g/ha PoE	55.44	54.97	4	0.86	1.26	26.51	16.11	1.55
Imazethapyr 70 g/ha PoE	64.69	65.87	4	0.93	1.34	28.90	18.48	1.77
Imazethapyr 80 g/ha PoE	79.47	79.49	4	1.00	1.77	31.05	20.63	1.98
Imazethapyr + imazamox 50 g/ha PE	73.13	73.76	0	0.86	1.28	26.57	16.14	1.55
Imazethapyr + imazamox 70 g/ha PE	84.91	86.61	0	1.03	2.00	31.78	21.33	2.04
Imazethapyr + imazamox 80 g/ha PE	90.16	89.38	0	1.07	2.91	33.19	22.72	2.17
Imazethapyr + imazamox 50 g/ha PoE	71.68	64.03	5	0.97	1.71	30.01	19.58	1.88
Imazethapyr + imazamox 70 g/ha PoE	87.29	86.08	5	1.12	2.33	34.58	24.13	2.31
Imazethapyr + imazamox 80 g/ha PoE	88.98	86.70	5	1.10	2.50	34.12	23.66	2.26
Pendimethalin 1000 g/ha PE	69.79	83.33	3	1.10	2.28	34.00	23.09	2.12
Imazethapyr 2% + pendimethalin 30% 1000 g/ha	94.07	83.67	2	0.94	1.51	29.04	17.94	1.62
Hoeing twice	76.36	91.46	0	0.96	1.58	29.73	12.68	0.74
Weedy check	0.00	0.00	0	0.66	1.03	20.38	8.98	0.79
LSD (p=0.05)	17.72	22.57	0.45	0.16	0.71	4.58	4.58	0.42

WCE - Weed control efficiency

Table 4. Weed control methods in blackgram and its effect on yield attributing character and yield of mustard

Treatment	No. of siliqua/plant	1000 seeds weight	No. of branches/ plant	No. of plants/m^2	Yield (t/ha)	Straw yield (t/ha)
Imazethapyr 50 g/ha PE	95	3.78	6	34	1.01	3.13
Imazethapyr 70 g/ha PE	83	3.83	5	36	1.07	2.88
Imazethapyr 80 g/ha PE	94	3.70	8	36	1.07	2.82
Imazethapyr 50 g/ha PoE	150	3.74	7	35	1.38	3.54
Imazethapyr 70 g/ha PoE	88	3.83	5	38	1.10	2.80
Imazethapyr 80 g/ha PoE	114	3.76	7	32	0.96	2.69
Imazethapyr + imazamox 50 g/ha PE	115	3.77	8	35	1.29	3.38
Imazethapyr + imazamox 70 g/ha PE	101	3.72	6	37	1.09	3.10
Imazethapyr + imazamox 80 g/ha PE	63	3.72	4	38	1.25	3.54
Imazethapyr + imazamox 50 g/ha PoE	62	3.74	4	38	1.16	3.11
Imazethapyr + imazamox 70 g/ha PoE	79	3.74	5	32	1.21	3.01
Imazethapyr + imazamox 80 g/ha PoE	107	3.74	7	36	1.11	2.91
Pendimethalin 1000 g/ha PE	92	3.87	6	30	0.92	2.64
Imazethapyr 2% + pendimethalin 30% 1000 g/ha	102	3.52	7	37	1.25	3.38
Hoeing twice	102	3.93	6	37	1.23	3.48
Weedy check	65	3.91	4	32	0.85	2.62
LSD (p=0.05)	NS	NS	NS	2.8	0.40	1.22

Yield and economics

Post-emergence of imazethapyr + imazamox 70 g/ha similar to PE of imazethapyre 80 g/ha, imazethapyr + imazamox 70 g/ha, imazethapyr + imazamox 80 g/ha, pendimethalin 1000 g/ha and PoE of imazethapyr 80 g/ha, imazethapyr + imazamox 50 g/ha, recorded significantly higher seed (1.12 t/ha) and straw yield (2.33 t/ha), gross return (` 34,583/-ha), net return (` 24,126/-) and B:C ratio (2.31).

Residual effect of herbicides applied in blackgram on succeeding mustard crop

No residual effect of herbicides application on succeeding mustard crop was observed except PE of pendimethalin 1000 g/ha and PoE of imazethapyr 80 g/ha when these herbicides reduced mustard plant density to the extent of 10.58 and 16.17% compared to mean plant density of 35.79 plant/m^2. Post-emergence application of imazethapyr 50 g/ha applied in blackgram similar to all treatments except PoE of imazethapyr 80 g/ha, PE of pendimethalin 1000 g/ha and weedy check recorded significantly higher mustard seed yield (1.38 t/ha) and PoE of imazethapyr 50 g/ha similar to PE of imazethapyr + imazamox 50 g/ha, PE of imazethapyr + imazamox 80 g/ha, application of imazethapyr + pendimethalin 1000 g/ha and hoeing twice recorded significantly higher straw yield (**Table 4**). Punia *et al.* (2015) have also reported no residual carry over effect of these herbicides applied in blackgram was visible on succeeding mustard crop as number of plants/meter row length., number of leaves/plant and seed yield of mustard in untreated and herbicide applied treatments was same

On the basis of two year pooled data it can be inferred that PoE of imazethapyr + imazamox 70 g/ha recorded maximum seed (1.12 t/ha) and straw yield (2.33 t/ha), net return (` 24,126/-) and B:C ratio (2.31) without affecting succeeding mustard yield (1.21 t/ha).

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Herbicides for weed management in lentil under rainfed drought prone ecology of Bihar

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ABSTRACT

In context of the emerging challenge of weed management in lentil under rainfed drought prone ecologies in India, a field experiment was conducted in the winter seasons of 2012-13 and 2013-14 to evaluate the performance of different herbicides in lentil under rainfed conditions. Among the herbicidal treatments, the maximum plant height (40.5 cm), plant population (143.7 plants/m^2), branches per plant (5.67), pods per plant (59.03), nodules per plant (21.27), dry weight of nodules per plant (29.44 mg) and dry matter accumulation (486.30 g/m^2) of lentil at maturity were recorded in plots treated with pendimethalin (pre-emergence) followed by quizalofop-ethyl (post-emergence) at 750 g and 50 g/ha. Pendimethalin followed by quizalofop-ethyl recorded significantly lower weed index (12.97%) with higher grain yield (1741.0 kg/ha) as compared with control and it was closely followed by pendimethalin alone (14.64%). Imazamox plus imazethapyr caused severe crop phytotoxicity and the crop had a slow growth and reduced crop biomass. The maximum benefit cost ratio of 3.83 was recorded in the plot treated with pendimethalin at 750 g/ha (pre-emergence) as compared to other herbicides. Thus, pendimethalin alone and with quizalofop-ethyl were equally effective in controlling the broad-spectrum of weeds in lentil with high yield advantage.

Key words: Herbicides, Lentil, Phytotoxicity, Rainfed ecology, Weed control efficiency, Weed index

Weeds can grow faster and taller than short statured crops like lentil and inhibit tillering and branching when weed management practices are not used. They can curb sunlight and adversely affect photosynthesis as well as ultimate yield (Rao 2000). The losses in crops yields due to weed were estimated as 15-30% in wheat, 30-35% in rice and 18-85% in maize, sorghum, pulses and oilseeds (Mukhopadhyay 1992). Rao (1995) reported that the weeds are competitive and adaptable to all adverse environments. There is a severe competition between weeds and plants for nutrients, moisture, light and space which leads to a reduction of agricultural produce up to 45%. Recent estimates showed that annual yield loss due to overall weeds in India is 33% accounting nearly $ 309.37 million to Indian agriculture, which is more than the combined losses caused by insect, pests and disease. It has been further estimated that losses in crop yields due to weeds in advanced countries are 5% and in the least developed countries, about 25% (Gupta 2002). The loss caused by weeds in lentil production is considerable for two reasons, first, the lentil has a slow rate of development and, thus, is overwhelmed by weeds in the early stages of its development. Secondly, weeds are easily compatible with the lentil and grow without difficulty by utilizing soil moisture and plant nutrients in prevailing environmental conditions efficiently at its initial development stages (Bukun and Guler 2005). Besides yield loss, weeds also harbour certain insect, pest, which feed on prevailing crop and affect their economic yield (Singh *et al.* 2008). Therefore, weeds are of crucial importance and need to be reconsidered under experimentation at multi locational basis.

Cultural practices are the backbone of an integrated weed management plan, but they alone may not be enough to secure adequate weed control in lentil fields. Mechanical weed control practices in lentils, such as harrowing or rotary hoeing in the fields after weed emergence, represent a viable alternative. But the mechanical approach can cause injury to lentil shoots and roots leading to reduced plant stands. Chemical weed control can help reduced-till or no-till lentil producers to manage weeds. However, the applicability and success of herbicides in lentil fields depends on the cropping system, land preparation methods, soil conditions, and weed problems. Risk of crop injury due to soil

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applied herbicides is particularly important in areas with dry climate and prolonged winters. Furthermore, weed management in lentil is of particular importance as this crop is generally considered to be a poor competitor due to its slow establishment and limited vegetative growth (Chaudhary *et al*. 2011). Thus weed management through the use of various herbicides at local and regional level should be taken under consideration.

Among the different herbicides, pendimethalin is a group of dinitroaniline herbicides used as selective pre-emergence to control annual grasses and broad-leaved weeds in pulse crops. It interferes with the mitotic process by inhibiting the formation of the microtubule protein, tubulin (Appleby *et al.* 1989). It is also a low mobile herbicide, having low water solubility and low volatility (Schleicher *et al.* 1995). Persistence of it in the soil is affected by soil temperature, cultivation and moisture conditions (Gasper *et al.* 1994). Imazethapyr acts by inhibiting the enzyme acetolactate synthase (ALS) and is a selective systemic herbicide. It may be used alone or in co-formulation with imazamox or pendimethalin to control a broad spectrum of broad-leaved and grassy weeds in pluses. Padmaja *et al*. (2013) stated that imazethapyr 75 g/ha applied at 20 DAS significantly reduced the density and biomass of both dicot and monocot weeds recorded at 30 DAS compared to weedy check followed by pendimethalin 750 g/ha as pre-emergence in Andhra Pradesh, India. But still there is a lack of proper location specific herbicidal recommendation, explicitly in lentil to overcome labour shortage and mechanical crop damage. Furthermore, Zollinger (2006) specified very limited availability of post-emergence herbicides for lentils. Therefore there is a need of revised experimentation to evaluate suitable herbicides to manage weeds in lentil.

A fundamental reason for the widespread use of chemical herbicides in modern agriculture is their ability to control selective and immediately a wide spectrum of weeds in a variety of crops and in some situations where all other method fail or can not be adopted (Mukhopadhyay 1992). The hike in labour cost also led to increase use of herbicides. Thus, it has been a common observation that in recent years, farmers have started adopting chemical weed control themselves. The advent of chemical herbicides brought about a revolutionary change in weed management in the era of increased mechanization and intensive cropping programmes to increase yield. Application of herbicide is easy, rapid and more effective for controlling weeds over cultural and mechanical methods. Therefore, a few promising herbicides including pendimethalin, imazethapyr, imazamox plus imazethapyr, quizalofop-ethyl and metribuzin were evaluated in this study for their efficacy in managing weeds in lentil.

MATERIALS AND METHODS

A field experiment was conducted in the winter seasons of 2013-14 and 2014-15 on loam, Typic Ustochrept soil at the research farm of Bihar Agricultural University, Sabour, Bihar, India. The experimental site is located between $25^{0}23$‘N latitude and $87^{0}07$‘E longitude with the elevation of 37.19 m under sub-tropical climatic conditions characterized with hot desiccating summer, cold winter and moderate rainfall. The area is known as Ganges river flood plain. The soil at the experimental field at 0-15 cm depth was loam in texture with a bulk density of 1.43 g/cc, organic carbon content of 0.63% with low in nitrogen and phosphorus and medium in potassium status. The experimental site belongs to sub-tropical humid climate with an average annual rainfall of 1460 mm, mostly precipitated during June to September. The mean maximum and minimum temperature varied 20.2 to 31.3 °C and 5.2 to 15.3 °C respectively during the experimental months (November to March). Although, the rainfall was distributed mostly from July to September, irrespective of all years, but during the experimentation, maximum rainfall (36.5 mm) was recorded in the month February, 2014. The highest value of monthly mean maximum relative humidity (98.0%) was observed in the months of December, 2013.

The previous crop in the experimental field was rice. Lentil variety ‘*HUL-57*’ was sown in the last week of October manually with a hand plough at 30 cm row spacing using a seed rate of 25 kg/ha. For both the seasons, the plot size was 6 x 4 m. Recommended dose of fertilizers (23:60:20 kg N: P_2O_5: K_2O/ha) were applied through di-ammonium phosphate and muriate of potash at the time of seed bed preparation and no irrigation was given to the crop throughout the crop season. The experiment had treatments of imazethapyr at 20 and 40 g/ha each applied at 15 and 30 days after sowing (DAS), pendimethalin at 750 g/ha as pre-emergence (PE), pendimethalin PE at 750 g/ha followed by quizalofop-ethyl post-emergence (PoE) and 50 g/ha, imazamox + imazethapyr at 30 g/ha at 30 DAS, metribuzin at 250 g/ha as PE, weedy (non-treated) and weed free checks. In each year, the experiment was laid out in randomized block design with three replications. All other agronomic practices were kept uniform in each treatment. Herbicides were applied with a knapsack foot sprayer fitted with a flat fan nozzle using 500 l/ha spray volume. Data were recorded from randomly selected quadrats of 1.0 x 1.0 m size at 30, 60 and 90 DAS. Species-wise weed density and their biomass, crop plant population, yield attributes and seed yield were recorded. Biomass of weeds was recorded after drying the samples in an oven at 70 ^{0}C for 48 hours. Weed control efficiency (on weed dry weight basis) and weed index were also computed. Cost of cultivation and net return were computed on the basis of prevailing rates of labour, inputs, and the produce. The data were analyzed statistically using analysis of variance (Steel *et al.* 1997) in Microsoft Excel and means were compared using the least significant difference (LSD) test.

RESULTS AND DISCUSSION

Effect on weeds

Altogether 18 different species of weeds were observed in the experimental site. Among broad-leaved weeds, *Chenopodium album*, *Rumex dentatus, Vicia sativa, Vicia hirsuta, Medicago denticulate, Melilotus indica, Anagallis arvensis, Coronopus didiymous* and *Fumaria parviflora* were dominant. Among grassy weeds, *Polypogon monosplensis, Phalaris minor* and *Cynodan dactylon* were dominant. Whereas, among sedges, *Cyperus rotundus* only was major weed. The density of grassy, broad-leaf weeds and sedges recorded at different crop growth stages varied significantly due to different weed management practices (**Table 1**). The density and biomass of weeds were lower with imazamox + imazethapyr applied at 30 DAS, reflecting high weed control efficiency but with lower yield of lentil. Among the herbicidal treatments, pendimethalin PE and quizalofop-ethyl PoE resulted into second highest weed control efficiency with higher yield of lentil and lowest weed index (12.97%) over control (**Table 2**). It was closely followed by sole pendimethalin PE (WI 14.64%). In other study also, herbicides have been reported effective lentil (Elkoca *et al.* 2004).

The weed index explained 99.96% variability in lentil seed yield (R^2 = 0.9996). The treatment with higher weed index produced lower seed yield of lentil, as weed index expresses the reduction in yield due to the presence of weeds in comparison with weed-free situation (**Figure 1**). The weed control efficiency explained 97.34% variability in lentil seed yield (R^2 = 0.9734). The line in the graph (**Figure 2**) also represented initial increas then a decreasing tendency from 60% weed control efficiency point. The treatments, which had higher weed control efficiency produced more seed yield with less crop weed competition.

Effect on crop

Table 1. Effect of herbicides on density of grassy, broad-leaved weeds and sedges at different stages of crop growth (pooled data of two years)

Treatment	Weed density (no./m^2)											
	30 DAS				60 DAS				90 DAS			
	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total
Imazethapyr 20 g/ha 15 DAS	3.3 (10.0)	2.9 (7.7)	3.5 (11.0)	5.4 (28.7)	2.8 (7.0)	2.8 (7.0)	3.3 (9.7)	5.0 (23.7)	3.3 (9.7)	3.0 (8.0)	3.5 (11.3)	5.5 (29.0)
Imazethapyr 40 g/ha 15 DAS	3.1 (8.5)	2.7 (6.3)	3.3 (9.7)	5.0 (24.5)	2.7 (6.3)	2.6 (6.0)	3.0 (8.3)	4.6 (20.7)	3.0 (8.0)	2.6 (5.7)	3.0 (8.3)	4.8 (22.0)
Imazethapyr 20 g/ha 30 DAS	4.9 (22.7)	4.6 (20.3)	4.7 (21.0)	8.1 (64.0)	3.1 (8.3)	3.0 (8.0)	3.3 (9.7)	5.2 (26.0)	4.6 (20.0)	4.2 (16.7)	3.9 (14.7)	7.2 (51.3)
Imazethapyr 40 g/ha 30 DAS	5.0 (24.3)	4.6 (20.0)	4.8 (22.3)	8.2 (66.7)	2.9 (7.3)	2.8 (6.7)	3.2 (9.0)	4.9 (23.0)	4.3 (17.3)	3.9 (14.7)	3.4 (10.7)	6.6 (42.7)
Pendimethalin 750 g/ha PE	3.7 (12.7)	2.9 (7.7)	3.9 (14.3)	6.0 (34.7)	3.6 (12.3)	3.0 (8.3)	3.6 (12.3)	5.8 (33.0)	3.8 (13.3)	2.7 (6.3)	3.6 (11.7)	5.7 (31.3)
Pendimethalin *fb* quizalofop-ethyl 750 g + 50 g/ha PE+ PoE	3.5 (11.3)	2.9 (7.7)	3.6 (12.3)	5.7 (31.3)	3.5 (11.3)	3.0 (8.3)	3.5 (11.0)	5.6 (30.7)	3.4 (10.3)	2.7 (6.7)	3.1 (8.7)	5.2 (25.7)
Imazomox 30 g/ha 30 DAS	4.9 (23.0)	4.4 (18.3)	4.8 (22.0)	8.0 (63.3)	2.5 (5.3)	2.5 (5.3)	2.3 (4.3)	4.0 (15.0)	3.2 (9.7)	2.2 (4.0)	2.1 (3.7)	4.3 (17.3)
Metribuzin 250 g/ha PE	3.6 (12.0)	3.2 (9.0)	3.8 (13.7)	6.0 (34.7)	3.8 (13.3)	3.1 (8.7)	3.6 (12.0)	5.9 (34.0)	3.6 (12.3)	2.8 (7.0)	3.5 (11.3)	5.6 (30.7)
Weedy check	5.4 (28.0)	5.4 (28.7)	5.4 (28.7)	9.3 (85.3)	5.5 (29.3)	5.6 (30.7)	5.5 (29.3)	9.5 (89.3)	5.8 (33.0)	5.0 (24.0)	5.2 (26.3)	9.2 (83.3)
Weed free	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
LSD (p=0.05)	0.55	0.55	0.50	0.53	0.42	0.60	0.56	0.53	0.63	0.53	0.54	0.51

DAS=Days after seeding PE = Pre-emergence; PoE=Post-emergence; BLW= Broad-leaved weeds; *fb* = Followed by

All weed management practices significantly increased the growth parameters and yield attributes of lentil as compared to the weedy check (**Table 3 and 4**). Among the herbicidal treatments, plots treated with pendimethalin PE followed by quizalofop-ethyl PoE documented maximum plant height (40.5 cm), plant population (143.7/m^2), branches/plant (5.67), pods/plant (59.03), nodules/plant (21.27), dry weight of nodules/plant (29.44 mg), and dry matter accumulation of lentil at maturity (486.30 g/m^2). The maximum seed yield (2.01 t/ha) was attained in the weed free check (**Table 4**), while it was minimum in the plots treated with imazamox plus imazethapyr (176 kg/ha), which was even less than the weedy check (1.05 t/ha). Hand weeding is an effective practice in traditional lentil growing areas, but it is not feasible on large areas (Gollojeh *et al.* 2013) because it is labour-intensive and expensive operation (Mohamed *et al.* 1997). The use of herbicides can eliminate weeds at early stages and prevent the yield losses successfully. Pendimethalin alone and in combination with quizalofop-ethyl being equally effective against weeds in lentil recorded 1.71 and 1.74 t/ha seed yield, respectively (**Table 4**).

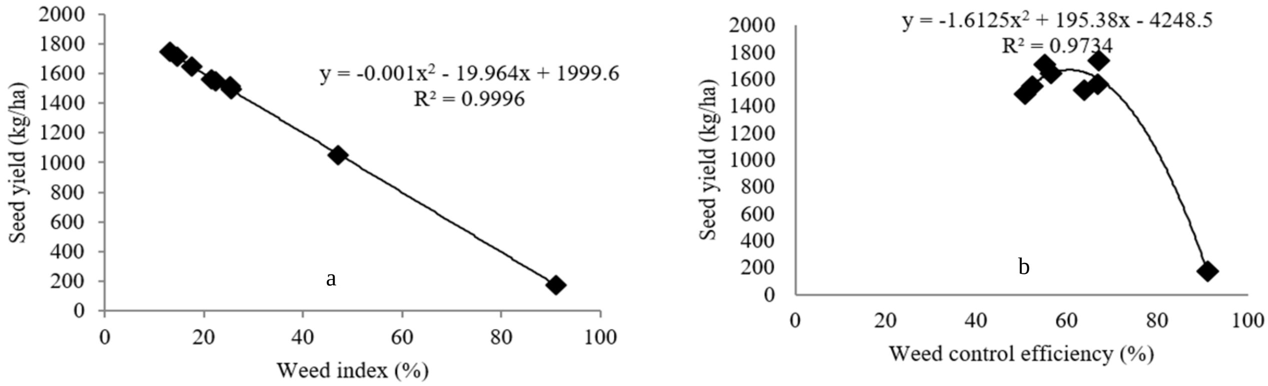

Figure 1. Relationship between seed yield with weed index (a) and weed control efficiency (b) in lentil

Table 2. Effect of herbicides on weeds in lentil (pooled data of two years)

Treatment	Weed biomass (g/m^2) 90 DAS	Weed control efficiency (%) 90 DAS	Weed index (%)
Imazethapyr 20 g/ha 15 DAS	345.3	52.5	22.3
Imazethapyr 40 g/ha 15 DAS	312.3	56.5	17.4
Imazethapyr 20 g/ha 30 DAS	356.7	50.8	25.4
Imazethapyr 40 g/ha 30 DAS	241.3	66.8	21.5
Pendimethalin 750 g/ha PE	327.7	55.1	14.6
Pendimethalin *fb* quizalofop-ethyl 750 g *fb* 50 g/ha PE+ PoE	242.0	67.0	13.0
Imazomox 30 g/ha 30 DAS	64.7	91.0	90.9
Metribuzin 250 g/ha PE	262.7	63.7	25.3
Weedy check	731.3	0.0	47.1
Weed free	0.0	100.0	0.0
LSD (p=0.05)	64.3	6.3	17.1

DAS=days after seeding' PE = Pre-emergence; PoE=Post-emergence

Table 3. Effect of different herbicides on growth and development of lentil at maturity in rice-lentil cropping system (pooled data of two years)

Treatment	Crop density (m^2)	Plant height (cm)	Branches/ plant (no.)	Nodules/ plant (no.)	Dry weight of nodules (mg/plant)	Dry matter accumulation (g/m^2)
Imazethapyr 20 g/ha 15 DAS	133.7	38.2	4.67	18.1	24.5	386.7
Imazethapyr 40 g/ha 15 DAS	139.0	38.9	4.93	16.7	23.1	386.4
Imazethapyr 20 g/ha 30 DAS	132.7	37.0	4.63	19.3	26.6	361.5
Imazethapyr 40 g/ha 30 DAS	135.7	38.2	5.00	19.1	26.1	360.5
Pendimethalin 750 g/ha PE	142.7	40.5	5.57	19.2	26.0	450.4
Pendimethalin *fb* quizalofop-ethyl 750 g *fb* 50 g/ha PE+ PoE	143.7	40.5	5.67	21.4	29.4	486.3
Imazomox 30 g/ha 30 DAS	46.0	19.0	3.77	9.1	11.9	87.7
Metribuzin 250 g/ha PE	130.0	36.1	4.40	18.2	25.2	431.5
Weedy check	124.3	34.6	3.93	20.4	20.4	363.0
Weed free	145.7	41.7	5.90	23.9	33.1	510.7
LSD (p=0.05)	11.9	2.6	1.07	2.3	3.9	100.0

Commercial mix formulation of imazamox + imazethapyr recorded lowest seed yield due to severe crop phytotoxicity. The crop growth was drastically reduced due to the application of imazamox + imazethapyr. Weeds allowed to grow throughout the crop season resulted into yield reduction of 47.1%. The yield reduction might be due to high intensity of weeds that robbed off the nutrient supply, sunlight, and water besides limited space for crop growth and development. Pendimethalin followed by the sequential application of quizalofop-ethyl proved more effective due to better weed management at an early stage by pendimethalin as well as follow up weed control by post-emergence application of quizalofop-ethyl. Yadav *et al.* (2013) also reported that pendimethalin 750 g/ha *fb* one hand weeding produced maximum grain yield and it was statistically at par with pendimethalin 1000 g/ha as well as weed free.

Pearson's correlation study also confirmed that weed index is significantly correlated with pod/plant (r = -0.99, p<0.01), no. of grains/pod (r = -0.92, p<0.01), grain yield (r = -1.0, p<0.01), straw yield (r = -0.85, p<0.01) and harvest index (r = -0.88, p<0.01) (**Table 5**).

Economics

Lentil under weed free conditions gave maximum net returns of ` 54,693/ha (**Table 6**). Among herbicidal treatments, the maximum net

Table 4. Effect of weed management practices on yield and yield attributing character of lentil (pooled of two years)

Treatment	Pods /plant	Grains /pod	Test weight (g)	Biological yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)
Imazethapyr 20 g/ha 15 DAS	51.63	1.43	23.6	3.87	1.55	2.32	40.10
Imazethapyr 40 g/ha 15 DAS	56.30	1.53	23.7	3.88	1.64	2.24	42.32
Imazethapyr 20 g/ha 30 DAS	47.93	1.47	23.7	3.65	1.49	2.16	40.99
Imazethapyr 40 g/ha 30 DAS	53.17	1.57	23.7	3.61	1.56	2.05	44.34
Pendimethalin 750 g/ha PE	57.97	1.60	23.8	4.56	1.71	2.84	38.61
Pendimethalin *fb* quizalofop-ethyl 750 g *fb* 50 g/ha PE + PoE	59.03	1.57	23.5	4.91	1.74	3.17	35.71
Imazomox 30 g/ha 30 DAS	12.73	1.17	23.8	0.87	0.18	0.69	20.32
Metribuzin 250 g/ha PE	46.83	1.37	23.8	4.15	1.52	2.63	36.09
Weedy check	38.33	1.33	23.5	3.63	1.05	2.58	28.97
Weed free	63.50	1.60	24.2	5.02	2.01	3.01	40.47
LSD (p=0.05)	10.48	0.34	NS	1.02	0.35	0.90	10.70

Table 5. Pearson's correlation among pod/plant, no. of grains/pod, grain yield, straw yield, harvest index and weed index

	Pods/plant	Grains/pod	Grain yield	Straw yield	Harvest index	Weed control efficiency	Weed index
Pods/plant	1						
Grains/pod	0.944**	1					
Grain yield	0.991**	0.912**	1				
Straw yield	0.849**	0.720*	0.854**	1			
Harvest index	0.867**	0.840**	0.872**	0.531	1		
Weed control efficiency	0.031	0.141	0.054	-0.203	0.032	1	
Weed Index	-0.993**	-0.916**	-1.000**	-0.851**	-0.877**	-0.050	1

Table 6. Economics of lentil production as influenced by herbicide treatments (pooled of two years)

Treatment	Gross return (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	Net return (x10^3 `/ha)	Benefit cost ratio
Imazethapyr 20 g/ha 15 DAS	62.05	17.53	44.52	2.54
Imazethapyr 40 g/ha 15 DAS	65.20	17.89	47.31	2.64
Imazethapyr 20 g/ha 30 DAS	59.56	17.53	42.03	2.40
Imazethapyr 40 g/ha 30 DAS	61.74	17.89	43.84	2.45
Pendimethalin 750 g/ha PE	69.55	18.14	51.41	2.83
Pendimethalin *fb* quizalofop-ethyl 750 g *fb* 50 g/ha PE+ PoE	71.53	19.58	51.94	2.65
Imazomox 30 g/ha 30 DAS	8.37	17.55	-9.18	-0.52
Metribuzin 250 g/ha PE	61.95	17.62	44.32	2.52
Weedy check	45.30	16.76	28.55	1.70
Weed free	80.59	25.90	54.69	2.11
LSD (p=0.05)	6.53	-	6.53	0.53

return of ` 51,945/ha and B-C ratio of 2.65 were recorded with pendimethalin PE followed by sequential application of quizalofop-ethyl PoE. However, the highest B-C ratio was achieved in the plots applied with pendimethalin alone. Application of pendimethalin after sowing of lentil has earlier been reported weak for the control of broad-leaved weeds (61%) whereas, it was effective (97%) against narrow-leaved weeds along with maximum returns (Chaudhary *et al*. 2011 and Ali *et al*. 2014). Correspondingly, Yadav *et al*. (2013) reported lowest density and biomass of weeds due to pendimethalin as pre-emergence *fb* one hand weeding, which was more economical but statistically at par with pendimethalin in producing seed yield of lentil. These findings also corroborate the other such findings elsewhere (Turk and Tawaha 2001, Jain 2007). They exhibited that the highest gross returns, net returns and B:C ratio was recorded by pendimethalin 750 g/ha PE *fb* one hand weeding under pulse crops. Every herbicidal treatment had a yield advantage over weedy check except imazamox + imazethapyr application. Ahmad *et al.* (1996), Mohamed *et al.* (1997), Stork (1998) and Fazal *et al*. (1999) also reported superiority of herbicides over weedy check. Pendimethalin followed by quizalofop-ethyl and pendimethalin alone could be the two better options as they fetched a fair net return and high B:C ratio.

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Fertility levels and weed management influence on weed dynamics, yield and nutrient uptake in lentil

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ABSTRACT

A field experiment was conducted during the winter seasons of 2012–13 and 2013–14 at Varanasi (U.P.) to evaluate the effect of fertility levels and weed management on lentil and associated weeds. *Cyperus rotundus*, *Chenopodium album*, *Solanum nigrum* and *Cynodon dactylon* were the major weeds found in association with lentil. Application of 75% RDF + Plantgro 9 kg/ha (foliar spray at 35, 50 and 65 DAS) recorded minimum density and dry matter accumulation of weeds and recorded higher yield attributes, yield (1.28 t/ha) and nutrient uptake by the crop followed by 100% RDF + 2% urea spray at pre-flowering and pod initiation. Among herbicides, application of imazethapyr 37.5 g/ha minimized the density and dry matter accumulation by weeds, and significantly increased yield attributes, yield and nutrient uptake by crop.

Key words: Fertility, Foliar, Imazethapyr, Lentil, Nutrient uptake, PlantGro, Weed management

Foliar application is regarded as a preferred solution when the quick supply of nutrients is hindered or the soil conditions are conducive for the absorption of nutrients (Salisbury and Ross 1995). Urea is the most suitable nitrogen source for foliar application due to its low salt index and high solubility in comparison to other nitrogen sources. Urea has been shown to stimulate absorption of other nutrients by increasing the permeability of leaf tissue. Plantgro Magic is a fertilizer product. The multi-nutrient water soluble fertilizer (57.1% total nutrients) includes nitrogen, phosphorus, and potassium as primary nutrients. It contains 18% total nitrogen of which 5.9% is ammonical nitrogen, 4.8% nitrate nitrogen and 7.3% urea nitrogen. This product also contains 30% available phosphate and 15% soluble potash. It also includes micronutrients such as boron (0.02%), copper (0.07%), iron (0.15%), manganese (0.10%), molybdenum (0.0005%), and zinc (0.15%).

Weeds compete with crop plants for nutrients, moisture, space and light. Crop yield reductions up to 70% have been reported due to weed competition. Impact of weeds on lentil varied as a function of climate, weed density and length of competition period (Dixit and Varshney 2009). The use of post-emergence herbicide for season-long weed control is preferred over early use of herbicides as pre-plant incorporation (fluchloralin and trifluralin) and pre-emergence (pendimethalin) as the latter control weeds only during initial crop growth stage (upto 30 DAS). The imidazolinone class of herbicides provides a broad-spectrum of weed control activity (Kantar *et al.* 1999). Therefore, the present study was undertaken to work out the effect of fertility levels and weed management on weed dynamics, yield and nutrient uptake by lentil crop.

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MATERIALS AND METHODS

A field experiment was conducted for two consecutive years (2012 and 2013) during winter season at Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (geographical location *i.e.* lat, long, altitude is required) (U.P.) The soil of the experimental field was clay loam in texture with neutral reaction (pH 7.31), low in organic carbon (0.37%), available N (212.50 kg/ha), medium in available phosphorus (25.17 kg/ha) and potassium (234.15 kg/ha). The experiment was laid out in a split plot design. Main plot treatments comprised of six fertility levels, *viz.* control, 100% RDF (20, 40, 30 kg N, P_2O_5 and K_2O/ha), 75% RDF + 2% urea spray at pre-flowering and pod initiation, 75% RDF + Plantgro 9 kg/ha at 35, 50 and 65 DAS as foliar spray, 100% RDF + 2% urea spray at pre-flowering at pod initiation, 100% RDF + Plantgro 9 kg/ha at 35, 50 and 65 DAS as foliar spray and four weed management practices, *viz.* control, weed free, pendimethalin 1.0 kg/ha (pre-emergence), imazethapyr 37.5 g/ha as post-emergence. All the treatments were replicated thrice. Fertilizers were applied as basal before sowing, to the different plots as per the treatment, through urea, single super phosphate and muriate of potash respectively. Sowing of the crop lentil variety '*HUL-57*' was done on November 22 in both the years by maintaining a spacing of 25 x 5 cm. The data recorded on density and dry matter accumulations by weed were subjected to square root transformation $\sqrt{x+0.5}$ for uniformity.

Crop responses to different treatments were measured in terms of various quantitative and qualitative indices. All the herbicides were applied as per protocol of application time. The data on weed density and dry matter were recorded with the help of a quadrate (0.5 x 0.5 m) placed in each plot and then converted into per square metre (m^2). Weed free and unweeded control treatments were kept for comparison with different treatments. Yield attributes *viz*. number of pods/plant, number of seeds/ pod, test weight and yield *i.e*. grain yield (t/ha) and straw yield (t/ha) were recorded at harvest during both the years of experimentation.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with broad-leaved weeds *viz*. *Chenopodium* spp. RD (relative density) varied from 11.08 to 27.44) and *Solanum nigrum* (RD 9.90 to 13.97); sedges *Cyperus* spp. (RD 43.24 to 49.65%) and *Cynodon dactylon* (RD 4.12 to 8.95%) to the grass group during the two years of field experimentation. Other weeds were in negligible presence and sparse in population, *viz*. *Parthenium hysterophorus*, *Fumaria parviflora*, *Anagallis arvensis*, *Vicia sativa*, *Melilotus indica* and *Medicago polymorpha*.

Data revealed that the density of grasses, sedges and broad-leaved weeds at 30 DAS was not affected significantly by varying fertility levels and weed management treatments except application of pendimethalin 1.0 kg/ha as pre-emergence (**Table 1**). Among fertility levels, application of 75% RDF + Plantgro 9 kg/ha recorded the minimum weed density of grasses, sedges and broad-leaved weeds and was at par with the application of 100% RDF + 2% urea spray. The highest weed control efficiency was recorded with the application of 75% RDF + Plantgro 9 kg/ha and was at par with 100% RDF + 2% urea spray. The results thus obtained corroborated with the findings of Mishra *et al*. (1999) and Prajapati *et al*. (2004).

Table 1.Weed density, weed dry matter accumulation, weed control efficiency and weed index as influenced by varying fertility levels and weed management treatments (pooled mean of two years)

Treatment	Weed density(no./m²)				Dry matter accumulation (g/m²)				WCE (%)[a]	Weed Index
	Cynodon dactylon	*Cyperus* spp.	*Cheno-podium album*	*Solanum nigrum*	*Cynodon dactylon*	*Cyperu s* spp.	*Cheno-podium album*	*Solanum nigrum*		
Fertility levels										
100 % RDF	1.91 (3.8)	5.53 (43.1)	3.39 (18.4)	2.40 (7.9)	1.45 (1.8)	2.69 (8.2)	2.34 (6.4)	1.57 (2.3)	52.8	11.1
75% RDF+ 2% urea spray at pre-flowering and pod initiation	1.97 (4.0)	5.67 (45.5)	3.51 (19.6)	2.52 (8.7)	1.47 (1.9)	2.86 (9.5)	2.44 (6.7)	1.60 (2.5)	50.9	14.6
75% RDF + Plantgro 9 kg/ha at 35, 50, 65 DAS as foliar spray	1.75 (3.0)	5.30 (39.7)	3.18 (16.6)	2.08 (5.5)	1.25 (1.2)	2.56 (7.4)	2.13 (5.3)	1.53 (2.1)	54.4	5.6
100% RDF + 2% urea spray at pre-flowering and pod initiation	1.86 (3.5)	5.39 (41.1)	3.27 (17.5)	2.32 (7.3)	1.31 (1.3)	2.67 (8.2)	2.25 (5.8)	1.54 (2.2)	53.5	8.1
100% RDF + Plantgro 9 kg/ha at 35, 50, 65 DAS as foliar spray	2.03 (4.3)	5.79 (47.3)	3.57 (20.1)	2.56 (9.2)	1.52 (2.2)	2.97 (10.3)	2.54 (7.5)	1.64 (2.7)	48.5	15.8
Control	2.21 (5.4)	5.89 (48.9)	3.75 (21.4)	2.70 (10.2)	1.70 (3.0)	3.11 (11.6)	2.69 (8.5)	1.86 (3.8)	47.8	16.9
LSD (p=0.05)	0.03	0.11	0.06	0.04	0.03	0.05	0.05	0.02	-	-
Weed management										
Pendimethalin 1.0 kg/ha as pre-emergece	2.47 (5.7)	8.91 (79.0)	3.37 (10.9)	1.60 (2.1)	1.58 (2.0)	3.64 (12.8)	2.84 (7.8)	1.52 (1.8)	41.4	15.0
Imazethapyr 37.5 g/ha as post-emergence	1.81 (2.8)	3.40 (11.1)	1.80 (2.8)	2.31 (4.9)	1.47 (1.7)	2.74 (7.1)	2.09 (3.9)	1.68 (2.3)	63.9	11.1
Unweeded	2.83 (7.6)	9.35 (87.1)	7.90 (62.0)	5.10 (25.7)	2.04 (3.9)	4.14 (16.9)	3.95 (15.1)	2.59 (6.3)	0.0	22.6
Weed free	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	100.0	0.0
LSD(p=0.05)	0.02	0.06	0.04	0.03	0.02	0.04	0.03	0.02	-	-

[a]Observation recorded at 60 DAS, Data subjected to square root ($\sqrt{X+0.5}$) transformation and original data presented in parentheses

Weed control treatments brought about a significant reduction in weed density. Among the weed management treatments at 60 DAS, the lowest density of grasses, sedges, broad-leaved weeds was observed with the application of imazethapyr 37.5 g/ha. Further, higher weed control efficiency (63.88%) was recorded under the application of imazethapyr 37.5 g/ha. Superiority of imazethapyr in suppressing the weed density and recording higher weed control efficiency has been reported by Punia *et al.* (2011).

Effect on growth

The growth parameters of lentil, *viz*. plant height, branches/plant and dry matter accumulation were highest under the treatment 100% RDF + Plantgro 9 kg/ha and it was at par with the application of 100% RDF + 2% urea spray (**Table 2**). Lower values of all the growth attributes was recorded with control (no fertilizer).These results are in confirmation with the findings of Jagdale *et al*. (2005). All the treatments of weed management showed significant improvement in growth attributes over unweeded during both the years of study. Higher values of all the growth attributes was recorded with the application of pendimethalin 1.0 kg/ha at early stages. After 30 DAS, higher values of growth attributes were recorded with the application of imazethapyr 37.5 g/ha during both the years.

Effect on yield attributes and yield

Different fertility levels produced significant impact on yield attributes and yield of lentil over control (**Table 2**). Significantly higher number of pods/plant, seeds/pod, test weight, grain yield and straw yield was recorded with the application of 75% RDF + Plantgro 9 kg/ha and it was at par with the application of 100% RDF + 2% urea spray during both the years. Higher straw yield was recorded with the treatment 100% RDF + Plantgro 9 kg/ha during the first year and 100% RDF + 2% urea spray during the second year. These results were similar with the findings of Singh *et al*. (2014). However, all the fertility levels proved significantly superior over control in increasing grain yield, straw yield and harvest index. Varying weed management treatments showed significant enhancement of yield attributes and yield over control during both the years. Among herbicide treatments, highest number of pods/plant, seeds/pod, test weight, grain yield, straw yield and harvest index was recorded with the application of imazethapyr 37.5g/ha and are in agreement with the findings of Chaudhary *et al.* (2011).

Quality attributes

Nutrient uptake is a function of dry weight and nutrient content is expected to follow the trend of dry weight influenced by the content. Weed control treatments brought about significant variation in

Table 2. Growth attributes, yield attributes, yield and B:C ratio of lentil as influenced by varying fertility levels and weed management treatments (pooled mean of two years)

Treatment	Growth attributes[a]			Yield attributes			Yield		Harvest index (%)	B:C ratio
	Plant height (cm)	Branches/ plant	Dry matter accumulation (g/m^2)	No. of pods/ plant	No. of seeds/ pod	Test weight (g)	Grain (t/ha)	Straw (t/ha)		
Fertility levels										
100% RDF	16.52	4.90	24.36	57.42	1.85	23.00	1.09	1.97	35.94	2.37
75% RDF+ 2% urea spray at pre-flowering and pod initiation	18.02	5.27	26.20	54.68	1.82	22.40	1.03	1.99	34.04	2.11
75% RDF + plantgro 9 kg/ha at 35, 50, 65 DAS as foliar spray	18.40	5.61	27.71	62.26	1.98	25.20	1.28	2.14	37.96	2.00
100% RDF + 2% urea spray at pre-flowering and pod initiation	18.88	5.97	28.97	58.79	1.87	23.65	1.14	2.36	32.82	2.29
100% RDF + Plantgro 9 kg/ha at 35, 50, 65 DAS as foliar spray	19.44	6.22	30.22	45.43	1.78	21.40	1.03	2.31	30.84	1.62
Control	14.35	4.55	21.29	34.18	1.73	20.29	0.99	1.80	33.19	2.19
LSD (p=0.05)	0.75	0.24	1.55	2.67	0.06	1.27	0.06	0.10	1.40	-
Weed management										
Pendimethalin 1.0 kg/ha as pre-emergence	17.43	5.40	25.74	53.74	1.79	22.28	1.04	2.10	33.48	2.16
Imazethapyr 37.5 g/ha as post-emergence	18.00	5.71	27.53	55.75	1.86	23.14	1.09	2.12	33.92	2.35

[a]Observation recorded at 60 DAS

Table 3. Protein yield, nutrient depletion by weeds and nutrient uptake of lentil after harvest as influenced by varying fertility levels and weed management treatments (pooled mean of two years)

Treatment	Protein yield (kg/ha)	Nutrient depletion by weeds (kg/ha)			Nutrient uptake by crop (kg/ha)		
		N	P	K	N	P	K
Fertility levels							
100% RDF	249.7	9.23	1.73	7.04	98.00	14.14	37.03
75% RDF + 2% urea spray at pre-flowering and pod initiation	231.0	9.86	1.90	7.72	89.09	11.15	32.16
75% RDF + Plantgro 9 kg/ha at 35, 50, 65 DAS as foliar spray	313.0	7.39	1.34	5.62	118.89	17.06	50.80
100% RDF + 2% urea spray at pre-flowering and pod initiation	266.2	9.03	1.65	6.76	114.49	16.61	43.70
100% RDF + Plantgro 9 kg/ha at 35, 50, 65 DAS as foliar spray	227.0	11.26	2.11	8.58	95.34	11.61	29.05
Control	188.6	13.80	2.61	10.73	71.09	6.80	16.47
LSD (p=0.05)	8.1	0.87	0.19	0.62	6.97	1.07	3.51
Weed management							
Pendimethalin 1.0 kg/ha as pre-emergence	228.2	10.46	1.97	7.65	94.40	11.56	30.68
Imazethapyr 37.5 g/ha as post-emergence	249.0	8.44	1.52	6.21	99.87	12.97	33.63
Unweeded	198.4	21.48	4.07	17.10	78.59	9.80	21.61
Weed free	308.1	0.00	0.00	0.00	118.42	17.26	53.57
LSD (p=0.05)	6.6	0.49	0.11	0.38	4.04	0.52	1.89

protein yield and N, P, K uptake by lentil during both the years (**Table 3**). All the weed control treatments were significantly superior to unweeded control in recording higher nutrient uptake by crop. Nutrient uptake (kg/ha) by crop was obtained significantly higher under the treatments 75% RDF + Plantgro 9 kg/ha followed by 100% RDF and 100% RDF + 2% urea spray for nutrient uptake.

All the treatments were found significantly superior over weedy check in recording higher nutrient uptake and protein yield by the crop at harvest stage. Among the weed management treatments, higher protein yield and N, P, K uptake (kg/ha) was recorded with the application of imazethapyr 37.5 g/ha.

It was concluded that application of 75% RDF along with PlantGRO 9 kg/ha (foliar spray at 35, 50 and 65 DAS) and imazethapyr 37.5 g/ha (post-emergence) showed best treatment for control of weeds and enhanced performance of lentil.

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Groundnut productivity and profitability as influenced by weed control measures

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ABSTRACT

A field experiment was conducted at Research Farm of Agriculture Research Station, SK Rajasthan Agricultural University, Bikaner during *Kharif* seasons of 2015 and 2016 to test the efficiency of herbicides in groundnut. The experiment comprised of 14 weed control treatments arranged in randomized block design (RBD) with three replications. Among the different herbicides tested, imazethapyr + pendamethalin 1000 g/ha recorded lowest weed density and weed biomass of both broad-leaved and grassy-weeds and significantly highest dry matter accumulation, number of pods/plant, pod, haulm and biological yield in groundnut over all the other herbicidal treatments.

Key words: Fenoxaprop p-ethyl, Groundnut, Imazethapyr, Pendimethalin, Weed management

Groundnut (*Arachis hypogaea* L.) is the second most important edible oilseed crop of the India, which is the second largest producer of groundnut in the world. Weed menace is one of the serious bottlenecks in limiting the productivity of groundnut (Chaitanya *et al.* 2012). India has a diverse climate and groundnut is grown throughout the year in *Kharif* (rainy), *Rabi*, (winter) and spring seasons in one or other part of the country. Among non-stable productivity factors, weed infestation is considered to be one of the major cause to reduce the productivity. Yield loss due to weed infestation amounts to 47% in groundnut. Weeds when allowed to compete till harvest depleted 162.8 kg N, 21.7 kg P_2O_5, 141.8 kg K_2O per ha. Weeds reduce yield by competing with the groundnut plants for resources such as sunlight, space, moisture and nutrients throughout the growing season (Regar 2017). During initial growth stages, crop canopy is relatively less, which allows higher weeds' growth making groundnut more susceptible to weeds competition in the earlier growth period of the crop. Weeds also create problem during digging and inverting procedures and reduce harvesting efficiency. Herbicides and hand weeding significantly brought down the nutrient removal by weeds and enhanced the uptake of nutrient by groundnut crop. The present study was therefore, carried out to assess the losses caused by weeds and the extent to which these losses would be minimized by use of herbicides alone or in combination with cultural methods and their effect on crop yield.

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MATERIALS AND METHODS

A field study was conducted for two years during *Kharif* season of 2015 and 2016 at Research farm of Agriculture Research Station, Swami Keshwanand Rajasthan Agricultural University, Bikaner (28.00^0 to 28.16^0 N latitude, 72.55^0 to 73.42^0 E longitude and 234.7 m (amsl). The experiment consisting of 14 weed control treatments, *viz*. pendimethalin 1.0 kg/ha (PPI), pendimethalin 1.0 kg/ha (PE), imazethapyr + pendimethalin 800 g/ha, imazethapyr + pendamethalin 900 g, imazethapyr + pendamethalin 1000 g, imazethapyr 50 g, imazethapyr 70 g/ha, imazethapyr + imazemox 60 g/ha, imazethapyr + imazemox 70 g/ha, oxyfluorfen 40 g/ha, fenoxaprop-p-ethyl 50 g/ha, propaquizafop 62 g/ha, weed free and weedy check (**Table 1**). They were evaluated in randomized block design with three replications. The soil of experimental site was loamy sand having 0.08% organic carbon, 8.2 pH, 78, 22 and 210 kg/ha available N, P and K, respectively. Groundnut '*HNG-10*' was sown on 21 June 2014, and 26 June 2015 at 30 cm row spacing and was harvested on 24 October 2014 and 28 October 2015, respectively. Recommended dose of fertilizers (20 kg N + 40 kg P + 40 kg K/ha) was applied as basal dose through urea, single super phosphate (SSP) and murate of potash (MOP) respectively. Pre-plant incorporation (PPI) of pendimethalin was done before sowing while pre-emergence application (PE) of pendimethalin was done on next day of sowing. Post-emergence application (PoE) of imazethapyr was done at 25 DAS as per the treatment with knapsack sprayer. Weed density was recorded by using quadrate of 0.25 m^2 at 60 DAS in all the treatments and then converted into number of weeds/m^2. The weeds were dried in oven till a constant weight was observed and then transformed into weed biomass (g/m^2) by using the appropriate formula. Growth, yield parameters and yield of groundnut were recorded for two consecutive years. The data on weed density were subjected to square root transformation to normalize their distribution (Gomez and Gomez 1984). Cost of cultivation, gross return and net return were calculated based on the prevailing price of inputs and outputs. Benefit cost ratio was calculated on the basis of gross return divided by the cost of cultivation. The weed density and weed biomass data were square-root transformed.

RESULTS AND DISCUSSION

Weed flora

The experimental field was infested with *Amaranths spinosus*, *Digera arvensis,Trianthema portulacastrum*, *Gisekia poiedious*, *Mollugo verticillata*, *Euphorbia hirta*, *Aristida depressa*, *Portulaca oleracea*, *Cenchrus biflorus*, *Cleome viscosa*, *Tribulus terrestris*, *Corchorus tridense*, *Cyperus rotundus*, *Elusion everticillata*, *Eragrastris tennela* and *Aerva tomentosa etc* species of weeds in both the years of experimentation.

All the herbicidal treatments were able to significantly reduced weed density and biomass over weedy check (**Table 1**). Weed free treatment resulted in the lowest weed density and biomass of weeds. However, among the different treatments, pre-emergence application of imazethapyr + pendamethalin 800 g/ha and its higher doses, imazethapyr 50 and 70 g, imazethapyr + imazemox 60 and 70 g were found to be at par with each other in respect of these weed parameters. Imazethapyr + pendamethalin 800 g was found effective in reducing the density and biomass of both broad-leaf and grassy weeds followed by its higher doses. Lower density of weeds by imazethapyr + pendamethalin in reducing weed biomass might be primarily due to broad spectrum activity of herbicidal combination particularly on establishment of plants of both broad-leaf and grassy weeds and its greater efficiency to retard cell division of meristems as a result of which weeds dry rapidly. The results were confirmed by the findings of Kantar *et al.* (1999), where about 84.6% weed biomass was controlled with application of imazethapyr. Papierniks *et al.* (2003) also recommended use of imazethapyr in legumes, which inhibit acetohydroxy acid synthase and the synthesis of branched chain amino acids. Data further revealed that application of fenoxaprop-p-ethyl 50 g/ha and propaquizafop 62g/ha as post-emergence also reduced the weed biomass compared to weedy check and other dose. Pendimethalin 1.0 kg/ha as PPI and pre-emergence was found effective in controlling grassy weeds.

Growth, yield attributes and yield

Significant lowest values of dry matter, pods/plant, kernel/pod, 100-kernel weight and shelling percentage were recorded under weedy check and the highest values for these parameters were recorded under weed free treatment (**Table 2**). Higher level of these parameters could be attributed due to low crop-weed competition in this treatment. Among herbicidal treatment, imazethapyr + pendimethalin 800 g/ha efficiently increased dry matter per plant, which was at par with its higher levels and weed free. The increase in the dry matter of groundnut was attributed to the decreased weed density and lesser biomass of weeds thus resulted in decreased competition by weeds to moisture, light and nutrients. The effect of which can be traced back to increased dry matter accumulation in stem, leaves and pods. Pannu *et al.* (1989) have reported significant reduction in the dry matter accumulation and lower pod yield in groundnut under weedy check. The dry matter production and its accumulation in reproductive parts depends upon the photosynthetic ability of the plant and can be analyzed through leaf area and dry matter accumulation in leaves, which in turn influence the photosynthetic ability, performance and yield of the crop. The results corroborated with the findings of Yadav *et al.* (2014). Pendimethalin 1.0 kg/ha as PPI and pendimethalin 1.0 kg/ha as pre-emergence was next best in increasing dry matter, pods/plant kernel/pod, 100 kernel weight and shelling percentage followed by imazethapyr + imazemox 60 and 70 g/ha. This might be due to minimizing the competition of weeds with main crop for resources, *viz.* space, light, nutrients and moisture with adaption of effective weed control methods. Singh and Giri (2001) also concluded that proper weed control was responsible for increase in plant height and dry matter production in groundnut. However, in case of other herbicidal treatments, imazethapyr 50 and 70 g, imazethapyr + imazemox 60 and 70 g/ha, oxyfluoren 40 g/ha, fenoxaprop p-ethyl 50 g/ha and propaquizafop 62 g/ha recorded higher yield and yield attributes of groundnut compared to weedy check but remained at par with each other.

All the weed management practices significantly enhanced pod, haulm and biological yield over weedy check and higher yield was obtained in weed free treatment (**Table 2**). However, there was no significant difference in imazethapyr 50 and 70 g/ha, imazethapyr + imazemox 60 and 70 g/ha with each other between pod, haulm and biological yield. This might be due to the fact that weed free environment in crop facilitated better peg initiation and development at the critical growth stages of groundnut which tends to increase in number of pods/plant and pod yield/hectare. Higher profitable pod yield of summer groundnut was also reported by Raj *et al.* (2008) with keeping the crop in weed free condition. Significantly lower values of plant height, number of pods and pod yield were recorded in treatment weedy check. There was no significant effect of weed management practices on harvest index in groundnut.

Among the different herbicidal treatments, pod, haulm and biological yield of groundnut was found maximum with the treatment received imazethapyr + pendimethalin 800 g/ha, which was significantly superior to weedy check, fenoxaprop-p-ethyl 50 g/ha, propaquizafop 62 g/ha, oxyfluorfen, pendimethalin 1.0 kg/ha as PPI and pre-emergence but statistically at par with + pendimethalin 900 g/ha and 1000 g/ha, imazethapyr 50 and 70 g/ha and imazethapyr + imazemox 60 and 70 g/ha. The increase in pod yield in above treatments might be due to the fact that these treatments resulted in beneficial effect on final yield. Also the pod yield is an end product, which obviously depends upon the dry matter production of crop growth and its partitioning into reproductive parts. Patra and Naik (2001) also

Table 1. Effect of different pre- and post-emergence herbicides on weed count and weed biomass and economics in groundnut (pooled over two years)

Treatment	Weed density/m^2			Weed biomass (g/m^2)	Economics (x10^3 `/ha)		
	Broad-leaved	Grassy	Total		Cost of cultivation	Net returns	B:C ratio
Pendimethalin 1.0 kg (PPI)	7.5 (56.9)	1.51 (1.81)	7.69 (58.8)	12.94	67000	77.3	2.14
Pendimethalin 1.0 kg (PE)	7.6 (57.9)	1.56 (1.93)	7.76 (59.9)	10.38	67000	74.4	2.09
Imazethapyr + pendimethalin 800 g (PE)	2.9 (8.1)	1.33 (1.26)	3.13 (9.4)	0.99	68500	93.8	2.35
Imazethapyr + pendimethalin 900 g (PE)	2.5 (5.7)	0.89 (0.35)	2.55 (6.1)	0.58	68500	96.7	2.39
Imazethapyr + pendimethalin 1000 g (PE)	1.8 (2.6)	0.95 (0.51)	1.90 (3.1)	0.47	68500	97.3	2.40
Imazethapyr 50 g PoE 25 DAS	2.9 (7.7)	2.08 (3.91)	3.48 (11.7)	6.80	67000	83.4	2.23
Imazethapyr 70 g PoE 25 DAS	2.6 (6.6)	1.80 (2.87)	3.15 (9.5)	4.78	67000	86.3	2.27
Imazethapyr + imazemox 60 g PoE 25 DAS	2.7 (7.1)	1.70 (2.42)	3.15 (9.5)	5.75	68000	91.9	2.33
Imazethapyr + imazemox 70 g PoE 25 DAS	2.3 (5.1)	1.35 (1.54)	2.65 (6.7)	0.78	68000	89.0	2.29
Oxyfluorfen 40 g PoE 25 DAS	6.7 (48.2)	1.52 (1.84)	7.01 (50.0)	15.12	67000	65.1	1.96
Fenoxaprop p-ethyl 50 g PoE 25 DAS	6.8 (47.9)	1.30 (1.38)	6.96 (49.4)	16.16	67000	59.9	1.88
Propaquizafop 62 g PoE 25 DAS	6.8(47.1)	1.52 (1.84)	6.96 (48.9)	13.16	67000	60.2	1.89
Weed free	1.8 (2.9)	1.21 (1.09)	2.08 (4.0)	0.42	69000	100.0	2.43
Weedy check	7.9 (61.9)	2.52 (5.93)	8.26 (67.8)	20.93	64000	35.5	1.55
LSD (p=0.05)	0.44	0.40	0.43	2.44	-	-	-

Table 2. Effect of different pre- and post-emergence herbicides on dry matter, pods per plant, kernel per pod, 100-kernel weight and shelling percent of groundnut (pooled over two years)

Treatment	Dry Matter accumulation (g/plant)	Pods/ plant	Kernels /pod	100-kernel weight (g)	Shelling %	Pod yield (t/ha)	Haulm yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
Pendimethalin 1.0 kg (PPI)	61.8	25.6	1.75	43.1	65.7	2.71	7.35	10.07	26.9
Pendimethalin 1.0 kg (PE)	62.1	26.1	1.71	41.9	64.8	2.66	7.22	9.88	26.9
Imazethapyr + pendimethalin 800 g (PE)	78.8	29.9	1.74	43.9	65.5	3.05	8.27	11.32	26.9
Imazethapyr + pendimethalin 900 g (PE)	78.4	30.3	1.78	44.5	66.4	3.11	8.37	11.48	27.1
Imazethapyr + pendimethalin 1000 g (PE)	78.8	30.3	1.85	44.6	67.8	3.13	8.32	11.45	27.3
Imazethapyr 50 g PoE 25 DAS	65.2	26.9	1.64	43.5	65.0	2.84	7.58	10.42	27.2
Imazethapyr 70 g PoE 25 DAS	66.6	27.5	1.63	44.1	65.0	2.89	7.72	10.61	27.3
Imazethapyr + imazemox 60 g PoE 25 DAS	68.8	28.4	1.71	43.5	65.3	3.02	8.00	11.02	27.2
Imazethapyr + imazemox 70 g PoE 25 DAS	68.9	28.7	1.73	44.1	65.4	2.96	7.90	10.86	27.3
Oxyfluorfen 40 g PoE 25 DAS	60.5	23.8	1.73	44.0	64.3	2.49	6.67	9.17	27.2
Fenoxaprop p-ethyl 50g PoE 25 DAS	58.4	21.4	1.59	42.4	65.1	2.39	6.49	8.87	26.9
Propaquizafop 62 g PoE 25 DAS	59.1	22.4	1.63	42.5	65.5	2.40	6.43	8.83	27.2
Weed free	84.0	31.9	1.84	44.9	70.1	3.18	8.53	11.71	27.2
Weedy check	53.9	17.6	1.62	40.9	63.5	1.90	4.93	6.83	28.0
LSD (p=0.05)	7.1	4.5	0.09	NS	2.1	0.35	0.56	0.62	NS

reported increased pod number due to weed control treatments. The differential contribution of yield components towards pod yield was obtained with different treatments. Effective control of weeds by herbicides might have resulted in better availability of soil moisture and nutrients as evidenced by the beneficial effect on crop growth. The higher pod yield in imazethapyr + pendimethalin 800 g/ha or its higher levels over weed free might be due to suppression of weed seed germination and seedling development at early stages due to pre-emergent herbicides. Weedy check gave reduced yields due to presence of weeds and resulted in increased weed competition for growth resources, especially for moisture, nutrients and light. Similar yield reduction due to presence of weeds has been reported by Kori *et al.* (2000). Among different herbicidal treatments, imazethapyr + pendimethalin 800 g/ha recorded 72.9, 47.0 and 53.6% higher pod, haulm and biological yield over weedy check. Kantar *et al.* (1999) also observed 63.6% higher seed yield over weedy check with application of imaze.

Economics

All the weed control treatments recorded higher net returns and B:C ratio over weedy check (**Table 1**). While, highest net returns and B:C ratio was obtained with weed free treatment. Among herbicidal treatments, imazethapyr + pendimethalin 800 g/ha recorded higher net returns (` 93761) and B:C (2.35) ratio closely followed by its higher doses. This was due to higher pod yield and subsequently lower cost of cultivation of groundnut crop, which was increased in treatment weed free due to the higher need of human labours and their higher wages. This cost was reduced in imazethypr 50 and 70 g/ha, imazethapyr + imazemox 60 and 70 g/ha and pendimethalin 1.0 kg/ha by using herbicides to effective control of weeds with minimizing human labours. Rao *et al.* (2011) have also reported higher net return and B:C ratio with pre- and post-emergence application of herbicides. Weedy check recorded lower net returns and B:C ratio. Tiwari *et al.* (1989) reported that the additional amount of income obtained under weed free appeared to be immaterial when compared to cost of weeding incurred to maintain weed free condition beyond eight weeks after sowing. Among other treatments, imazethapyr + imazemox 70 g/ha resulted in higher net returns (` 89027) with B:C ratio of 2.29 despite the higher cost involved.

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Halosulfuron + metribuzin effect on weed control in sugarcane and their carry over effect on succeeding lentil

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ABSTRACT

The study was conducted at G.B. Pant University of Agriculture and Technology, Pantnagar during rainy seasons of 2012-13 and 2013-14 to evaluate the efficacy of halosulfuron 12% + metribuzin 55% WG ready-mix (RM) coded as CPL-1255 in sugarcane, and its carry over impact on succeeding lentil. The maximum weed suppression and the highest weed control efficiency were obtained with application of halosulfuron + metribuzin (RM) at higher doses (600 and 900 g/ha) applied as post-emergence, and were significantly better than the alone application of atrazine 50% WP and 2,4-D amine salt 50% SL at recommended doses. Combination of halosulfuron + metribuzin (RM) even applied at 600 g/ha was also found superior over atrazine 50% WP at 2000 g and 2,4-D amine 58% SL at 3500 g/ha while execution of twice hoeing (30 and 60 day after planting (DAP)) was also comparable to combination of halosulfuron + metribuzin at lower and higher doses at 450 and 900 g/ha, respectively, during 2012 and only to lower dose during 2013 with respect to cane yield. The ready mix application of halosulfuron + metribuzin at any dose did not pronounce any phytotoxic effect on sugarcane as well as carry over effect on the succeeding lentil in respect to germination, growth and grain yield. Overall microbial population was higher before application and decreased after application of herbicide at harvest. Herbicidal treated plots had no significant effect on bacterial counts. There was drastic reduction in microbial population at 7 day after application (DAA) of herbicide and increased thereafter. At harvest overall population of actinomycetes varied from 43.7% to 20.1% over weedy check.

Key words: Herbicide efficiency index, Phytotoxicity, Soil microbial population, Sugarcane**,** Yield

Sugarcane (*Saccharum officinarum*) is an important agro-industrial cash crop grown primarily for sugar production in India, and plays a pivotal role in agricultural and industrial economy of the country. Sugarcane is the most adaptable plant under varied ecological conditions. In tropical *Tarai* parts of Uttarakhand, weeds are the major threat in sugarcane production which affects the crop yields considerably. Singh *et al.* (2009) reported 20.3% yield gap in sugarcane because of the heavy infestation of weeds. The nature of weed problem in sugarcane cultivation is quite different from other field crops because sugarcane is planted with relatively wider row spacing and crop growth is very slow in the initial stages. It takes about 30 - 45 days to complete germination and next 60-75 days for developing full canopy cover (Anonymous 2001). Weed control is the most critical in early season prior to sugarcane canopy closure over the row middles. Crop-weed competition has been recorded to be 60-120 days after planting in spring cane and 150 days in autumn cane (Singh *et al.* 2011). In sugarcane 2-3 harrowings are required. However, due to labour scarcity use at herbicide for weed management is gaining momentum. Several herbicides like atrazine, metribuzin and 2,4-D have been recommended. These herbicides effectively control only the specific weed species. Therefore, new herbicide combinations are required for broad-spectrum weed control in sugarcane.

Soil micro-organisms are an important link in soil-plant-herbicide-fauna-man relationships. Soil microbes are directly or indirectly affected by the impact of toxic substances of herbicides used to control in intensive agriculture. At normal recommended rates, herbicides of field are considered to have no major or long-term effect on microbial populations. It has been reported that some microorganisms were able to degrade the herbicide, while some others are adversely affected depending on the application rates and the type of herbicide used (Sebiomo *et al.* 2011). This soil microbial communities (like bacteria, fungi and actinomycetes) play critical role in litter decomposition and nutrient cycling, which in turn, affect soil fertility and plant growth (Chauhan *et al.* 2006, Tripathi *et al.* 2006, Pandey *et al.* 2007).

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Therefore, effects of herbicides on microbial growth, either stimulating or depressive, depend on the chemicals (type and concentration), microbial species weeds to be evaluated and environmental conditions (Zain *et al.* 2013). The study was aimed to evaluate the effect of commonly used herbicides on growth, yield and populations in soil microcosms from sugarcane crop.

MATERIALS AND METHODS

During first year (March, 2012 to January, 2013) and during second year (March, 2013 to January, 2014), the total annual rainfall received was 960 and 1759 mm and the relative humidity ranged from 18 to 97% and 23 to 97%, respectively. The maximum and minimum temperature ranged from 42.5 ^{0}C to 5.8 ^{0}C and 39.2 ^{0}C to 5.9 ^{0}C, respectively during first and second season. During succeeding crop growing season of both the year from January to March, 2013 and from February to March, 2014, the total rainfall 153.9 and 216.8 mm was received and the relative humidity ranged from 23 to 94% and 19 to 95%, respectively. The average maximum and minimum temperature were 38.9 ^{0}C and 9.5 ^{0}C and 37.5 and 7.0 ^{0}C during both the season, respectively.

The site of field experiment was at Norman E. Borlaug, Crop Research Center of G. B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand, India (28.97 ^{0}N, 79.41^{0}E and elevation 243.8 m above mean sea level. The experiment was conducted during 2012-13 and 2013-14 to evaluate the efficacy of various doses of halosulfuron + metribuzin and its phytotoxicity, microbes in soil of sugarcane crop and carry over studies in succeeding lentil crop. The mean values of the soil of experimental field were neutral in reaction, electrical conductivity 0.37 dS/m having 66% silt, 18% clay and 16% sand in the experimental soil. The soil of experimental field was silt loam in texture and low in nitrogen, medium in phosphors and potassium. Organic carbon content was slightly high *i.e.* 0.78%.

The field experiment was laid out in randomized block design in triplicates comprised of eight treatments of halosulfuron + metribuzin at 300, 450, 600 and 900 g/ha, another standard check atrazine 2000 g/ha, 2,4-D amine salt 3500 g/ha, twice hoeing 30 and 60 day after planting (DAP) and weedy check.

The sugarcane variety '*COP 90223*' was planted under irrigated ecosystem at spacing of 60 cm during 2012 and 2013. Atrazine 50% WP was applied as pre-emergence just after planting of cane sets, whereas, combination of halosulfuron + metribuzin (RM) and alone application of 2,4-D amine salt were used as post-emergence with help of knapsack sprayer fitted with flat fan nozzle at a spray volume of water 500 l/ha. All the agronomic management practices were followed as per the standard recommendations.

Data on weed flora were recorded at 60 day after application (DAA) by placing a quadrate of 0.25 m^2 at four randomly selected places in all the plots of the experimental field and expressed in per m^2. The removed weed flora samples for weed count were kept in brown paper bags and oven dried at 70 ^{0}C for 72 hrs and expressed in g/m^2 and weed control efficiency **(**WCE) and herbicide efficiency index (HEI) were calculated by using standard formula. Yield was calculated on the basis of net plot and expressed in t/ha.

Soil samples (0-15 cm depth) from each experimental plot were collected randomly from four different places with the help of trowel and mixed them thoroughly to make the representative composite sample. The samples were collected for analysis on different stage, first sampling was on before application, and remain on different interval after the application of herbicide at 7, 15, 30, 60 days and at harvest stage. Approximately 150 g soil sample stored at 4 °C in deep freezer until analysis for microbial studies and rest part of the samples were air dried, processed and sieved through 2 mm sieve and analyzed for basic soil microbial properties. Two year average microbial population of the soil before application of herbicide, *viz.* total bacteria, actinomycetes and fungi were 16.43 x 10^7 cfu/g, 17.43 x 10^5 cfu/g and 14.24 x 10^4 cfu/g, respectively.

The enumeration of the microbial population was done on agar plates containing appropriate media following serial dilution technique and pour plate method (Pramer and Schmidt 1965). Soil samples collected were analyzed by following serial dilution plating procedures. Soil extract agar medium (Lochhead and Chase 1943) was used for the count of total bacteria in soil. The population of fungi was estimated on Martin's Rose Bengal agar medium with streptomycin and Rose Bengal as dye in medium (Martin 1950). Actinomycetes population was counted by using Kenknight and Munaiers Medium agar medium (Chhonkar *et al.* 2002). After allowing for development of discrete microbial population during incubation at 28±2 ^{o}C in incubator, the colonies were counted and number of viable counts expressed as CFU/gram dry weight basis of soil. An incubation period of 48 h for bacteria, 48–72 h for fungi and one week for actinomycetes. Microbial population in the soil was computed by taking into account the soil dilutions.

For residual carry over study, the original experimental layout was kept undisturbed, and lentil was sown across the plots. The crop was raised as per recommended package and practices of lentil crop. Carry over effect of herbicides were studied in succeeding lentil crop in terms of plant population, pods/plant, number of grains/pod, 1000 grain weight and grain yield (t/ha).

To see the phytotoxicity of different treatments on crop, visual observations were recorded on chlorosis, necrosis, stunting, scorching, hyponasty and epinasty *etc*. on the prescribed 0-10 scale at 1, 3, 5, 7, 10, 15 and 30 days after herbicidal application in sugarcane.

The data were subjected to statistical analysis by analysis of variance method. All the data obtained from experiment were subjected to statistical analysis as per the method detailed by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Weed density

During both the seasons, major weed flora of the experimental field at 60 DAA consisted of grassy weeds, *viz. Echinochloa colona* (7.9 and 4.0%), *Eleusine indica* (6.4 and 12.2%), *Dactyloctenium aegyptium* (8.4 and 8.1%) and *Digitaria sanguinalis* (10.8 and 10.1%); broad-leaved weeds, (BLWs), *viz. Commelina benghalensis* (2.8 and 3.6%) and *Cleome viscosa* (1.6 and 3.0%), whereas, *Cyperus rotundus* (62.1 and 58.9%) was the only sedge.

Combination of halosulfuron + metribuzin (RM) applied as post-emergence at 600 and 900 g/ha and 2,4-D-amine salt applied at 3500 g/ha were the most effective against BLWs, and recorded 100% weed suppression as compared to other herbicidal treatments except *Cleome viscosa*. Whereas, two hoeing (30 and 60 DAS) were effective in complete removal of BLWs in year 2012 only. Among the grassy weeds, similar observation was recorded by ready mix (RM) combination of halosulfuron + metribuzin at 600 and 900 g/ha in total elimination of *Echinochloa colona* during 2013. The application of lower dose of halosulfuron + metribuzin at 300 g/ha and 2,4-D amine salt at 3500 g/ha was at par with weedy check in reducing the population of *Echinochloa colona*, *Dactyloctenium aegyptium* and *Digitaria sanguinalis*.

Weed dry matter accumulation and weed control efficiency (WCE)

The mean data on dry matter of grassy weed at 60 DAA revealed that minimum accumulation (5.4 and 6.5 g/m^2) and maximum weed control efficiency (71.0 and 81.1%) was obtained with ready mix application of halosulfuron + metribuzin at (900 g/ha) during 2012 and 2013, respectively, being at par with (600 g/ha), and significantly superior to rest of the treatments. Complete control of BLWs, was attained by the combined application of halosulfuron + metribuzin at 900 g/ha and 2,4-D amine at 3500 g/ha. The dry-matter accumulation of sedges (1.1 and 1.5 g/m^2) was minimum with the highest dose of halosulfuron + metribuzin at 900 g/ha followed by 600 g/ha (**Table 1** and **2**). The reduction in dry-matter by application of halosulfuron + metribuzin at (900 g/ ha) might be due to lower weed density. The effect of halosulfuron + metribuzin at (900 g/ha) was more pronounced as compared to atrazine in respect to non-grassy (BLWs and sedges) weeds in reducing the dry matter accumulation.

Herbicide efficiency index

Herbicide efficiency index (HEI) of different herbicides in each plot of the experiment was recorded at 60 DAA by addition of dry-matter

Table 1. Effect of different treatments on weed dry weight at 60 DAA during 2012 and 2013

Treatment	Dose (g/ha)	Total weed dry weight (g/m^2)					
		Grasses		BLWs		Sedges	
		2012	2013	2012	2013	2012	2013
Halosulfuron + metribuzin	300	7.8(60.1)	11.4(128.1)	1.9(2.6)	2.9(7.9)	1.4(1.2)	2.1(3.3)
Halosulfuron + metribuzin	450	6.6(42.5)	7.3(53.1)	1.2(0.4)	1.9(2.7)	1.3(0.7)	1.7(1.7)
Halosulfuron + metribuzin	600	6.1(36.6)	6.7(43.3)	1.1(0.2)	1.5(1.5)	1.2(0.5)	1.6(1.5)
Halosulfuron + metribuzin	900	5.4(28.5)	6.5(41.1)	1.0(0.0)	1.0(0.0)	1.1(0.3)	1.5(1.1)
Atrazine 50% WP (standard check)	2000	7.3(53.0)	9.8(95.4)	2.4(4.9)	3.6(12.2)	4.0(15.3)	13.9(14.7)
2,4-D Amine salt 58% SL (standard check)	3500	9.7(93.7)	12.7(161.2)	1.0(0.0)	1.0(0.0)	1.7(1.8)	1.5(1.3)
Hoeing twice	30 & 60 DAP	7.9(61.2)	9.7(93.5)	1.0(0.0)	2.2(4.5)	2.2(3.9)	2.3(4.1)
Untreated	-	10.0(98.3)	14.8(217.3)	2.7(6.2)	4.4(18.3)	4.2(16.3)	4.1(15.5)
LSD (p=0.05)		0.74	0.7	0.25	0.7	0.21	0.3

Values in parentheses were original and transformed to square root ($\sqrt{x+1}$) for analysis, DAP- Days after transplanting, DAA- Days after herbicidal application accumulation of total grassy and non-grassy weeds (**Table 2**). HEI which indicates weed killing potential and phytotoxicity on the crop was the highest under combined application of halosulfuron + metribuzin at 900 g/ha followed by 600 g/ha. However, the application of 2,4-D amine salt at 3500 g/ha resulted in the lowest HEI.

Study on microbial population

Overall microbial population was high before herbicide application and decreased after application even upto harvest of the crop. Decline of the overall soil microbial population was more pronounced and drastic up to 7 DAA and then increased. Buildup of the micro flora was observed up to harvest of the crop.

Bacterial population (10^7 cfu/g)

Herbicidal treated plots had no significant effect on bacterial counts. Soil bacterial populations in the control plot was higher than those of herbicide treated plots. The bacterial populations for all soil samples increased after 7 to 60 DAA. After the 7 to 60 DAA, the bacterial population varied from 6.51 x 10^7 cfu/g to 12.59 x 10^7 cfu/g. Drastic reduction was observed in microbial population at 7 DAA of herbicide (**Figure 1A**).

Actinomycetes population (10^5 cfu/g)

The population of actinomycetes varied from 3.0 x 10^7 cfu/g to 13.0 x 10^7 cfu/g after 7 to 60 DAA of herbicide. At harvest, overall population of actinomycetes varied from 43.7 to 20.1% over weedy check (**Figure 1B**).

Fungal population (10^4 cfu/g)

The fungal population fluctuated between the first and second week, while the control samples had the highest fungal population. The lowest population of fungus (3.61 x 10^5 cfu/g) at 7 DAA was obtained with application of halosulfuron + metribuzin at 450 g/ha and increased by 70.2% after harvest of crop. It's evident from the results that up to 15 DAA, the herbicide had adverse effect on population of fungi in rhizosphere region. This indicates that the population of fungi started to increase from 30 DAA. Herbicidal application gave higher population (70.2 to 78.3%) of fungi from 7 DAA to harvest of crop (**Figure 1C**).

Table 2. Effect of different treatments on weed control efficiency (%) and herbicide efficiency index (%) at 60 DAA during 2012 and 2013

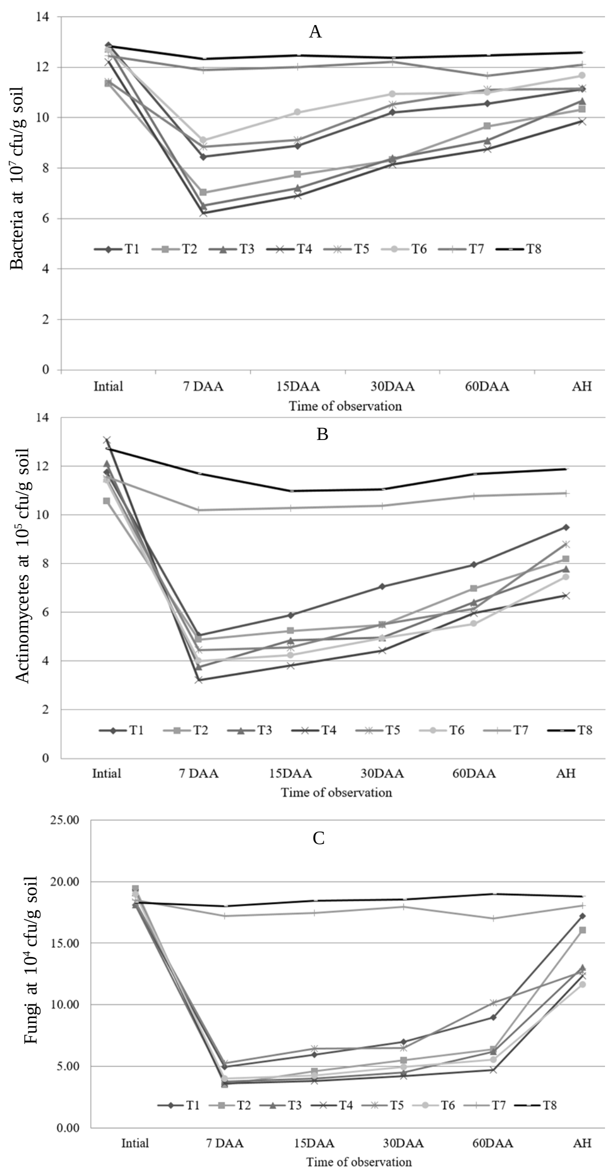
Treatment	Dose (g/ha)	Weed control efficiency (%)						Herbicide efficiency index (%)	
		Grasses		BLWs		Sedges			
		2012	2013	2012	2013	2012	2013	2012	2013
Halosulfuron + metribuzin	300	38.9	41.0	67.7	56.8	92.6	78.7	1.13	1.19
Halosulfuron + metribuzin	450	56.8	75.6	93.5	85.2	95.7	89.0	3.34	5.13
Halosulfuron + metribuzin	600	62.8	80.1	96.8	91.8	96.9	90.3	4.04	6.69
Halosulfuron + metribuzin	900	71.0	81.1	100.0	100.0	98.2	92.9	5.04	7.15
Atrazine 50% WP (standard check)	2000	46.1	56.1	20.9	33.3	6.1	5.1	1.29	1.11
2,4-D Amine salt 58% SL (standard check)	3500	4.7	25.8	100.0	100.0	88.9	91.6	0.47	0.23
Hoeing twice	30 & 60 DAP	37.7	56.9	100.0	75.4	76.1	73.5	1.39	1.14
Untreated	-	-	-	-	-	-	-	-	-
LSD (p=0.05)		-	-	-	--	-	-	-	-

DAP- Days after planting, BLWs- Broad-leaf weeds, DAA- Days after herbicidal application

Table 3. Effect of different treatments on cane yield attributes of sugarcane during 2012 and 2013

Treatment	Dose (g/ha)	Milliable cane (t/ha)		Cane length (m)		Cane girth (cm)		Per cane weight (g)		Cane yield (t/ha)		Percent increase in yield over weedy	
		2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Halosulfuron + metribuzin	300	71.4	86.4	1.9	2.1	7.4	7.2	873	817	63.5	71.1	59.9	66.5
Halosulfuron + metribuzin	450	89.9	90.8	2.0	2.2	7.8	7.4	990	1045	87.5	92.6	120.4	116.9
Halosulfuron + metribuzin	600	90.3	93.8	2.0	2.2	7.8	7.4	1000	1053	89.3	98.9	124.9	131.6
Halosulfuron + metribuzin	900	87.2	91.3	2.0	2.1	7.7	7.3	1003	1017	87.3	90.7	119.9	112.4
Atrazine 50% WP (standard. check)	2000	70.9	65.9	2.0	2.1	7.8	7.4	1000	1015	70.7	65.8	78.1	54.1
2,4-D Amine salt 58% SL (standard check)	3500	61.4	53.3	1.9	2.0	7.5	7.0	887	900	54.6	49.2	37.5	15.2
Hoeing twice	30&60DAP	70.5	64.3	1.9	2.0	7.9	7.3	988	947	69.5	62.5	75.1	46.4
Untreated	-	49.2	46.8	1.6	1.9	7.1	6.9	807	820	39.7	42.7	-	-
LSD (p=0.05)		6.8	6.3	0.09	0.14	0.4	0.3	6.8	106.0	66.3	80.9	-	-

DAP- Days after planting



T[1] - Halosulfuron + metribuzin, T[2] - Halosulfuron + metribuzin, T[3] - Halosulfuron + metribuzin, T[4] - Halosulfuron + metribuzin, T[5] - Atrazine (standard. check), T[6] - 2,4-D Amine salt (standard check), T[7] - Hoeing (2), T[8] - Untreated

Figure 1. Effect of halosulfuron + metribuzin herbicide on soil bacterial (A), actinomycetes (B) and fungal (C) population at diferent intervals

Yield attributes and yield

Yield attributes of sugarcane varied significantly with various weed control treatments except cane length which did not show any significance over the herbicidal application (**Table 3**). During both the years maximum number of milliable cane (‘000/ha) were recorded with ready mix application of halosulfuron + metribuzin at 600 g/ha, which was at par with 450 and 900 g/ha. Application of halosulfuron + metribuzin at 450 and 600 g/ha and atrazine (standard check) at 2000 g/ha was found to be similar for cane girth. Maximum cane weight (1003 g/cane) was recorded with application of halosulfuron + metribuzin at 900 g/ha and was at par with 600 g/ha during 2012. Whereas, during 2013, maximum cane weight (1053 g/cane) was obtained with application of halosulfuron + metribuzin 600 g/ ha and was significantly superior to only lower dose applied at 300 g/ha. The yield parameters like milliable cane, cane length, cane girth, cane weight were significantly influenced by weed control treatments over the weedy check.

Maximum cane yield (89.3 and 98.9 t/ha) was recorded under halosulfuron + metribuzin applied at 600 g/ha. The effective control of weeds at early stage of growth might have resulted in better growth and yield of sugarcane. These results were in coincidence with findings of Singh *et al*. (2011). Application of 2,4-D amine salt at 3500 g/ha recorded significantly lower cane yield than other herbicidal treatments as well as twice hoeing (30 and 60 DAP).

Phytotoxic effect

During both the years, no phytotoxic effect in terms of scorching, necrosis, hyponasty and epinasty were seen in sugarcane crop with the application of halosulfuron + metribuzin at different doses. However, moderate to slight chlorosis and stunting was noted up to 3 DAA at highest dose of halosulfuron + metribuzin, which itself recovered and no phytotoxicity symptoms were observed thereafter

Table 4. Effect of different treatments on succeeding lentil during 2012 and 2013

Treatment	Dose (g/ha)	Plant (no./m^2) 15 DAS		Plant (no./m^2) At harvest		Pods/plant		Grain/pod		1000 seed weight (g)		Grain yield (t/ha)	
		2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Halosulfuron + metribuzin	300	105	98.2	92	84.0	46.0	42.8	1.60	1.50	21.6	21.1	1.45	1.12
Halosulfuron + metribuzin	450	107	97.5	93	82.5	46.2	43.0	1.62	1.48	21.7	21.0	1.47	1.07
Halosulfuron + metribuzin	600	106	98.0	93	83.2	46.1	43.4	1.61	1.51	22.0	21.2	1.39	1.15
Halosulfuron + metribuzin	900	107	101.0	94	83.5	46.5	42.8	1.59	1.49	22.2	21.5	1.42	1.10
Untreated		108	101.3	89	83.7	46.3	42.3	1.60	1.50	21.8	21.3	1.42	1.07
LSD (p=0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

at 5, 7, 10, 15 and 30 DAA. Test herbicides did not show any phytotoxicity effect even at higher doses. Hence, there was no reduction in yield parameters due to phytotoxicity. Etheredge *et al.* (2010) also did not observe any reduction in sugarcane growth later in the growing season and any injury to the crop due to halosulfuron.

Residual effect of halosulfuron + metribuzin applied in sugarcane on succeeding lentil crop

The residual effect of treatments (applied to sugarcane) was not well pronounced on germination per cent and yield of lentil during both the years. All the yield and yield attributing characters were not significantly influenced at all the doses of halosulfuron + metribuzin and they were almost similar in all the treatments, including weedy check plots. Post-emergence application of halosulfuron + metribuzin against weeds in sugarcane crop during both the years was safe for growing lentil. These results were in coincidence with the findings of Chand *et al.* (2014) who also reported that none of the doses of halosulfuron affect the growth and yield of succeeding lentil crop. The combination of halosulfuron + metribuzin applied as post-emergence in sugarcane crop during both the years didn't cause any adverse effect on grain yield of succeeding lentil crop as yield achieved in treated plot was similar to the untreated plot. Therefore, application of halosulfuron + metribuzin against weeds in sugarcane was safe for growing succeeding lentil in winter season (**Table 4**).

Application of halosulfuron + metribuzin at 600 g/ha achieved maximum yield of sugarcane. Ready mix combination of halosulfuron + metribuzin was found more effective in reducing the population of BLWs and sedges as compared to grasses, without any phytotoxic effect on sugarcane and succeeding lentil. The bacterial population was more sensitive to herbicide application than fungi and actinomycetes.

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Integrated weed management in turmeric

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ABSTRACT

A field experiment was conducted during *Kharif* 2014 and 2015 at Agriculture and Horticulture Research Station, Kathalagere, Davanagere district of Karnataka state, to study the effect of various weed management practices on weed density, weed dry weight, growth, yield and economics of turmeric. Pre-emergence (PE) application of pendimethalin at 1.0 kg/ha *fb* two hand weeding on 45 and 75 DAP recorded the highest rhizome yield, weed control efficiency, net returns and B:C ratio (23.2 t/ha, 89.2%, ` 1,45,309/ha and 2.50, respectively) in 2014. Whereas, PE application of oxyflourfen at 0.30 kg/ha *fb* 2 hand weeding on 45 and 75 DAP recoded the highest rhizome yield, weed control efficiency, net returns and B:C ratio (21.9 t/ha, 89.1%, ` 133236/ha and 2.60, respectively) in 2015. Integrated weed management using a broad-spectrum PE herbicide like pendimethalin or oxyflourfen *fb* 2 hand weedings on 45 and 75 DAP was effective in controlling weeds and obtaining higher yield and economic returns in turmeric.

Key words: Hand weeding, Integrated weed management, Oxyflourfen, Pendimethalin, Turmeric

Turmeric (*Curcuma longa* L.), is an herbaceous perennial plant, belonging to the family Zinziberaceae, native to tropical South-east Asia. It is one of the most-valuable spices all over the world. Turmeric, an ancient and sacred spice of India, is a major rhizomatous spice produced and exported from India. In India, it is grown over an area of 1,94,000 ha with an average production of 9,71,000 MT and productivity of 5 MT/ha (Indian Horticulture data base 2014). Turmeric forms an important adjuvant in Indian culinary as it gives colour and aromatic flavour to various dishes. Turmeric is widely used as an important condiment in the preparation of pickles and curries and as a colouring agent in textiles, food and confectionary industries. Turmeric has long been used in India for the treatment of sprains and inflammatory conditions. Turmeric, largely grown as a rainfed crop during *Kharif* (rainy) season, takes long time span of about 8–9 months (Barla *et al*. 2015). Delayed emergence, slow initial growth, poor canopy development of turmeric provides ideal environment for weeds to grow and cover the ground quickly and compete with the crop for nutrients, moisture and space causing considerable yield reduction of about 30-75% (Krishnamurthi and Ayyaswamy 2000). Weed control by hand weeding becomes expensive, time consuming and laborious. Sometimes, due to scarcity of labour specially during critical stages of crop growth, the yield may be reduced drastically. Hence, the use of herbicides in turmeric production becomes essential. The effectiveness of each herbicide is determined by the factors like type of weed flora, soil type, organic matter content of the soil, weather conditions *etc*. Turmeric requires a weed free condition of 70 to 160 days after planting (DAP) for better production of rhizomes. This necessitates development of an effective and economically better integrated weed control strategy for realizing higher productivity of turmeric. Keeping these in view, the present investigation was conducted with an objective to find the best weed management practice for effective control of weeds.

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MATERIALS AND METHODS

A field experiment was conducted at Agriculture and Horticulture Research Station, Kathalagere during *Kharif* season of 2014 and 2015. The experiment comprised 15 treatments, *viz*. metribuzin 0.7 kg/ha at 0-5 days after planting (DAP) followed by (*fb*) 2-hand weeding (HW) at 45 and 75 DAP, metribuzin 0.7 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP, metribuzin 0.7 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW 75 DAP, pendimethalin 1.0 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP, pendimethalin 1.0 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP, pendimethalin 1.0 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha at 10 DAP *fb* HW 75 DAP, atrazine 0.75 kg/ha at 0-5 DAP *fb* 2 HW 45 and 75 DAP, atrazine 0.75 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP, atrazine 0.75 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW at 75 DAP, oxyfluorfen 0.30 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP, oxadiargyl 0.25 kg/ha at 0-5 DAP *fb* 2 HW at

45 and 75 DAP, glyphosate 5.0 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP, glyphosate 7.5 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP, hand weeding at 25, 45 and 75 DAP, un-weeded check, tested in a Randomized Complete Block Design with three replications. The crop was planted at a spacing of 45 x 30 cm and 150:125:250 kg N: P_2O_5:K_2O/ha, were applied. The data on weed density and weed dry weight were recorded at 75 DAP using a quadrant of 50 x 50 cm. The data on weed density and dry weight were subjected to square root transformation using the formula square root of x + 1. When the leaves turned yellow and dry, the crop from net plots was harvested. The rhizomes were dug taking care that they were not cut or damaged, then cleaned to remove soil and weighed for fresh weight. Economics of the treatments was computed based on the prevalent market prices of the inputs used and rhizomes produced.

RESULTS AND DISCUSSION

Weed flora

The major weed flora observed in the experimental plots were *Cyperus rotundus* and *Scirpus* sp. (among sedges); *Cynadon dactylon* and *Echinochloa colona* (among grasses); *Spillanthus acmella, Portulaca oleracia, Parthenium hysteroporus, Phyllanthus niruri* and *Euphorbia geniculata* (among broad-leaf weeds). Among different categories, grasses were recorded in higher number *fb* broad-leaf weeds and sedges at 75 DAP in turmeric.

Weed density and weed dry weight

All the weed management practices significantly reduced the weed density and dry weight in turmeric (**Tables 1** and **2**). Among the various integrated weed management practices, PE application of pendimethalin at 1.0 kg/ha, oxyflourfen at 0.30 kg/ha and atrazine at 0.75 kg/ha *fb* 2 HW at 45 and 75 DAP had recorded the lowest density and dry weight of grasses, broad-leaf weeds and sedges during both the years of experimentation. PE application of pendimethalin, oxyflourfen, atrazine had broad spectrum effect on weeds *fb* 2 HW on 45 and 75 DAP had reduced the major weed flora in turmeric and resulted in lower weed density and dry weight. Similar indications of weed control by integrated weed management had been observed by Ashok and Sanjay (2014), Nidhi *et al.* (2015), Ratnum *et al.* (2012) and Barla *et al.* 2015.

Growth and rhizome yield

Effect of different weed management practices on plant height and number of leaves in turmeric at 75 DAP is presented in **Table 3**. In 2014, the highest plant height and number of leaves were recorded in pre-emergence application of pendimethalin at 1.0 kg/ha *fb* 2 HW on 45 and 75 DAP. Whereas in 2015, PE application of oxyflourfen at 0.30 kg/ha *fb* 2 HW at 45 and 75 DAP recoded the highest plant height and number of leaves. Reduced competition between the crop and weeds resulted in higher plant height and number of leaves in turmeric. Channappagoudar *et al.* (2013) also noticed similar results.

Table 1. Effect of weed management practices on weed density (no./m^2) in turmeric at 75 days after planting

Treatment	Weeds density (no./m^2)							
	Sedges + 2014	Sedges + 2015	Grasses+ 2014	Grasses+ 2015	Broad-leaf # 2014	Broad-leaf # 2015	Total # 2014	Total # 2015
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	3.2(9.7)$^+$	3.45(11.0)$^+$	3.4(10.3)$^+$	2.6(6.3)$^+$	1.5(27.7)$^\#$	1.4(29.8)$^\#$	1.7(47.7)$^\#$	1.6(47.1)$^\#$
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP	3.7(12.7)	3.83(13.7)	4.3(17.7)	3.5(12.0)	1.6(35.7)	1.7(51.2)	1.8(66.0)	1.8(76.8)
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW 75 DAP	3.2(9.3)	3.56(11.7)	3.7(12.7)	3.2(10.0)	1.5(33.3)	1.5(38.8)	1.7(55.3)	1.7(60.5)
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	2.7(6.7)	3.27(9.7)	2.8(7.0)	2.5(5.3)	1.3(18.0)	1.4(28.2)	1.5(31.7)	1.6(43.1)
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP	3.8(13.7)	4.12(16.0)	3.9(14.7)	4.2(17.3)	1.7(43.7)	1.7(54.8)	1.9(72.0)	1.9(88.2)
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha at 10 DAP *fb* HW 75 DAP	3.2(10.3)	3.56(13.0)	3.9(14.0)	3.2(10.0)	1.6(34.7)	1.6(42.8)	1.8(59.0)	1.8(65.8)
Atrazine 0.75 kg/ha at 0-5 DAP *fb* 2 HW 45 and 75 DAP	2.8(7.3)	3.32(10.3)	3.3(10.0)	2.9(8.0)	1.4(25.7)	1.5(30.8)	1.6(43.0)	1.7 (49.2)
Atrazine 0.75 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP	3.8(14.7)	4.03(15.3)	4.2(17.0)	4.4(18.7)	1.7(44.7)	1.7(58.3)	1.9(76.3)	1.9 (92.3)
Atrazine 0.75 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW at 75 DAP	3.2(9.7)	3.60(12.0)	4.0(14.7)	3.4(11.0)	1.6(36.0)	1.6(47.5)	1.8(60.3)	1.8(71.3)
Oxyfluorfen 0.30 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	2.9(7.3)	3.16(9.3)	3.1(8.7)	2.7(6.3)	1.4(22.0)	1.4(24.7)	1.6(38.0)	1.6(40.3)
Oxadiargyl 0.25 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	3.1(9.7)	3.44(11.3)	3.4(11.0)	3.1(9.0)	1.5(29.3)	1.5(32.5)	1.7(50.0)	1.7(52.9)
Glyphosate 5.0 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP	3.4(10.7)	3.77(13.3)	4.1(16.7)	3.5(11.7)	1.6(37.3)	1.6(47.5)	1.8(64.7)	1.8(72.6)
Glyphosate 7.5 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP	3.3(10.3)	3.55(11.7)	3.7(12.7)	3.1(8.7)	1.5(30.0)	1.5(35.8)	1.7(53.0)	1.7(56.2)
Hand weeding at 25, 45 and 75 DAP	3.2(9.7)	3.41(11.0)	3.9(14.0)	3.1(9.0)	1.5(32.3)	1.6(40.4)	1.8(56.0)	1.7(60.4)
Un-weeded check	6.2(37.7)	6.40(41.3)	5.6(31.0)	5.8(34.0)	1.9(86.0)	1.9(100.1)	2.2(154.7)	2.2(175.5)
LSD (p=0.05)	1.29	1.07	0.84	0.95	0.17	0.22	0.21	0.16

Data within the parentheses are original values; Transformed values - # = log ($\sqrt{x+2}$), + = square root of ($\sqrt{x+1}$)

Weed control treatments significantly influenced the rhizome yield of turmeric (**Table 3**). Pre-emergence application of pendimethalin at 1.0 kg/ha *fb* 2 HW on 45 and 75 DAP had recorded the highest rhizome yield (23.2 t/ha) in 2014 followed by pre-emergence application of oxyflourfen at 0.30 kg/ha or atrazine at 0.75 kg/ha *fb* 2 HW on 45 and 75 DAP (22.5 and 22.3 t/ha, repectively). In 2015, pre-emergence application of oxyflourfen at 0.30 kg/ha *fb* 2 HW on 45 and 75 DAP recoded the highest rhizome yield (21.9 t/ha). Unweeded check recorded the lowest yield during both the years. Increased growth parameters and reduced weed pressure on crop has led to increase in yield. The results are in conformity with to results obtained by Gill *et al*. (2000), Ashok and Sanjay (2014) and Barla *et al*. (2015).

Weed control efficiency

Integrated weed management practices registered higher weed control efficiency during both

Table 2. Effect of weed management practices on major weed dry weight in turmeric crop at 75 days after planting

Treatment	Weed dry weight (g/m^2)							
	Sedges + 2014	Sedges + 2015	Grasses+ 2014	Grasses+ 2015	Broad-leaf # 2014	Broad-leaf # 2015	Total # 2014	Total # 2015
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	2.4(4.7)$^{+}$	2.3(4.7)$^{+}$	2.5(5.3)$^{+}$	1.9(2.9)$^{+}$	1.2(15.5)$^{+}$	1.2(16.9)$^{\#}$	1.4(25.5)$^{\#}$	1.4(24.6)$^{\#}$
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP	3.0(8.2)	3.2(9.6)	3.6(12.5)	3.0(8.8)	1.4(26.8)	1.6(40.6)	1.7(47.5)	1.7(58.9)
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW 75 DAP	2.5(5.4)	2.7(6.3)	2.9(7.7)	2.5(5.8)	1.3(21.3)	1.4(25.6)	1.5(34.5)	1.5(38.0)
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	1.9(2.7)	2.2(4.1)	2.0(3.3)	1.8(2.4)	1.0(9.2)	1.2(15.0)	1.2(15.2)	1.3(21.5)
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP	3.2(9.7)	3.5(11.8)	3.4(10.9)	3.7(13.2)	1.6(34.5)	1.6(44.3)	1.8(55.1)	1.8(69.3)
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha at 10 DAP *fb* HW 75 DAP	2.5(6.1)	2.8(7.8)	3.1(8.8)	2.6(6.5)	1.4(22.9)	1.4(29.4)	1.6(37.8)	1.6(43.7)
Atrazine 0.75 kg/ha at 0-5 DAP *fb* 2 HW 45 and 75 DAP	2.1(3.4)	2.3(4.9)	2.2(4.9)	2.1(3.8)	1.2(13.9)	1.2(17.8)	1.4(22.1)	1.4(26.4)
Atrazine 0.75 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67 + 4 g/ha at 45 DAP	3.4(11.0)	3.5(12.0)	3.7(13.3)	3.9(14.9)	1.6(36.6)	1.6(49.0)	1.8(60.9)	1.8(75.9)
Atrazine 0.75 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW at 75 DAP	2.6(5.9)	3.0(8.0)	3.2(9.5)	2.9(7.8)	1.4(24.8)	1.5(36.7)	1.6(40.3)	1.7(52.6)
Oxyfluorfen 0.30 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	2.0(3.2)	2.1(3.8)	2.1(4.2)	1.9(2.8)	1.1(11.4)	1.1(13.1)	1.3(18.8)	1.3(19.7)
Oxadiargyl 0.25 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	2.4(4.9)	2.4(5.4)	2.6(5.9)	2.3(4.7)	1.2(17.0)	1.3(19.6)	1.5(27.9)	1.4(29.7)
Glyphosate 5.0 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP	2.8(6.7)	3.1(8.8)	3.5(11.3)	2.9(8.1)	1.4(26.9)	1.5(35.0)	1.7(44.9)	1.7(51.9)
Glyphosate 7.5 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP	2.5(5.4)	2.5(5.7)	2.8(7.1)	2.3(4.7)	1.3(18.0)	1.3(22.1)	1.5(30.5)	1.5(32.5)
Hand weeding at 25, 45 and 75 DAP	2.4(5.1)	2.6(6.3)	3.0(8.3)	2.4(5.4)	1.3(20.0)	1.4(27.4)	1.5(33.4)	1.6(39.1)
Un-weeded check	5.7(32.4)	6.1(37.6)	5.3(28.8)	5.8(33.3)	1.9(85.1)	2.0(110.0)	2.2(146.4)	2.2(180.9)
LSD (p=0.05)	0.98	0.84	1.46	0.76	0.31	0.22	0.20	0.17

Data within the parentheses are original values; Transformed values - # = log $(\sqrt{x+2})$, + = square root of $(\sqrt{x+1})$

Table 3. Effect of weed management practices on plant height, number of leaves, fresh rhizome yield and weed control efficiency in turmeric

Treatment	75 DAP				Fresh rhizome yield (t/ha) 2014	Fresh rhizome yield (t/ha) 2015	Weed control efficiency (%) 2014	Weed control efficiency (%) 2015
	Plant height (cm) 2014	Plant height (cm) 2015	No. of leaves/ plant 2014	No. of leaves/ plant 2015				
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	80	78	19	19	21.4	20.6	82.6	86.4
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67+4 g/ha at 45 DAP	65	63	15	13	13.8	12.6	67.5	67.5
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW 75 DAP	74	73	17	17	19.7	18.1	76.4	79.0
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	87	79	20	20	23.2	21.7	89.6	88.1
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67+4 g/ha at 45 DAP	65	63	14	13	12.0	11.4	62.4	61.7
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha at 10 DAP *fb* HW 75 DAP	73	71	17	16	17.4	16.9	74.2	75.8
Atrazine 0.75 kg/ha at 0-5 DAP *fb* 2 HW 45 and 75 DAP	81	80	19	19	22.3	20.3	84.9	85.4
Atrazine 0.75 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67+4 g/ha at 45 DAP	61	60	14	13	11.5	11.1	58.4	58.1
Atrazine 0.75 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW at 75 DAP	69	69	16	16	15.6	14.1	72.5	70.9
Oxyfluorfen 0.30 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	83	80	20	20	22.5	21.9	87.2	89.1
Oxadiargyl 0.25 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	79	75	18	19	21.1	19.7	80.9	83.6
Glyphosate 5.0 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP	66	71	15	15	14.8	14.2	69.3	71.3
Glyphosate 7.5 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP	78	76	19	18	20.7	18.5	79.2	82.0
Hand weeding at 25, 45 and 75 DAP	77	72	18	17	19.9	17.4	77.2	78.4
Un-weeded check	58	58	11	10	6.4	6.1	0.0	0.0
LSD (p=0.05)	10.9	8.8	4.7	2.5	5.8	2.6	NA	NA

NA: Not analyzed

Table 4. Effect of weed management practices on economics of turmeric production

Treatment	Cost of cultivation ($x10^3$ `/ha) 2014	Cost of cultivation ($x10^3$ `/ha) 2015	Gross returns ($x10^3$ `/ha) 2014	Gross returns ($x10^3$ `/ha) 2015	Net returns ($x10^3$ `/ha) 2014	Net returns ($x10^3$ `/ha) 2015	B:C Ratio 2014	B:C Ratio 2015
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	86.25	86.25	214.00	205.67	127.75	119.42	2.5	2.4
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67+4 g/ha at 45 DAP	79.38	79.38	138.00	125.67	58.62	46.29	1.7	1.6
Metribuzin 0.7 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW 75 DAP	81.75	81.75	197.06	181.00	115.31	99.25	2.4	2.2
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	86.74	86.74	232.04	216.67	145.301	129.93	2.7	2.5
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67+4 g/ha at 45 DAP	79.86	79.86	120.00	114.33	40.14	34.47	1.5	1.4
Pendimethalin 1.0 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha at 10 DAP *fb* HW 75 DAP	82.24	82.24	173.72	168.67	91.49	86.43	2.1	2.1
Atrazine 0.75 kg/ha at 0-5 DAP *fb* 2 HW 45 and 75 DAP	84.90	84.90	223.00	203.33	138.10	118.43	2.6	2.4
Atrazine 0.75 kg/ha at 0-5 DAP *fb* fenoxaprop + metsulfuron 67+4 g/ha at 45 DAP	78.03	78.03	115.33	111.00	37.31	32.97	1.5	1.4
Atrazine 0.75 kg/ha at 0-5 DAP *fb* straw mulch at 5 t/ha *fb* at 10 DAP *fb* HW at 75 DAP	80.40	80.40	156.31	140.67	75.91	60.27	1.9	1.7
Oxyfluorfen 0.30 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	85.76	85.76	224.87	219.00	139.11	133.24	2.6	2.6
Oxadiargyl 0.25 kg/ha at 0-5 DAP *fb* 2 HW at 45 and 75 DAP	86.82	86.82	210.89	197.33	124.06	110.51	2.4	2.3
Glyphosate 5.0 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP	84.45	84.45	148.00	142.33	63.54	57.88	1.8	1.7
Glyphosate 7.5 ml/l at 25 DAP *fb* 2 HW at 45 and 75 DAP	84.45	84.45	206.98	185.00	122.53	100.54	2.5	2.2
Hand weeding at 25, 45 and 75 DAP	88.50	88.50	198.99	174.00	110.49	85.50	2.2	2.0
Un-weeded check	75.00	75.00	64.33	61.00	-10.67	-14.00	-0.9	0.8

Cost of herbicides: metribuzin = ` 180/100 g, pendimethalin = ` 700/lit, atrazine = ` 300/kg, oxyfluorfen = ` 515/250ml, oxadiargyl = ` 760/100 g, glyphosate = ` 380/lit, fenoxaprop= ` 417/250 ml, metsulfuron= ` 217/10 g, Men Labour: ` 200 per day; Women Labour: ` 150 per day price of turmeric= ` 10/kg.

the years (**Table 3**). Pre-emergence (PE) application of pendimethalin at 1.0 kg/ha *fb* 2 HW on 45 and 75 DAP recorded higher weed control efficiency (89.6%) in 2014. Closer results were obtained in PE application of oxyflourfen at 0.30 kg/ha or atrazine at 0.75 kg/ha *fb* 2 HW at 45 and 75 DAP (87.2 and 84.9%, respectively). In 2015, higher weed control efficiency was observed in PE application of oxyflourfen at 0.30 kg/ha *fb* 2 HW on 45 and 75 DAP (89.1%). The higher weed control efficiency in these treatments was due to lower weed dry weight.

Economics

Economics is the ultimate criteria for acceptance and wider adoption of any technology. Among different indicators of economics efficiency in any production system, net returns and B:C ratio have greater impact on the practical utility and acceptance of the technology by the farmers. In the present study, PE application of pendimethalin at 1.0 kg/ha *fb* HW on 45 and 75 DAP recorded higher net returns and B:C ratio (` 1,45,309/ha and 2.7, repectively) in 2014. Whereas in 2015, higher net returns and B:C ratio was observed in PE application of oxyflourfen at 0.30 kg/ha *fb* 2 HW on 45 and 75 DAP (` 1,33,236/ha and 2.6, respectively). Integrated management of weeds reduced the cost of weed management, improved the yield and thus led to higher net returns and B:C ratio. Similar findings have been reported by Roy and Dharminder (2015).

The findings of present investigation conclusively inferred that weeds in turmeric can be effectively managed along with higher yield and profit by PE application of pendimethalin (1.0 kg/ha) or oxyflourfen (0.30 kg/ha) *fb* 2 HW on 45 and 75 DAP.

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Weed management in guava orchards

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ABSTRACT

The comparative efficacy of orchard soil management practices like mulching (paddy straw, white polythene, black polythene) and weed control methods (mechanical and chemical) were evaluated for managing weeds growth in guava orchard. A weedy plot was also kept as control for comparative assessment of different orchard floor management practices. The results revealed a significant effect of different treatments on grassy as well as broad-leaf weeds in the orchard. Although the black polythene mulch kept the area weed free throughout the season, the paddy straw mulch exhibited promising results, with 69.1 and 93.2% reduction in total weed biomass during first and second year of application, respectively. The white polythene was poor performer as it resulted in heavy weed growth under the mulch and tearing of polythene sheet. Chemical weed management as well as mechanical weeding also reduced the intensity of weeds but resurgence of weeds resulted significantly higher weed biomass compared to paddy straw mulch. The paddy straw mulch exhibited potential to manage weeds in guava orchard.

Key words: Guava, Mulching, Orchard, Weed biomass, Weed management

Weeds are considered major obstacle in agricultural production systems particularly in fruit crops. It is estimated that losses caused by weeds exceeded the losses from any category of agricultural pests (Abouziena and Haggag 2016). On a global scale, the potential crop yield loss without weed control was estimated as 43% (Oerke 2006). However, Rao (2000) reported the annual loss of agricultural produce due to weeds as 45%, insects as 30%, diseases as 20% and other pests as 5%. In cultivated crops and established orchards, the weeds can be suppressed by various methods such as chemical, mechanical, manual, biological and by mulching etc. Although the chemical weed management is most effective, it has its own constraints like the injury to non-target vegetation, crop injury, residues in soil and water, toxicity to non-target organisms. The conventional method of managing weeds through manual method is very expensive and labour intensive. Mechanical control of weeds in established orchards is rather difficult and less effective due to spreading canopies of trees, limited coverage of the implements and potential damage to root and shoots of fruit trees. Mulching or covering the soil with organic or synthetic materials has been recorded as a safe method to control weeds in comparison to herbicides application (Ramakrishna 2006). The paddy straw mulch is easily available and cheap, while, the plastic mulch is costly affair for management of weeds in established orchards. Covering or mulching the soil surface can check the germination of weed seeds or physically suppress weed emergence (Stout 1985). Organic mulches reported to be beneficial for plant growth and fruit yield and quality in addition to weed suppression (Childers *et al.* 1995). There was a substantial reduction of weed growth with organic mulches in avocado and citrus over a period of four year (Faber *et al.* 2001). Transparent or white mulch and green covering had slight effect on weeds, while, the coloured mulches such as brown, black, blue or double colored films reduce the weed emergence (Bond and Grundy 2001). Abouziena *et al.* (2008) obtained the greatest control (94-100%) of weeds occurred with the plastic mulch (200 or 150 µm) and three mulch layers of rice straw.

The guava is major fruit crop of India having ranked fifth among all fruit crops with respect to acreage. Presently, India is producing 2.68 mMT guava fruits from 2.54 million hectare plantation (NHB 2015). In Punjab, except citrus, this fruit crop has highest area amidst all fruit crops and total of 0.176 mMT produce is being obtained from 8160 hectare area (Anon 2016). The profusely grown weeds in orchards compete for water and nutrients with fruit plants. The higher soil and canopy temperature under clean cultivation lead to excessive flower and fruit drop in guava. Therefore, the floor management in orchards is of utmost importance. The present study was undertaken to evaluate the response of weed population and biomass to different orchards soil management treatments.

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MATERIALS AND METHODS

The experiment was laid in Punjab Agricultural University, Ludhiana (India) during 2015 and 2016 on ten year old guava plants grown at 6.0 x 3.0 m spacing. Under various orchard soil management treatments, different type of mulches, *viz*. paddy straw mulch (PSM), white polythene mulch (WPM) and black polythene mulch (BPM) were applied under the canopy of the trees. The chemical weed management, mechanical control and a weedy field were also kept for comparative assessment to ascertain their effects on weed growth and population in established guava orchard. The paddy straw mulch was applied at about 10 t/ha by spreading under the tree canopy leaving 40% area in between the rows of trees. The black as well as white polythene mulch of 30 µ thickness was also applied in similar manner. Under chemical floor management treatment, glyphosate 4.0 l/ha was sprayed as post-emergence (PoE) herbicide during May and July prior to flowering and seed set in weeds. The mechanical weeding was done using disc harrow at the same time.

The treatments were initiated in the month of May after cleaning the orchard and application of recommended doses of organic manures as well as inorganic fertilizers. Three replicated plots were kept for each treatment and control. The weed density was estimated by using quadrat (1 x 1 m) placed randomly in all the replications of each treatment and control. The grasses and sedges were counted separately from broad-leaf weeds. The counting of weeds was done at monthly interval from June to September. The weed biomass was recorded by drying the weeds of each treatment at monthly interval in hot air oven at 65 ^{0}C temperature. The weeds were removed from the orchard after placing the quadrat at random places under each treatment by cutting the weeds at ground level. The dry weight of weeds was expressed in g/m^2.

RESULTS AND DISCUSSION

The experimental site was infested with diverse weed flora comprising of grasses, broad-leaf weeds and sedges (**Table 1**). The weed density data in different treatment showed that all the orchard soil management practices exhibited significant reduction in weed density and biomass as compared to control during both years of investigations (**Figure 1** and **2**). Although, no weed growth occurred under black polythene mulch but, white polythene mulch and paddy straw mulch also resulted 79.12 and 73.09% reduction in weed biomass as compared to control during first year and 46.44 and 92.68% reduction during second year, respectively (**Figure 3**). Mechanical and chemical weed management practices also exhibited significant reduction in weeds in summer and rainy season in guava orchard. After treatments, weed emergence occurs at faster rate during first month and rather slower rate from July to September except under mechanical and chemical weed control treatments as these treatments were

Table 1. Weed flora in the experimental site during 2015 and 2016

Grasses and Sedges (GS)	Broad-leaf weeds (BLW)
Grasses	
Cynodon dactylon	*Cannabis sativa*
Sorghum halepense	*Parthenium hysterophorus*
Eleusine indica	*Trianthema portulacastrum*
Eragrostis tenella	*Solanum nigrum*
Cenchrus catharticus	*Cleome viscosa*
Digitaria sanguinalis	*Ipomoea pestigridis*
Commelina benghalensis	*Boerhaavia diffusa*
Echinochloa colonum	*Digera arvensis*
Dactyloctenium aegyptium	*Physalis minima*
Eragrostis pilosa	*Amaranthus viridis*
Acrachne racemosa	*Euphorbia hirta*
Sedges	*Euphorbia microphylla*
Cyperus rotundus	*Phyllanthus niruri*
Cyperus compressus	

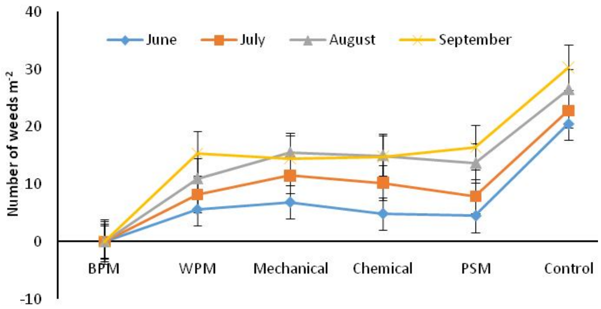

Figure 1. Weed density (no./m^2) under different orchard floor management treatments during 2015. Vertical bars represents mean S.E. of three replications

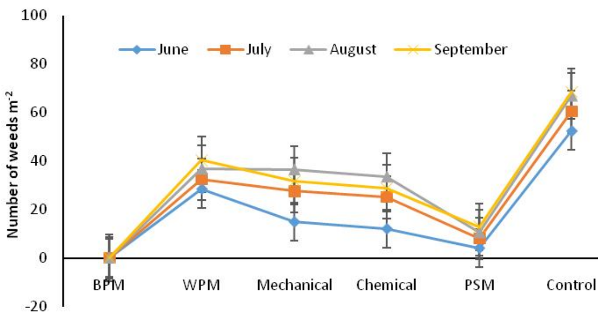

Figure 2. Weed density (no./m^2) under different orchard floor management treatments during 2016. Vertical bars represents mean S.E. of three replications

repeated in July-August, however, the biomass increases constantly from May to September. Higher biomass of sedges and grass weeds was recorded than broad-leaf weeds throughout the season (**Table 2**). In second year, the weed pressure under all treatments was higher as compared to first year except black polythene and paddy straw mulch. The paddy straw mulch was effective to the maximum extent in managing the weeds next to BPM during second year of study. Merwin *et al.* (1995) also reported that the loose materials such as straw, bark and composted waste can provide effective weed control, but, the thickness of mulch layer should be enough to suppress weed emergence.

All the orchard floor management treatments reduced the sedges, grasses and broad-leaf weed density with maximum reduction with PSM followed by chemical weed management after one month of treatment application. Highest weeds density was in control (20.50) and least (4.50) under PSM. The weed density increased significantly upto September under all treatments, while, under mechanical and chemical treatments it was reduced from August to September due to second spray of herbicide and mechanical weeding (**Figure 1**). The minimum weed density was recorded in treatment of pendimethalin as post-planting herbicide in guava nursery three months after treatment (Boora *et al.* 2014). The average weed density from May to September during first year under all treatments ranged from 0 to 30.30 weeds per square meter area. Highest weed density (30.3 m^2) was recorded in control plots, which was significantly highest than PSM, WPM, chemical and mechanical soil management treatments. The minimum average weed count (0/m^2) was recorded under BPM followed by 10.02 under WPM, 10.60 under PSM, 11.23 under chemical and 12.09 under mechanical soil management treatment, while, the highest average weed density (25.02/m^2) was recorded under control treatment.

During second year, the weed density in the first month was increased abruptly under control with 52.5 weeds/m^2 of different species followed by 28.5/m^2 under white polythene mulch which was ripped due to excessive weed growth beneath the polythene sheet (**Figure 2**). Minimum number of weeds were emerged under paddy straw mulch (4/m^2) followed by chemical (12/m^2) and mechanical (14.87/m^2) methods of orchard management, although it was nil under BPM. During second month, the weeds density was almost doubled under chemical, mechanical and PSM treatments, while under control and WPM, less number of weeds were emerged (**Figure 1**). In last month of observations, the weed density was significantly at par under mechanical and chemical treatments while, it was significantly highest (68.50/m^2) under control followed by WPM (40.30/m^2) treatment. The mean periodic weed density from May to September during second year in all treatments ranged from 0 to 62.09 per square meter area. The minimum average weed density (0.0/m^2) was recorded under BPM followed by WPM (34.52/m^2), mechanical (27.63/m^2), chemical (24.84/m^2) and paddy straw mulching (8.84/m^2). The average weed density was highest (62.09/m^2) under control treatment. The monthly weed density under various

Table 2. Effect of different treatments on weed biomass (g/m^2) in different months of year 2015 and 2016*

Treatment	June		July		August		September	
	GS	BLW	GS	BLW	GS	BLW	GS	BLW
2015								
PSM	2.99 (8.0)	1.46 (1.0)	3.88 (14.0)	1.59 (2.0)	4.33 (18.0)	1.75 (2.0)	4.46 (19.0)	1.86 (3.0)
WPM	2.77 (7.0)	1.42 (1.0)	3.32 (10.0)	1.56 (1.0)	3.79 (13.0)	1.71 (2.0)	3.95 (15.0)	1.89 (3.0)
BPM	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 (0.0)
Mechanical	3.44 (11.0)	1.59 (2.0)	4.10 (16.0)	1.79 (2.0)	4.53 (20.0)	1.85 (2.0)	5.22 (26.0)	1.93 (3.0)
Chemical	2.99 (8.0)	1.32 (0.7)	4.13 (16.0)	1.60 (2.0)	4.55 (20.0)	1.71 (2.0)	5.24 (26.0)	1.92 (3.0)
Control	5.92 (34.0)	1.97 (3.0)	7.35 (53.0)	2.29 (4.0)	8.13 (65.0)	2.59 (6.0)	8.83 (77.0)	2.89 (7.0)
LSD (p=0.05)	0.09	0.04	0.13	0.05	0.21	0.05	0.28	0.11
2016								
PSM	2.80 (7)	1.45 (1)	3.60 (12)	1.82 (2)	4.37 (18)	2.21 (4)	5.01 (24)	2.23 (4)
WPM	6.93 (47)	3.00 (8)	9.55 (90)	4.16 (16)	11.86(140)	5.08 (25)	13.14(172)	5.44 (29)
BPM	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Cultivation	4.89 (23)	2.79 (7)	6.37 (40)	3.80 (14)	8.49 (71)	5.06 (25)	9.13 (82)	5.07 (25)
Chemical	4.50 (19)	2.62 (6)	5.82 (33)	3.62 (12)	8.08 (64)	4.89 (23)	8.20 (66)	4.76 (22)
Control	9.92 (98)	3.21 (9)	13.0 (168)	4.77 (22)	16.54(273)	5.81 (33)	18.61(346)	6.03 (35)
LSD (p=0.05)	0.42	0.12	0.47	0.22	0.70	0.46	0.83	0.31

*Values represent the square root transformation of actual data (in parentheses).GS: Grasses and sedges, BLW: Broad-leaf weeds, PSM: Paddy straw mulch, WPM: White polythene mulch, BPM: Black polythene mulch

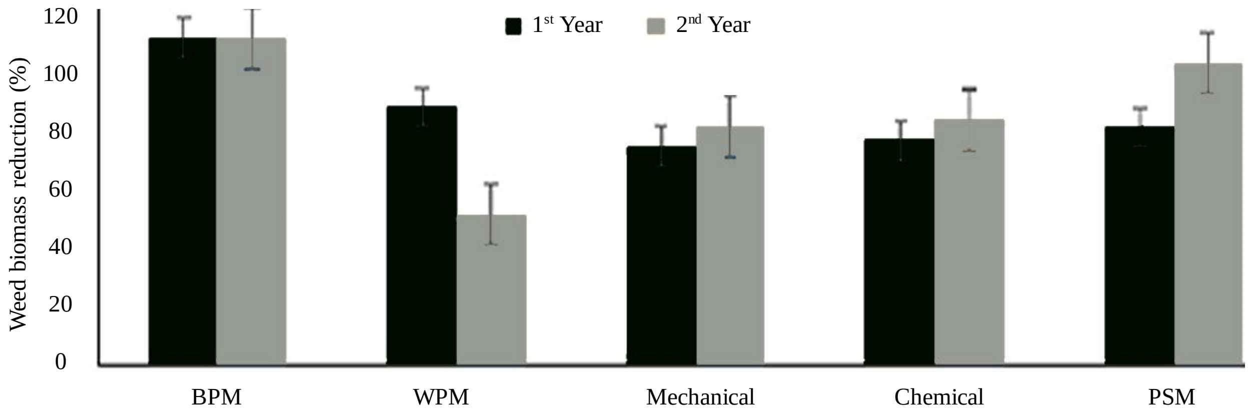

Figure 3. Reduction (%) in weed biomass under different orchard floor management treatments *vs* control during 1st and 2nd year of treatments. Vertical bars represents mean S.E. of three replications

treatments demonstrated effectiveness of BPM and PSM for weed suppression. Plastic mulches should not be used where creeping perennials are present (*e.g.*, nutsedge), since these weeds can puncture the plastic, providing light to stimulate germination of additional weeds (Smeda and Weston 1995). Shirgure *et al.* (2013) also achieved better soil-moisture conservation and weed reduction with black polyethylene mulch and grass mulching in drip irrigated Nagpur mandarin.

Covering soil under mandarin trees with two layers of cattail or rice straw mulch gave 85 to 98% weeds control (Abouziena *et al.* 2008). The inhibitory effect of organic mulch on weeds may be due to both the physical (the reduced passage of solar radiation and temperature range on soil superficial layer) effect of suppression in emergence and the possible chemical effects arising from allele chemicals released by straw that may have contributed to reduction in emergence (Oliveira *et al.* 2014). It can be concluded that the paddy straw mulching holds potential for weed management in guava orchards.

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Efficacy of post-emergence herbicides alone and as tank mixtures on weed control, growth and yield of roselle (*Hibiscus sabdariffa*)

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ABSTRACT

A field experiment was conducted during rainy season of 2010-11 and 2011-12 at Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh to evaluate the efficacy of post-emergence herbicides alone and as tank mixtures on weed control, growth and fibre yield of roselle (*Hibiscus sabdariffa*). The post-emergence treatments applied at 20 days after sowing (DAS) include, fenoaxaprop-ethyl 56, quizalofop-ethyl 50, pyrithiobac 63 g/ha alone and tank mixtures of fenoxaprop-ethyl 56 + pyrithiobac 63 g/ha, quizalofop-ethyl 50 + pyrithiobac 63 g/ha in comparison with standard herbicide, pendimethalin 750 g/ha (pre-emergence), hand weeding at 20 and 40 DAS and weedy check. All the treatments were replicated thrice in a randomized block design. Results indicated that post-emergence (PoE) tank mix application of pyrithiobac 63 g/ha with quizalofop-ethyl 50 or fenoxaprop-ethyl 56 g/ha reduced weed growth at par with pre-emergence (PE) application of pendimethalin 750 g/ha both at 60 DAS and harvest. Post-emergence application of pyrithiobac 63 g/ha either alone or as tank mixture with fenoxaprop-ethyl 56,or quizalofop-ethyl 50 g/ha caused upto 40% injury to roselle crop at 14 days after application. All the weed control treatments significantly influenced crop growth and fibre yield. Among the weed control treatments, maximum fibre yield (2.36 t/ha) and benefit cost ratio (1.65) was obtained with pre-emergence application of pendimethalin 750 g/ha and was at par with alone PoE application of fenoxaprop-ethyl 56 g/ha (2.11 t/ha) and quizalofop-ethyl 50 g/ha (2.03 t/ha). None of the treatments could reach the level of hand weeding at 20 and 40 DAS, which significantly recorded the highest fibre yield (2.91 t/ha). Season long weed competition caused 46% reduction in fibre yield of roselle. It was concluded that the pre-emergence application of pendimethalin 750 g/ha was found to be effective and economical in controlling weeds in roselle.

Keywords: *Hibiscus sabdariffa,* Post-emergence herbicides, Roselle, Tank mixtures, Weed control

Roselle (*Hibiscus sabdariffa*) is an important fibre crop in North coastal districts of Andhra Pradesh, India. Due to initial slow growth during early stage of crop, weeds effectively compete with the crop for nutrients, water *etc.* and reduce the yield upto an extent of 60% depending upon type and intensity of weed flora (Fageiry 1985 and Ghorai *et al*. 2008). Further, during rainy season due to incessant rains, inter-cultivation is not possible which also results in severe weed competition. Due to shortage of labour and increased cost of labour wages, farmers are repeatedly asking for selective post-emergence herbicides. Lack of effective herbicides and the increased risk involved in application of herbicides to roselle crop which is very sensitive to herbicides are the major bottle-necks in realization of potential yield of roselle. Though information on selectivity of some of the PE herbicides like trifluralin, pendimethalin and post-emergence herbicide like quizalofop-ethyl *etc* is available (Fageiry 1985, Ghorai *et al*. 2008) information pertaining to efficacy of fenoxaprop-ethyl, quizalofop-ethyl, pyrithiobac on roselle is scanty, particularly under local conditions of Andhra Pradesh, India. Keeping all these in view, the present investigation was undertaken to evaluate the efficacy of different post-emergence herbicides alone and as tank mixtures for broad-spectrum weed control in comparison with present recommended herbicide like pendimethalin in roselle.

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MATERIALS AND METHODS

A field experiment was conducted consecutively for two years during rainy seasons of 2010-11 and 2011-12 at Acharya N.G. Ranga Agricultural University, Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh, India. The soil of the experimental field was clay loam with a p^H of 7.8, with low in available nitrogen and phosphorus and high in available potassium. The experiment consisting of eight treatments (**Table 1**) was laid out in a randomized block design with three applications. Roselle variety '*AMV5 (Durga)*' was sown by adopting a spacing of 30 x 10 cm during last week of June 2010 (first year) and 1st week of July, 2011 (second year). The crop survived entirely on the rainfall received only during both the years (1084.1 mm in 48 rainy days during first year and 568.8 mm in 38 rainy days during second year). All the locally recommended package of practices except weed control were followed to raise the roselle crop. All the post-emergence herbicides were sprayed with knapsack sprayer fitted with a flat fan nozzle at 20 DAS as per schedule using a spray volume of 500 l/ ha. Crop injury score was assessed by visual scoring at 7 and 14 days after spraying herbicides (Rao 2000). The data on total weed density and weed dry weight per unit area were recorded at 60 days after sowing (DAS) and at harvest. The data on weed density and dry weight were subjected to square root transformation before statistical analysis to normalize their distribution (Panse and Sukhatme 1978). Economics of different treatments were calculated taking into prevailing market prices of inputs and out put.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was dominated by the natural infestation of grasses like *Echinochloa colona* (L.) Link, *Dinebra retroflexa* Jacq, *Panicum repens* L. *Dactyloctenium aegyptium* L, *Cynodon dactylon* (L) Pers, (grasses). Among broad-leaved weeds, *Phyllanthus niruri* L, *Celosia argenteaL*, *Abutilon indicum* G. Don, *Digera arvensis* Forsk, *Cleome viscosa* L., *Trianthema portulacastrum* L., *Parthenium hysterophorus* L, *Physalis minima* L, *Cynotis cucullata* Kunth were dominated and *Cyperus rotundus* L (sedge) also present but its population was negligible. Among the weed groups, broad-leaf weeds constituted 60 grasses 37 sedge 3%.

The density and dry weight of weeds were significantly reduced by all the treatments except alone PoE application of fenoxaprop-ethyl 56 g/ha and quizalofopethyl 50 g/ha compared to weedy check (**Table 1**) at both stages of observation. Among the weed control treatments, PoE tank mix application of pyrithiobac 63 g + quizalofop 50 g/ha was effective in reducing the weed growth and recorded maximum weed control efficiency (WCE) and was found to be at par with tank mix application of pyrithiobac 63 g + fenoxaprop-ethyl 56 g/ha and also with alone PoE application of pyrithiobac 63 g/ha and PE application of pendimethalin 750 g/ha. The increased weed control in these treatments might be due to effective control of weeds during the critical period of crop growth. However, none of the weed control treatments could reach the level of hand weeding at 20 and 40DAS which recorded the highest WCE at both stages of observation.

Effect on roselle crop

Among the treatments, PoE application of pyrithiobac 63 g/ha applied either alone or in combination with grassy herbicides (fenoxaprop-ethy 56 g/ha and quizalofop-ethyl 50 g/ha) resulted in severe crop injury of 40% at 14 days after application. Further, these treatments recorded lower plant height and crop dry weight compared to weedy check at both stages of observation due to crop injury (**Table 2**). Among the treatments, the maximum plant girth of 4.6 cm was recorded in the treatment PE application of pendimethalin 750 g/ha and was at par with all other treatments except with alone application of pyrithiobac 63 g/ha. Among the herbicide treatments, PE application of pendimethalin 750 g/ha significantly recorded the highest fiber yield (2.36 t/ ha) over PoE application of pyrithiobac 63 g/ha either alone or in combination with grassy herbicides, but was at par with alone application of grassy herbicides. The increased yield in these treatments

Table1. Effect of different treatments on density and dry weight of weeds in roselle (pooled data of 2 years)

Treatment	Dose (g/ha)	Time of application (DAS)	Total Weed density (no./m^2) at		Total weed dry wt. (g/m^2) at		WCE (%) at	
			60 DAS	Harvest	60 DAS	Harvest	60 DAS	Harvest
Weedy check	-	-	12.8(192.5)	8.0(80.7)	21.4(483.3)	11.0(135.7)	-	-
Hand weeding	-	20 & 40	5.9(38.2)	2.7(9.2)	5.0(32.2)	5.0(32.2)	76.6	54.5
Pendimethalin	750	pre	7.7(64.2)	5.3(39.2)	17.3(326.4)	8.3(87.3)	19.2	24.5
Fenoxaprop-ethyl	56	20	11.1(64.2)	5.9(53.0)	18.9(377.0)	10.1(128.2)	11.7	9.1
Quizalofop-ethyl	50	20	10.8(132.2)	5.8(50.0)	19.6(402.5)	9.4(118.2)	8.4	14.5
Pyrithiobac	63	20	8.8(88.8)	4.0(23.3)	16.3(280.0)	8.3(87.8)	23.8	23.6
Fenoxaprop-ethyl + pyrithiobac	56+ 63	20	8.8(87.2)	3.2(15.2)	15.0(233.8)	6.2(53.4)	29.9	43.6
Quizalofop-ethyl + pyrithiobac	50 +63	20	7.6(61.5)	3.2(11.5)	14.8(229.2)	6.1(53.2)	30.8	44.6
LSD (p=0.05)			2.22	1.73	2.90	2.27		

DAS: Days after sowing. Data transformed to $\sqrt{x+0.5}$ transformation. Figures in parentheses are original values

Table 2. Effect of different treatments on growth, yield and yield attributes in roselle (pooled data of 2years)

Treatment	Dose (g/ha)	Time of application (DAS)	Crop Injury % at 7 DAA	Crop injury % at 14 DAA	Plant height (cm)		Crop dry weight (g/m^2) at		Plant girth (cm)	Fibre yield (t/ha)	Cost of treatment (Rs/ha)	BCR (Rs/R)
					60 DAS	Harvest	60 DAS	Harvest				
Weedy check	-		0	0	95.1	218.0	340.3	1707	3.9	1.57	-	0.89s
Hand weeding	-	20 and 40	0	0	117.7	261.1	659.0	2885	5.3	2.91	9000	1.18
Pendimethalin	750	pre	5	0	100.8	236.4	512.4	2229	4.6	2.36	1050	1.65
Fenoxaprop-ethyl	56	20	0	0	92.8	230.0	451.2	1979	4.4	2.11	1050	1.37
Quizalofop-ethyl	50	20	0	0	101.0	234.6	434.5	2007	4.5	2.03	1550	1.08
Pyrithiobac	63	20	50	40	72.1	215.6	332.7	1745	4.0	1.73	1560	0.88
Fenoxaprop-ethyl + pyrithiobac	56 + 63	20	43.3	40	81.4	219.2	318.2	1779	4.5	1.73	2310	0.80
Quizalofop-ethyl + pyrithiobac	50 + 63	20	43.3	40	80.0	223.0	327.6	1851	4.3	1.83	2810	0.85
LSD (p=0.05)					11.65	16.1	86.7	431	0.57	0.42		

DAA: Days after application

might be due to effective control of weeds during the critical period as evidenced by higher WCE, which favoured the increased crop growth and ultimately on yield components and yield. None of the treatments could reach the level of hand weeding at 20 and 40 DAS which recorded the highest fiber yield (2.91 t/ha) among all the treatments under study. The uncontrolled weed growth during the crop season reduced the fiber yield to the extent of 46% corroborating with those reported by Ghorai *et al.* (2013). Further, the highest benefit cost ratio (BCR) of 1.65 was observed with the PE application of pendimethalin 750 g/ha among all the treatments because of higher fibre yield and lower cost of treatment. Though, hand weeding recorded the highest fibre yield, but BCR is lower (1.18) because of higher cost of labour involved.

Based on the present study, it was concluded that PE application of pendimethalin 750 g/ha was found to be effective and economical in controlling weeds without any crop injury in roselle as an alternative to hand weeding.

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Effect of weed management practices on productivity and profitability of jute fibre

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ABSTRACT

A field experiment was conducted at Kendrapara, Odisha to find out suitable and cost effective weed management practices for jute. Different doses of pre-emergence butachlor (both liquid and granule formulation) and post-emergence (quizalofop-ethyl) herbicides followed by (*fb*) one hand weeding (HW) were tested in jute crop and the treatment effects were compared with unweeded and two hand weeding treatments. Application of quizalofop-ethyl 60 g/ha at 20 days after crop emergence (DAE) followed by one HW at 15-20 days after herbicide application recorded higher weed control efficiency (78.3%), plant height (351 cm), basal diameter (1.40 cm) and fiber yield (2.9 t/ha) of jute as well as higher B:C ratio (2.13) compared to other weed control treatments. Values of the said parameters recorded with the quizalofop-ethyl treatment were statistically at par with those recorded with two hand weeding. Butachlor 1.5 kg/ha *fb* one HW at 20 DAE was the next best treatment with respect to weed control efficiency (68.7%), plant height (341.0 cm), basal diameter (1.39 cm), fibre yield (2.64 t/ha), and B:C ratio (1.99). Thus application of pre-emergence herbicide butachlor 1.5 kg/ha or post-emergence herbicide quizalofop-ethyl 60 g/ha in combination with one manual weeding may be recommended to the jute growers as more effective and economic weed control practices compared to the existing manual weeding practice.

Key words: Butachlor, Quizalofop-ethyl, Jute, Weed control efficiency, Weed management, Yield

Jute (*Corchorus olitorius* and *C. capsularis*) crop has become an integral part of farming in Eastern India as it provides livelihood support to about four million farm families in this region and also generates employment to the tune of 10 million paid man days (Mahapatra *et al.* 2012). In addition to its biodegradability and its ability to be used as an annual renewable resource, the short growing period (100-120 days) of jute enables the farmers to fit the crop in the prevalent rice based cropping system during the pre-*Kharif* (summer) season even under rainfed condition. Jute also helps in the maintenance of the soil productivity as it adds significant amount of organic matter along with nutrients to the soil through leaf fall during its growth (Singh *et al.* 2015). Among the various factors contributing to high production cost of jute, heavy weed infestation is a major one and manual weeding operation alone contributes to 16.3% of the total production cost (Ghimire and Thakur 2013). Sinha *et al.* (2009) had reported that at present, around 65-70% cost of production is spent for weeding and retting only. Hot and humid climate coupled with intermittent rainfall during the jute-growing season, encourages weed growth resulting in severe crop-weed competition (Kumar *et al.* 2013) and yield losses up to 75 to 80% (Sarkar *et al.* 2005, Ghorai *et al.* 2013). Though, the chemical weed control methods are very effective to control grassy weeds in jute (Ghorai *et al.* 2004, Sarkar 2006), there is lack of selective herbicides, which can control the broad spectrum weed flora in jute (Kumar *et al.* 2013). Keeping the above facts, the present experiment was conducted to develop suitable weed management practices through effective integration of pre- or post-emergence herbicides with hand weeding (HW).

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MATERIALS AND METHODS

The experiment was conducted during pre-*Kharif* seasons of 2013 and 2014 at Jute Research Station, Kendrapara, Odisha ($19^0 34'$N latitude and $86^0 30'$E longitude). The soil of the experimental plot was sandy loam, low in organic carbon (0.45%) and available nitrogen (232 kg/ha), medium in phosphorus (33 kg/ha) and high in potassium (354 kg/ha) and the pH of the soil was 4.7. The experiment was carried out in a randomized block design, with seven treatments, replicated thrice. The experimental plot size was 5 × 4 m and a space of 1.0 m was kept between the plots, blocks and also around the field. Jute cultivar '*JRO 524*' was sown at a spacing of 30

× 10 cm. Nitrogen, phosphate and potash were added 60:30:30 kg/ha during both the years of experimentation while farm yard manure was added 5 t/ha as recommended for Odisha. The crop was sown on 12th and 4th April during 2013 and 2014, respectively. Herbicides as per treatments were applied using 500 litres of water/ha with a flat fan nozzle attached in a high volume knapsack sprayer 24 hrs after sowing. Granular herbicides were applied by mixing with sand 30 kg per hectare basis. Harvesting of jute crop was done on 31st and 23rd August in 2013 and 2014, respectively. Weed samples were collected periodically with 50 × 50 cm quadrate from all the treatments, dried in shade and then were oven dried at 65 ± 5 ^{0}C and the weed biomass was expressed in t/ha. To have overall picture of ecological importance of a weed species, importance value index (IVI) of a plant species was calculated by adding relative frequency, relative density and relative dominance from the species wise weed sample collected from unweeded plot. Weed control efficiency (WCE) and weed index (WI) were calculated at the time of harvest using the formula:

WCE= $[(WD_c\text{-}WD_t) / WD_c] \times 100$ where WCE = weed control efficiency, WD_c = weed biomass in control plot and WD_t = weed biomass in treated plot

WI = $(Y_f\text{-}Y_t)/Y_f \times 100$ where WI = weed index, Y_f = yield of weed free plot, and Y_t = yield from treated plot.

Data on biological parameters such as plant height, basal diameter were recorded from ten plants randomly selected from second row of each plot at the time of harvest. Harvesting of jute crop was done on 31st and 23rd August in 2013 and 2014, respectively. The jute fibre obtained after retting were sun dried and fibre yield was expressed in t/ha. The data on weed biomass, plant height, basal diameter and fibre yield of jute were analysed statistically using ANOVA.

RESULTS AND DISCUSSION

Weed flora

A total of ten weed species were recorded in weedy plot (**Figure 1**), which comprised of four grass weeds, *viz. Echinochloa colona* (L.) Link (IVI - 47.8%), *Paspalam digitatum* L. (IVI - 27.7), *Cynodon dactylon* L. (IVI - 30%), *Eleusine indica* Gaertn (IVI - 41%); five broad-leaved weeds, *viz. Portulaca oleracea* L. (IVI- 33.1%), *Melochia corcorifolia* L. (IVI - 26.2%), *Cleome viscosa* L. (IVI - 30.3%), *Euphorbia hirata* L. (IVI - 4.1%), *Scoparia fulvis* L. (IVI - 19.7%) and only one sedge

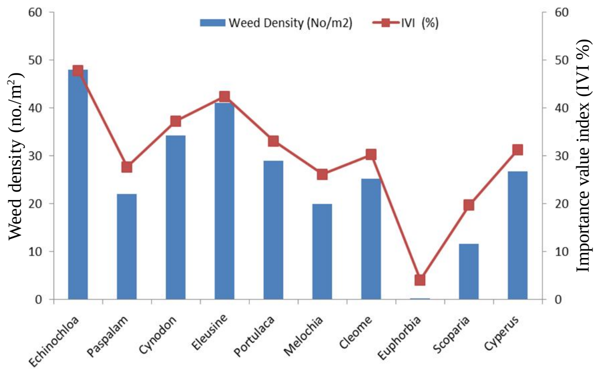


Figure 1. Weed dynamics in unweeded plot in experimental field

Cyperus rotundus L. (IVI - 26.7%). The data on weed flora indicated the dominance of grass weeds among, which *Echinochloa colona* was the most dominant one.

Effect on weeds

Weed biomass increased with increase in crop growth in unweeded plot and it reached up to 0.89 - 0.93 t/ha at 45 DAS which resulted in higher weed index (35.36) in this treatment **(Table 1).** The vigorous growth of weeds in the control plots resulted in increased competition with jute crop for natural resources like sunlight, soil nutrient and moisture, which finally led to highest weed index during both the years. All weed control treatments significantly (p=0.05) reduced the weed biomass at 30 and 45 DAS compared to unweeded control. Application of quizalofop-ethyl 60 g/ha *fb* one HW significantly (p=0.05) reduced the weed biomass as compared to the remaining treatments, though, it was at par with two hand weeding treatment. Pre-emergence application of butachlor (EC) 1.0 or 1.5 kg/ha *fb* one HW also reduced the weed density in the early growth stages of jute but the second flush of weeds emerged thereafter in the butachlor treated plots. Butachlor (EC) at a higher dose (1.5 kg/ha) was also found more effective in controlling weeds compared to recommended doses of butachlor (1.0 kg/ha) or its application in granular form. The superiority of quizalofop-ethyl (60 g/ha) over butachlor (both in liquid or granular form) may be attributed to the fact that the experimental plots were dominated with grass weeds. Similar results were observed earlier in jute by Ghorai *et al.* (2013, 2013a, 2014) and in ramie by Kumar *et al.* (2015a). Weed control efficiency (WCE) of the treatments tested varied from 63.2 to 78.7% with two hand weeding and quizalofop-ethyl treatment showing the much higher WCE value (78.5–78.7%) as both the treatments provided more weed free situation to the

Table 1. Effect of weed management practices on weed biomass at different crop growth stages

Treatment	Weed biomass (kg/ha)						WCE (%)	WI
	15 DAS		30 DAS		45 DAS			
	2013	2014	2013	2014	2013	2014		
Butachlor 50% EC 1.0 kg/ha as PE + one HW at 20 DAE	116	114	134	139	233	243	67.9	11.6
Butachlor 50% EC 1.5 kg/ha as PE + one HW at 20 DAE	106	110	144	149	221	225	68.7	8.85
Butachlor 5G 1.0 kg/ha as PE + one HW at 20 DAE	123	122	173	179	258	266	63.24	12.25
Butachlor 5G 1.5 kg/ha as PE + one HW at 20 DAE	120	119	166	177	239	256	64.2	10.6
Quizalofop-ethyl 5% EC 60 g/ha + sticker 1 ml/ L at 15 DAE + one hand at 15-20 days after herbicide application	158	158	115	112	64	63	78.5	0.0
Unweeded check	160	197	399	415	890	933	0.0	35.56
Two hand weedings weeder at 20 DAE and 40 DAE	139	141	129	133	54	55	78.7	3.94
LSD (p=0.05)	40	31	43	43	65	77	-	-

PE: Pre-emergence; HW: Hand weeding; DAE: Days after emergence of crop; WCE: Weed control efficiency, WI: Weed index

jute crop compared to the rest of the weed control treatments (**Table 1**). Interestingly, application of butachlor (EC) 1.5 kg/ha followed by one HW also showed 68.7% WCE possibly due to suppression of most of the grassy/narrow leaved weeds, which constituted the major share of total weed density. Effective control of grass weed and some broad-leaved weed through application of butachlor (EC) as pre-emergence herbicide followed by one hand weeding had also been reported earlier in jute (Ghorai *et al.* 2013).

Effect on crop growth and fibre yield

The yield attributes (basal diameter and plant height) as well as fibre yield of jute crop was significantly influenced by the various weed control methods as all the weed control treatments significantly (p=0.05) increased the plant height, basal diameter and fibre yield of the crop over un-weeded control in both the years (**Table 2**). Maximum values of fibre yield of jute was recorded with the plots receiving quizalofop-ethyl treatment during the individual years (2.85 - 2.94 t/ha) followed by two hand weeding (2.74 - 2.75 t/ha) and butachlor (EC) (butachlor 1.5 kg/ha + 1 HW at 20 DAS) (2.59 - 2.68 t/ha). Similar trend was observed in the pooled data also. Maximum value of plant height in jute was recorded with two hand weeding treatment followed by quizalofop-ethyl treatment while the latter recorded maximum values of basal diameter of the crop during both the years (**Table 2**). The results indicated that all the weed control treatments were almost equally effective in controlling the weed growth thereby minimizing the crop – weed competition. The relatively higher fibre yield of jute recorded with quizalofop-ethyl or butachlor (EC) at higher dose (1.5 kg/ha) was possibly due to better control of grassy weeds as compared to other herbicides under study. A negative correlation was observed between weed biomass and fibre yield of jute (**Figure 2**). The regression equation clearly showed that an increase of 0.1 t/ha in weed biomass resulted in decrease of fibre yield by 0.095 and 0.12 t/ha in 2013 and 2014, respectively. The results corroborated the earlier findings of Kumar *et al.* (2015).

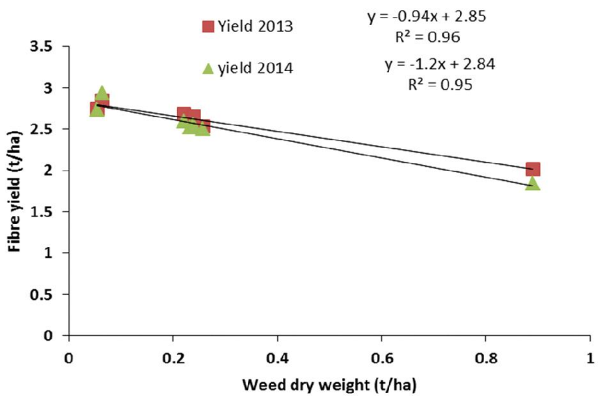


Figure 2. Regression analysis of weed biomass and fibre yield

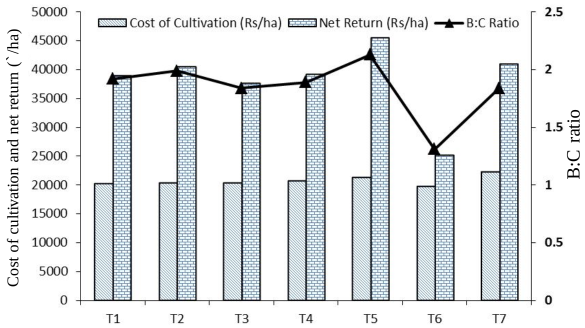
Economics

Application of pre- and post-emergence herbicides followed by one hand weeding recorded significantly higher return over unweeded control and were also comparable to two hand weeding (**Figure 3**). Highest net return (` 45,400/ha) and B:C ratio (2.13) were observed with post-emergence application of quizalofop-ethyl (60 g/ha) + one HW treatment followed by butachlor (EC) (1.5 kg/ha) + 1 hand weeding at 15 DAE (` 40390/ha and 1.98, respectively). The results were in accordance with the findings of Alam *et al.* (2010), who also observed that herbicide application followed by one hand weeding lead to effective weed control along with increased yield as well as better economic return.

Table 2. Effect of weed control treatments on yield attributes and fibre yield of jute

Treatment	Plant height (cm)		Basal diameter (cm)		Fibre yield (t/ha)		
	2013	2014	2013	2014	2013	2014	Pooled
Butachlor 50% EC 1.0 kg/ha as PE + one HW at 20 DAE	335.7	330.0	1.32	1.31	2.62	2.52	2.57
Butachlor 50% EC 1.5 kg/ha as PE + one HW at 20 DAE	341.7	343.0	1.29	1.39	2.68	2.59	2.64
Butachlor 5 G 1.0 kg/ha as PE + one HW at 20 DAE	336.3	341.3	1.17	1.38	2.53	2.50	2.52
Butachlor 5 G 1.5 kg/ha as PE + one HW at 20 DAE	334.0	331.0	1.23	1.33	2.65	2.55	2.60
Quizalofop-ethyl 5 % EC 60 g/ha + sticker 1 ml/ L at 15 DAE + one hand at 15-20 days after herbicide application	343.7	358.3	1.31	1.49	2.85	2.94	2.89
Unweeded check	309.3	297.0	1.01	1.12	2.02	1.84	1.93
Two hand weedings weeder at 20 DAE and 40 DAE	347.7	352.6	1.28	1.44	2.75	2.74	2.74
LSD (p=0.05)	15.55	35.5	0.215	0.12	0.55	0.55	0.36

PE: Pre-emergence; HW: hand weeding; DAE: Days after emergence of crop



(T_1: Butachlor 50% EC 1.0 kg/ha + 1 HW at 15 DAE; T_2: Butachlor 50% EC 1.5 kg/ha + 1 HW at 15 DAE; T_3: Butachlor 5G 1.0 kg/ha +1 HW at 15 DAE ; T_4: Butachlor 5G 1.5 kg/ha + 1 HW at 15 DAE ; T_5: Quizalofop-ethyl 60 g/ha at 20 DAE +1 HW at 15 days after herbicide application ; T_6: Un weeded check ; T_7: Two HW)

Figure 3. Economics of different weed management practices

It was concluded that application of pre-emergence herbicide butachlor (EC) 1.5 kg/ha followed by one hand weeding at 15 DAE or application of post-emergence herbicide quizalofop-ethyl 60 g/ha with one hand weeding at 15 days after herbicide application effectively controlled the weeds, increased fibre productivity and profitability in jute cultivation.

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Germination ecology of wrinkle grass (*Ischaemum rugosum*) population of Indo-Gangetic plain region

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ABSTRACT

Wrinkle grass (*Ischaemum rugosum* Salisb.) is a highly competitive weed in rice production that can cause huge yield reductions. Information on germination ecology of this weed is essential for the development of effective integrated weed management systems. No information is available on germination ecology for populations of this weed from Indo-Gangetic plain region of India. This study was conducted to generate information on effects of major environmental factors, *viz*. light, temperature, burial depth, moisture, salinity and pH on germination/emergence of this weed. Seed germination was independent of light and more than 50% germination was recorded under a wide temperature range of 20/10 to 35/25 °C day/night (12/12 h). Maximum emergence was observed when seeds were placed on surface or buried up to 1 cm; but considerable emergence was also observed from deeper soil layers (up to 6 cm depth). Germination was above 75% at 160 mM but completely inhibited at 320 mM of NaCl. Germination was sensitive to moisture stress and was completely inhibited at water potential of -0.8 MPa. Seeds were able to germinate under wide pH range of 3-10.

Key words: Burial depth, Germination, *Ischaemum rugosum*, Light, pH, Salinity, Temperature

Weed infestations are the major biotic constraints in the rice production. Globally, weeds are estimated to account for 32% potential and 9% actual yield losses in rice (Oerke and Dehne 2004). Depending on ecological and climatic conditions, weeds can reduce rice yields by 45-95% (Manandhar *et al.* 2007). Yield reductions due to weed competition vary under different rice establishment systems. Singh *et al.* (2005) estimated 76, 71 and 63% rice yield reduction due to weeds in dry-seeded, wet-seeded and transplanted rice, respectively. Herbicides have been the major tool for weed control in rice in Indo-Gangetic plains region (IGPR) particularly in north western India. Even after herbicide applications, weeds can decrease rice yield by 10-30% (Hossain *et al.* 2016). Escaped weed plants need to be removed by manual labour, which is impractical owing to labour scarcity and rising labour wages in the region. Continuous use of herbicides with similar mode of action has resulted in the evolution of herbicide resistance in barnyard grass (*Echinochloa crus-galli*) and wrinkle grass (Iwakami *et al.* 2015, Plaza and Hernandez 2014). To counter these problems, it is necessary to develop sustainable weed management systems that may reduce both herbicide dependency and the burden of manual weeding.

Wrinkle grass (*Ischaemum rugosum* Salisb.) is an annual grass weed that is native to tropical Asia but has invaded rice fields in South Asia and Africa (Holm *et al.* 1977). At its vegetative stage, this weed resembles the rice plant, making it difficult to distinguish (Ampong-Nyarko and De Datta 1991). It is a highly competitive weed in rice production and can cause up to 48% yield reductions (Lim *et al.* 2015). Limited herbicide options like anilophos as pre- and fenoxaprop and cyhalofop as post-emergence are available for its control in rice (Duary *et al.* 2015). Many of the commonly used herbicides in rice like butachlor, pendimethalin, pretilachlor, pyrazosulfuron and oxadiargyl provide poor control of this weed (Anonymous 2015). Due to labour and water scarcity, IGPR farmers are shifting from puddled transplanted rice (PTR) to dry-direct seeded rice (DSR). In PTR, ponding of water serves as an effective weed control measure against emergence of wrinkle grass, but this weed control tool is missing in DSR resulting in more weed competitiveness (Lim *et al.* 2015). Continuous depletion of ground water in IGPR is further complicating the weed problem in PTR, as it becomes difficult to obtain enough water resulting in aerobic weeds like wrinkle grass appearing in PTR fields (Bhatt *et al.* 2016).

Information on germination ecology may identify the weakest link in the life-history of a weed which is essential for the identification and development of effective integrated weed management systems for better weed control (Bhowmik 1997). Seed germination is the first stage at which the weed can compete for an ecological

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niche and is mediated by various environmental variables such as temperature, light, pH, soil salinity and moisture (Chachalis and Reddy 2000). Competitiveness of any weed species in an agro-ecosystem depends on the ability of seeds to germinate in response to different environmental factors. The requirement for light is the principal means by which germination may be restricted to an area close to the soil surface and species requiring light for germination are likely to be more prevalent in no-till cropping systems (Cousens *et al.* 1993). Temperature is an important factor for successful seed germination; some weeds may germinate over wide range of temperature while others require narrow temperature range for germination (Shoab *et al.* 2012, Derakhshan and Gherekhloo 2013). Soil pH, salinity and moisture stress are other environmental factors affecting seed germination and thus distribution of various weeds. Information on germination ecology has been available for wrinkle grass populations belonging to Malaysia (Bakar and Nabi 2003) and Philippines (Lim *et al.* 2015), but no such information is available for weed populations from Indian IGPR. Knowledge of the response of wrinkle grass to environmental factors will help to bring a broader perspective for its effective management and in predicting its potential to spread. This study was conducted to enhance our understanding of the role of temperature, light, moisture, salinity, pH and soil depth in germination ecology of wrinkle grass population from Indian IGPR.

MATERIALS AND METHODS

Wrinkle grass seeds were collected from several rice fields of Punjab Agricultural University, Ludhiana, India (30°56' N and 75°52' E). Cleaned seeds were stored at room temperature in air tight plastic containers. The 1000-seed weight was 3.70 ± 0.28 g.

Germination protocol: Before initiating laboratory and field experiments, wrinkle grass seeds were tested for viability using 1% tetrazolium chloride solution (Steadman 2004) and seeds possessed more than 95% viability. Uniform-sized seeds were surface sterilized using 0.1% mercuric chloride for 2 min, followed by thorough washing with distilled water to protect against any fungal infection (ISTA 2010). Seed germination was tested in 3 replicates with 30 seeds placed evenly on Whatman No.1 filter paper in 9-cm petri dishes. For studying the effect of light, moisture stress, salinity and pH, petri dishes were moistened with 5 ml of treatment solution and incubated at 30/20 ^{o}C day/night (optimal temperature) in an environmental chamber (Model MAC MSW-127, Delhi, India). For control treatment, seeds were germinated using distilled water.

Light and temperature experiment: The germination of seeds was tested under fluctuating day/night temperatures (12/12 h), *viz.* 15/5, 20/10, 25/15, 30/20, 35/25 and 40/30 °C and two light regimes – light/dark for day/night environments (12/12 h) and continuous dark (24 h). For continuous dark treatment, Petri dishes were immediately wrapped in double layers of aluminum foil after adding water to prevent light penetration; and germination count was taken on 15th day only.

Burial depth experiment: This experiment was conducted using 25-cm plastic pots placed under field conditions during months of June to August. Soil used in pots was collected from fields which had no previous incidence of wrinkle grass. Fifty seeds were sown on the soil surface in pots and covered to a depth of 0, 1, 2, 4, 6, 8 and 10 cm. The pot surface was kept moist throughout the study period. Emergence of wrinkle grass was recorded daily for one month. One set of 3 pots was not seeded to test for presence of wrinkle grass in the field soil. This experiment was repeated thrice using four replications each time.

Moisture and salinity experiment: The germination response of seeds under different levels of simulated moisture stress (0, -0.1, -0.2, -0.4, -0.6, -0.8 and -1.0 MPa) was tested using solutions of PEG 8000 prepared according to equations of Michel and Kaufmann (1973). The germination ability of seeds under different levels of salt stress was examined using NaCl solutions of 1, 10, 20, 40, 80, 160, 240, 320, 400, 450 and 500 mM concentrations.

pH experiment: The effect of pH on seed germination was investigated using buffered solutions with pH ranging from 3 to 10 (Chachalis and Reddy 2000). A 2 mM potassium hydrogen phthalate buffer solution was adjusted to pH 3 and 4 with 1 N HCl. Buffer solutions of pH 5 and 6 were prepared using 2-mM solution of MES [2-(N-morpholino) ethane sulfonic acid] adjusted with 1 N HCl or NaOH. A 2-mM HEPES [N-(2-hydroxymethyl) piperazine-N'-(2-ethane sulfonic acid)] solution was adjusted to pH 7 or 8 and 2-mM tricine [N-tris-(hydroxymethyl) methylglycine] buffer solution was adjusted to pH 9 or 10 with 1 N NaOH. Unbuffered distilled water (pH 6.6) was used as control.

Except for continuous dark treatment, germination counts were recorded at 24-h intervals for 15 days after start of the experiment, with the criterion for germination being visible protrusion of the radicle. Germination (%) was calculated as: Percent germination= (number of seeds germinated / total number of seeds sown) × 100.

Speed of germination (germination index, GI) was calculated as described by the Association of Official Seed Analysts (1983) using the following formula:

$$GI = \frac{\text{No. of germinated seeds}}{\text{Days of first count}} + \cdots\cdots\cdots + \frac{\text{No. of germinated seeds}}{\text{Days of final count}}$$

Seedling vigor index (SVI) was calculated using the formula given by Abdul Baki and Anderson (1973):

Seedling vigor Index (I) = seedling length (cm) x germination (%)

Statistical analysis: All experiments were repeated three times in a completely randomized design. There were no significant differences among the results of repeated experiments, so data were pooled and analyzed (ANOVA) using statistical analysis software version 9.2 (SAS 2009). Means were separated at $\alpha \leq 0.05$ using Fisher's Protected Least Significant Difference (LSD) test (Cochran and Cox 1957).

RESULTS AND DISCUSSION

Effect of light

Wrinkle grass germinated under complete darkness indicating that germination of this weed was independent of light. The seedlings that germinated under complete darkness were etiolated having elongated and chlorotic shoots. Seed germination response to light may vary considerably from species to species. Seeds of some species like Chinese sprangletop (*Leptochloa chinensis*), rice flatsedge (*Cyperus iria*) and grass like fimbry (*Fimbristylis miliacea*) have an absolute requirement of light to germinate (Chauhan and Johnson 2008, 2009a) while for others like natalgrass (*Melinis repens*), light is not a pre-requisite for the germination (Strokes *et al.* 2011). Light is an important ecological determinant for germination, and the absence of light acts as a soil depth indicator that prevents germination of many weed species (Crisraudo *et al.* 2007). However, biotypes of a species in different geographical regions may vary in their response to light, as in the present study germination of this wrinkle grass population from IGPR was independent of light but Malaysia and Philippine populations did not germinate under complete darkness ((Bakar and Nabi 2003, Lim *et al.* 2015).

Effect of temperature

Wrinkle grass seeds of this IGPR population germinated best in the temperature regime of 30/20°C day/night (**Table 1**); however, seeds were able to germinate under a wide temperature range from15/5 to 35/25°C. The highest value of germination index (important indicator of germination speed) was recorded in diurnal temperature regime of 30/20°C day/night followed by 35/25°C. Seedlings grown at 30/20°C also exhibited greatest seedling vigor index indicating their higher competitiveness than seedlings grown at other temperatures. The weed did not germinate at 40/30°C. Temperature is an environmental factor that can influence emergence patterns and timing of seed germination (Derakhshan and Gherekhloo 2013). In IGPR, direct-seeded rice is planted in the months of May-June when mean day and night time temperature lies between 25-35°C (Gill and Kingra 2011), so emergence of wrinkle grass may occur along with rice seedlings and thus may compete during early establishment period of rice. Temperature during the months of July-August also ranges between 30-35°C and moisture also is not likely to be a constraint both in DSR and PTR situations. Therefore emergence of many flushes of this weed may be expected during the rice season in IGPR owing to its ability to germinate in wide temperature range of 15/5 to 35/25°C day/night.

Effect of burial depth

Wrinkle grass seeds exhibited maximum emergence at 0-1 cm depth (**Figure 1**). At 4 cm depth, emergence was reduced by about 50% compared to surface placed seeds. Emergence was 22% when placed at 6 cm depth and no emergence was recorded when seeds were buried at 8 cm. Apparently, this weed can germinate from deeper soil layers as its germination can take place in complete absence of light. This IGPR population exhibited 66.5% emergence when seeds were buried at 2 cm depth. In contrast to our results, the germination of wrinkle grass population of Philippines was

Table 1. Effect of temperature on germination and seedling growth of wrinkle grass

Temperature (°C) Day/night (12/12 h)	Germination (%)	Germination index	Seedling vigor index (I)
15/5	20	0.32	99.7
20/10	60	1.8	673.8
25/15	82.2	4.0	1071.5
30/20	95.5	6.1	1547.4
35/25	80.0	4.4	1145.8
40/30	0	-	-
LSD (p=0.05)	9.52	0.29	66.5

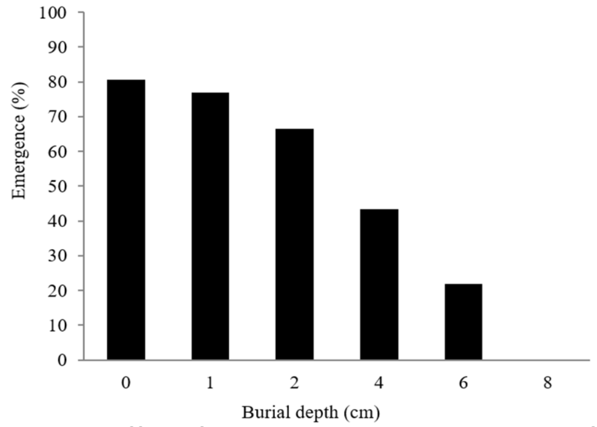

Figure 1. Effect of burial depth on emergence (%) of wrinkle grass

completely inhibited at a depth of 2 cm (Lim *et al.* 2015) indicating differential germination requirements of different populations of this weed. The requirement of light and limited availability of storage reserves are two major constraints for reduced emergence of weeds from deeper soil layers (John Bullied *et al.* 2012). In case of our population, germination was independent of light and owing to the bigger seed size of this population (1000 seed weight is 3.70 g); this weed emerged even when buried deep in the soil profile. It may be that Philippine populations have light requirements for germination or it had limited seed reserves or both (information regarding seed size of Philippines population is not available with us), factors which inhibited seed emergence from deeper soil layers. Wrinkle grass population of IGPR can germinate from deeper soil layers unlike other grass weeds of rice such as Chinese sprangletop (*Leptochloa chinensis*) which cannot emerge from soil layers deeper than 0.5 cm (Chauhan and Johnson 2008), and crowfoot grass (*Dactyloctenium aegyptium*) that exhibits only 10% emergence at 4 cm depth (Chauhan 2011). These findings indicate that emergence of this weed is not influenced by different tillage practices practiced in the IGPR and this plant can become problematic both under conventional and zero tillage systems.

Effect of salinity

Salinity stress reduced germination, germination speed and seedling vigor index starting at 10 mM NaCl (**Table 2**). Germination was completely inhibited at 320 mM of NaCl. The NaCl concentration required for 50% inhibition of maximum germination was 168 mM (**Figure 2**). This IGPR population of wrinkle grass exhibited 75.5% germination at 160 mM NaCl in contrast to Philippines population of this weed whose germination was completely inhibited at 150 mM NaCl indicating differential salt tolerance of

Table 2. Effect of sodium chloride on seed germination and seedling growth of wrinkle grass

Sodium chloride (mM)	Germination (%)	Germination index	Seedling vigor index I
10	92.2	11.8	758.9
20	87.8	11.4	640.5
40	86.1	9.63	613.5
80	77.8	9.03	554.9
160	75.5	7.00	392.3
240	17.8	0.565	40.2
320	0	0	0
Control	98.9	13.4	923.5
LSD (p=0.05)	4.73	0.881	89.7

different biotypes of same weed (Lim *et al.* 2015). Considering the seed production potential of this weed which is about 4000 seeds per plant (Holm *et al.* 1977) and ability of this population to exhibit 18% germination even at 240 mM NaCl, it can become a problematic weed even in salinity affected areas of the state. Many other weeds of rice-wheat cropping systems like junglerice (*Echinochloa colona*), common purslane (*Portulaca oleracea*) and little seed canary grass (*Phalaris minor*) have also been reported to be salt tolerant and can germinate when exposed to NaCl concentrations higher than 100 mM (Chauhan and Johnson 2009b, 2009c, Sethi and Kaur 2016). This shows that many of the weeds can germinate and grow under adverse environmental conditions where crops may have to encounter not only harsh environmental conditions but also intense weed competition.

Effect of moisture stress

Germination of wrinkle grass was sensitive to moisture stress with complete inhibition at a water potential of -0.8 MPa (**Table 3**). At -0.4 MPa,

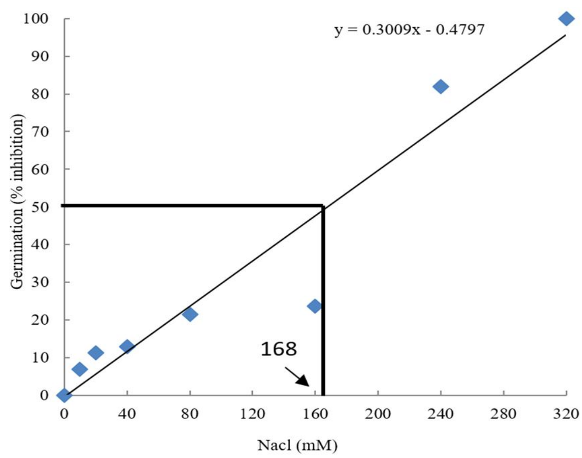

Figure 2. Effect of NaCl on germination of wrinkle grass. The NaCl concentration (168 mM) required to inhibit 50% of maximum germination is shown by an arrow

Table 3. Effect of moisture stress on seed germination and seedling growth of wrinkle grass

Osmotic potential (MPa)	Germination (%)	Germination index	Seedling vigor index (I)
-0.1	86.7	11.0	682.3
-0.2	76.7	8.09	562.3
-0.4	63.3	6.13	394.5
-0.6	57.8	4.47	271.5
-0.8	0	0	0
Control	96.7	12.9	963.8
LSD (p=0.05)	4.97	0.872	66.8

germination was reduced by 33.4% with germination speed reduced to half and seedling vigor reduced by more than half as compared to their respective controls. Like this IGPR wrinkle grass population, germination of Philippine populations of this weed were also completely inhibited at -0.8 MPa. Wrinkle grass populations of Philippines exhibited 31.5, 3.5 and 3.5% compared to 86.7, 63.3 and 57.8% germination of this IGPR population at -0.1, -0.4 and -0.6 MPa, respectively (Lim *et al.* 2015). Germination of major paddy weeds like crowfoot grass and junglerice has also been reported to be very sensitive to water stress which exhibit complete germination inhibition and only 1% germination at -0.8 MPa, respectively (Chauhan and Johnson 2009b, Chauhan 2011).

Effect of pH

The seeds of wrinkle grass were able to germinate over a pH range of 3-10. Germination of wrinkle grass at neutral pH buffer was at par with control (distilled water having pH 6.6) and it was 85.5%. Although, there was a decrease in germination with either increases or decreases in pH, wrinkle grass was able to maintain more than 50% germination under wide pH range of 3-10 except at pH 3, where it exhibited 47% germination (**Table 4**). Acidic pH proved to be more detrimental to seedling growth and vigor as compared to alkaline pH. Germination speed and seedling vigor index were maximum in control and minimum at pH 3. At pH 3, seedling vigor was reduced by 98% as compared to their control and only emergence of radicle without any shoot was exhibited by wrinkle grass seedlings. Ability of wrinkle grass to germinate under wide pH range of 3-10 indicates that this weed can become problematic in soils having extremes of pH. Germination of some weeds like slender amaranth (*Amaranthus viridis*) and coffee senna (*Cassia occidentalis*) is very sensitive to pH and can germinate only within a narrow pH range (Norsworthy and Oliveira 2005, Thomas *et al.* 2006) but other weeds like turnip weed (*Rapistrum rugosum*), cadillo (*Urena lobata*) and alien weed

Table 4. Effect of pH on seed germination and seedling growth of wrinkle grass

pH	Germination (%)	Germination index	Seedling vigor index (I)
3	46.7	5.9	16.2
4	55.5	6.2	216.4
5	54.4	5.8	510.5
6	72.2	8.9	624.4
7	85.5	10.7	845.7
8	75.5	8.7	820.0
9	74.4	8.0	637.3
10	67.7	7.7	580.2
Control (6.6)	90.4	12.3	880.0
LSD (p=0.05)	5.63	1.86	105.2

(*Tridax procumbens*) possess the ability to germinate under wide pH range from pH 4-10 (Chauhan *et al.* 2006, Wang *et al.* 2009, Vanijajiva 2014).

Seed germination is one of the most critical life events for the success of any plant species because it represents the first stage at which they can compete for an ecological niche. Germination is mediated by various environmental variables such as temperature, light, pH, soil salinity and moisture (Chachalis and Reddy 2000). Germination of the IGPR wrinkle grass population is independent of light which enables this weed to emerge not only from surface but also from deeper soil layers. Germination of this weed is sensitive to moisture stress but can occur in a wide temperature range of 20/10 to 35/25°C day/night (12/12 h), so it can germinate whenever it will encounter favorable moisture conditions in rice season of IGPR. This weed is able to germinate under high salinity conditions and wide pH range of 3-10 indicating that it may emerge as a very competitive weed even in saline, acidic and alkaline soils. Because of its high seed production potential (4000 seeds per plant), extra care should be taken by those farmers who have shifted or are shifting towards direct-seeded rice to remove this plant before seed production in order to prevent the buildup of soil seed bank of this weed. Alternatively using a stale seed bed technique before crop establishment might help in exhausting the existing seed bank of wrinkle grass.

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Phototransformation of isoproturon in soil

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ABSTRACT

The present experiment was conducted with an objective to reveal the photochemical behaviour of isoproturon on different soil surfaces, *viz.* red, black and alluvial soil under sunlight. The half-life values of isoproturon on glass surface was found as 25.38 days. But on soil surfaces, the rate of photolysis was changed with half-life values of 20.76, 27.38 and 28.02 days under sunlight for red, black and alluvial soil, respectively. The slower reaction rate on the surfaces of black and alluvial soil was due to the quenching effect imparted by humic substances, which were absent on glass surface and less in red soil. The sunlight-irradiated extracts of isoproturon and its degradation products were analysed by LC-MS/MS using electrospray interfacing technique and the structures of six different photoproducts were characterised by their respective spectra as 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-hydroxymethylurea (I), 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-(*N,N*-dimethylcarbamoyl)urea (II), 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-(*N*-methylcarbamoyl)urea (III), 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-carbamoyl urea (IV), *N*-dimethyl-*N′*-methyl urea (V), *N*-dimethyl-*N′*-dimethyl urea (VI). The products were mainly formed through demethylation, ring oxidation and rearrangement. Thus, sunlight induced photodegradation may contribute in the dissipation of isoproturon in soil minimising the load of environmental hazards.

Key words: Dissipation, Isoproturon, Phototramsformation, Soil

Isoproturon, (3-(4-isopropylphenyl)-1,1-dimethyl urea) is a widely used herbicide for the weed management in wheat (*Triticum aestivum*). It kills broad-leaved weeds like *Phalaris minor* and *Avena ludoviciana* by inhibiting photosynthetic electron transport. The fate and toxicology of isoproturon are well documented. Its half-life ($T_{1/2}$) values in soil were observed to be 40 and 15 days, respectively in temperate and tropical climates (Kulshrestha and Muckerjee 1986). It undergoes slow hydrolysis in water with a half-life of 30 days (The WHO 2003). Due to its considerable persistency and mobility in soil, it carries the risk contaminating ground and surface water. The residues of isoproturon was detected in the ground water of different countries (Stuart *et al.* 2011). The degradation of this herbicide in soil may only minimise the risk of ground water contamination. In soil, it degrades mainly through microbial action generating non-toxic or less toxic degradation products (Sorensen and Aamand 2001, Sorensen *et al*. 2003). The rate of degradation of isoproturon by microbes may depend on the soil pH (Bending *et al*. 2003). Dureja *et al.* (1991) observed that the process of photolysis also plays a vital role on its degradation in water and identified 11 photoproducts in an aqueous solution irradiated under pure UV light within the range of 254 and 360 nm. The rate of photolysis of isoproturon is higher in organic solvent like methanol than that in water (de Saint-Laumer 1997). Thus in liquid phase, the role of photo-chemical reaction in the degradation of isoproturon was well investigated. Whereas no such thorough report on the photolysis of this herbicide in soil is available so far. Keeping this in view, an investigation was carried out on the photolysis of isoproturon under sunlight in different soils to find out the rate of degradation and to identify the various products thus formed.

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MATERIALS AND METHODS

Analytical grade isoproturon (99% purity) was procured from Sigma-Aldrich and used without further purification. Technical grade isoproturon (purity 96%) was procured from industry and purified further by silica gel-based column chromatography followed by repeated crystallization from cold ethanol until a constant melting point of 157^0C was achieved. Purity was checked by HPLC analysis comparing with analytical grade of it. Laboratory grade reagents and solvents were procured from Merck India, Mumbai. All solvents were dried and distilled before use. HPLC-grade solvents and reagents were used during chromatographic and spectroscopic analysis. Deionized water was obtained from the Milli-Q SP Reagent water system (Millipore).

The alluvial, black and red soils used in this study were collected from the field of ICAR-IGFRI, Jhansi; ICAR-DWR, Jabalpur; and UAS, Bengaluru, respectively. The soils were air-dried and sieved through a 2 mm sieve. The physico-chemical properties of the soils (**Table 1**) were analysed by following standard procedures (Reeuwijk 2002).

Preparation of soil thin film: Thin films of soil were prepared from a suspension of 1 g soil in 2 ml of distilled water in the glass petridishes of 55 mm radius and air dried. All the surfaces, soil coated glass and non coated glass were coated uniformly with 1 ml of 10 µg/ml solutions of isoproturon in hexane.

Exposure of isoproturon on thin film under sunlight: For rate kinetic study, the thin films of isoproturon on soil and glass surfaces were irradiated under sunlight in cloudless days in the months of April and May between 9.30 am to 5.30 pm (8 h per day). The temperature during the irradiation varied at the test surface between 30 and 35^{0}C in sunlight. Samples from each surface were taken in triplicate at intervals of 0, 3, 6, 9, 15 and 21 days from initiation of exposure under sunlight. A set of 3 replications of each surface was kept under dark condition. For the photoproduct formation study, isoproturon was irradiated on the thin film of black soil under sunlight for 15 days following similar conditions maintained during the rate kinetic study.

Sample preparation and extraction procedure: Soil samples from each plate were scratched and collected in a 50 ml Erlenmeyer flask together with 15 ml acetone. It was shaken for 30 minutes and filtered in 100 ml round bottom flask using a 2µ filter paper. The process was repeated twice with the remaining soil in the Erlenmeyer flask and the filtrates were pooled together each time and concentrated under vacuum to a volume of 2 to 3 ml portion. It was then poured into a 25 ml separatory funnel containing 5 ml of 5% NaCl solution. The round bottom flask was washed with 10 ml of hexane that was added into the separatory funnel. It was shaken vigorously for about 2 minutes. The hexane layer was collected in round bottom flask. The process was repeated twice and the hexane layer was pooled together each time. The solution in hexane was then reduced to dryness at 45^{0}C and collected in spectroscopic grade methanol in water (60:40) of known volume. The samples from glass surface were directly taken in spectroscopic-grade methanol in water (60:40).

In order to standardise the extraction procedure a separate set of extraction and cleanup of samples was carried out with the isoproturon fortified sample of alluvial, black and red soil. Following the above mentioned extraction procedures, the recoveries of isoproturon were found to be 89.68 $\pm$ 5.57% from alluvial soil, 87.84 $\pm$ 3.38% from black soil, 92.22 $\pm$ 2.13% from red soil and 97.39 $\pm$ 1.09% from the glass surface.

For the isolation of photoproducts, the irradiated soil samples were extracted in ethyl acetate. The solvent was evaporated to dryness. It was then collected in spectroscopic grade acetonitrile, cleaned up through nylon-made membrane filters of 0.45 µm pore size and concentrated for mass analysis by LC-MS/MS.

Analysis of samples for rate kinetic study: For the rate kinetic study, the quantity of isoproturon extracted from each thin film was estimated on a Shimadzu LC 8A isocratic HPLC apparatus equipped with a photo diode array detector. The analysis of isoproturon was performed on a stainless steel column 250 mm long, 4.6 mm internal diameter filled with octadecyl silane chemically bonded to porous silica particles of 5 µm diameter (ODS, C18, 5µ, 250 × 4.6 mm id). The eluent was a methanol/water mixture in 60/40 (v/v) proportion. The flow rate of the solvent was maintained at 1 ml/minute and the eluent was monitored at the wavelength of 240 nm. A calibration was made for concentrations between 0.2 ppm and 1.4 ppm isoproturon with a linearity of R^2 = 0.9983.

Analysis of samples for the study on photoproduct formation: For the structural elucidation, products in the extract were characterized by LC-MS/MS. An API 3200 Qtrap mass spectrometer (AB Sykes Pvt. Ltd.) was used for the mass characterization of degraded products. Mass spectrometry analysis was performed with the electrospray ionization (ESI) in positive (5500 eV) mode for each sample. The nebulizer and heater gases were adjusted at 30 psi and 55 psi, respectively. The

Table 1. Physico-chemical properties of different soils

Soil	Order	Soil class	pH	EC (dS/m)	Clay (%)	Organic carbon (%)
Alluvial	Inceptisol	Clay loam	6.5	0.60	30.0	0.94
Black	Vertisol	Sandy clay loam	6.8	0.38	35.5	0.75
Red	Alfisol	Sandy loam	6.3	0.27	10.0	0.50

ion source temperature was set at 500°C. Each sample was injected by infusion technique at the rate of 10 µl/s.

UV-Visible spectra: UV-visible spectra of isoproturon in methanol was recorded on a Thermo-Fischer UV-VIS spectro-photometer using a quartz cuvette (1 cm path length).

Data analysis: Since the plots of natural log of isoproturon against time were assumed to be linear, a first-order equation was used to determine the rate constants (k) using the following equation:

$N_t = N_0 e^{-kt}$

Where, N_0 is the initial concentration of isoproturon, N_t concentration after a time t *i.e.* sampling time in days. The half-life was calculated by $t_{1/2} = 0.693/k$.

RESULTS AND DISCUSSION

Photodegradation of isoproturon

Isoproturon is reasonably photostable under sunlight condition. Its absorption maxima (λ_{max}) is 240 nm (**Figure 1**). The peak started from 210 nm ending at 255 nm exhibits the absorption due to the allowed π-π* transition and forbidden π-π* transition of the phenyl ring. The absorption of light at 275 nm is essentially n-ð* in character resulting from the urea group. The absorption spectrum of isoproturon in methanol overlaps the solar spectrum from 290 nm to 325 nm. The absorption of sunlight by isoproturon is, therefore, significant for the possibility of various photochemical reactions.

The rate of degradation of isoproturon was studied on the glass surface and soil surfaces. No significant change in the initial concentration was noticed in the control samples which were kept in the dark. Hence, the degradation observed in the irradiated samples must be attributed to a phototransformation process. Photolysis of isoproturon on all the surfaces followed first-order rate kinetic with significant regression coefficients (R^2) (**Table 2**). The glass surface provides an almost inert environment in which organic compound undergoes direct photolysis under irradiation. The half-life values of isoproturon on glass surface was 25.38 days. But on soil surfaces, values were 20.76, 27.38 and 28.02 days for red, black and alluvial soil, respectively (**Table 2**). Probably, the organic matter or humic substances present in black or alluvial soil acted as a photoquencher for isoproturon slowing down the rate of reaction.

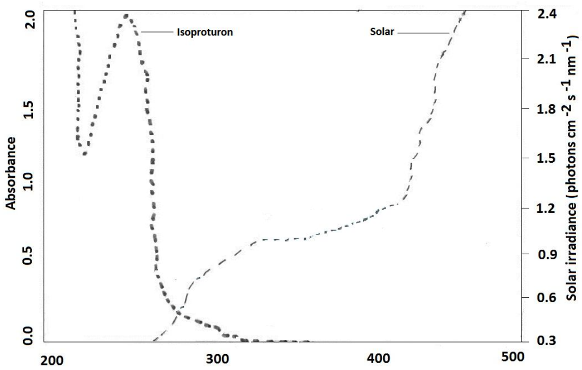

Figure 1. Comparison between isoproturon absorption spectrum and solar spectrum

Table 2. Rate kinetic equations and half-life values for the degradation of isoproturon on solid surfaces under the influence sunlight

Surface	Source of light	Rate constant (per day)	R^2	Half-life (days)
Glass	Sunlight	1.19×10^{-2}	0.8240	25.38
Red soil	Sunlight	1.45×10^{-2}	0.7770	20.76
Black soil	Sunlight	1.10×10^{-2}	0.8647	27.38
Alluvial soil	Sunlight	1.07×10^{-2}	0.9589	28.02

Though isoproturon is reasonably photostable under sunlight, it still can undergo photolysis as it absorbs considerable amount of radiation in the UV-portion of sunlight. The degradation may also be possible due to the interaction between isoprturon and reactive species like singlet oxygen, hydroxyl radical, methyl radical, *etc*. which are formed due to the irradiation of humic substances present in soil (Hessler *et al*. 1996, Schmitt *et al*. 1995, Wenk *et al*. 2011, Remucal 2014). In the present experiment, photolysis of isoproturon on different surfaces, *viz*. glass, red soil, black soil and alluvial soil generated six major photoproducts, the structures of which were elucidated by mass spectra obtained from LC-MS/MS analysis and confimed by related literatures (**Figure 2**). The products are 3-(4-isopropyl-2/3-hydroxy-phenyl)-1-methyl-1-hydroxymethylurea (I), 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-(*N*,*N*-dimethylcarbamoyl)urea (II), 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-(*N*-methylcarbamoyl) urea (III), 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-carbamoyl urea (IV), *N*-dimethyl-*N′*-methyl urea (V), *N*-dimethyl-*N′*-dimethyl urea (VI) (**Figure 3**).

The product I was formed due to the hydroxylation at *N*-methyl group forming an intermediate OH-adduct of isoproturon, followed by the ring hydroxylation at either *o*- or *m*-position. Similar ring hydroxylation was also observed by Azizi *et al*. (2013) during the photolysis of isoproturon mediated by advanced oxidation processes. Halladja

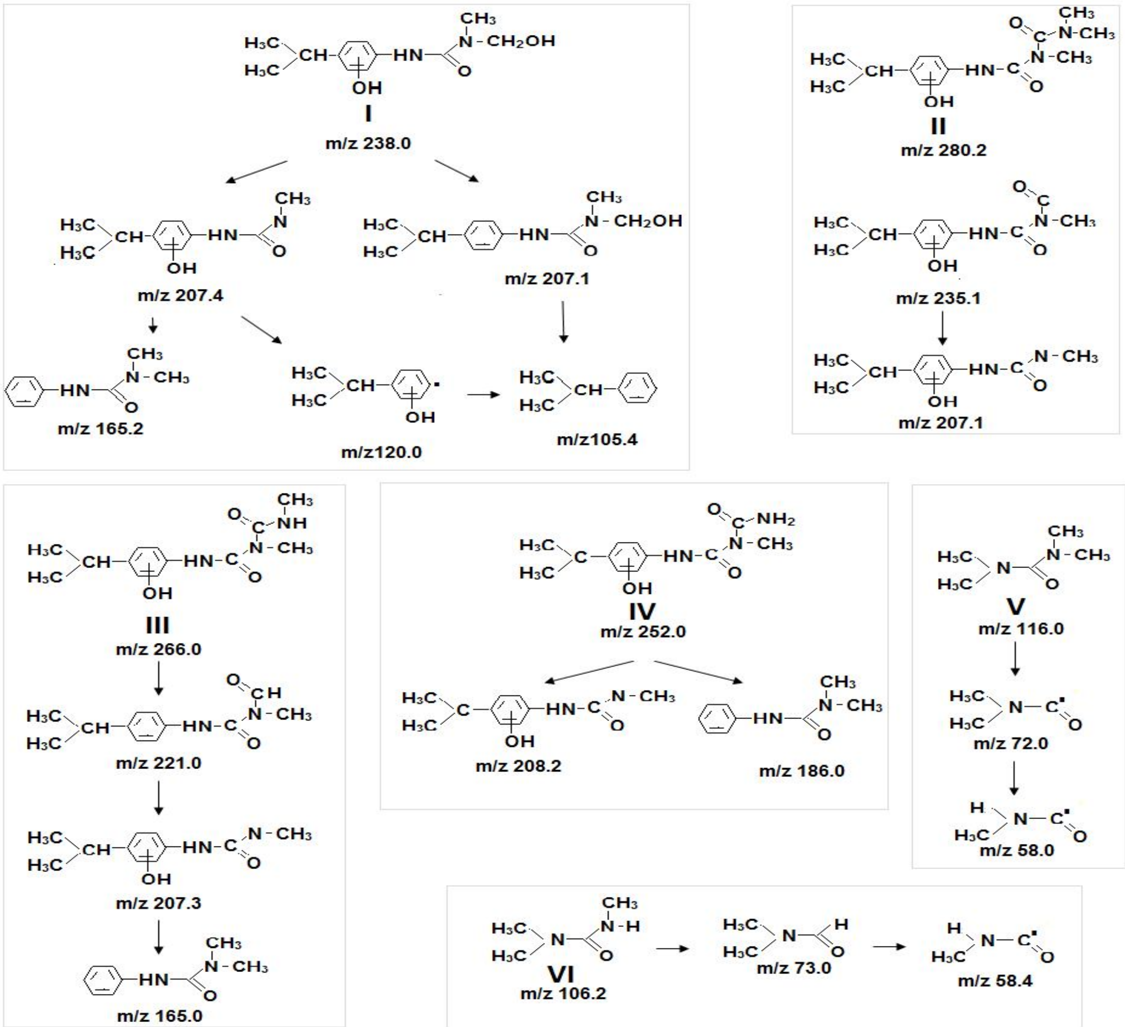

Figure 2. Mass fragmentation patterns of photo products formed during the photolysis of isoproturon on black soil surface under sunlight [I: 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-hydroxymethyl urea; II: 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-(*N,N*-dimethylcarbamoyl)urea; III: 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-(*N*-methylcarbamoyl)urea; IV: 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-carbamoyl urea; V: *N*-dimethyl-*N′*-methyl urea; VI: *N*-dimethyl-*N′*-dimethyl urea]

et al. (2007) also noticed the phenomenon of ring hydroxylation of another urea herbicide fluometuron during its photolysis in aqueous phase in presence of nitrate and fulvic acid, which on irradiation assisted in the generation of hydroxyl group. In our experiment, hydroxyl group containing chemical constituents present in humic substances are probably the source of active hydroxyl ions. During the irradiation process, homolysis of different bonds of isoproturon, *viz.* C(ring)-N, C(carbonyl)-N, C(methyl)-N led to the formation of different radicals, which in consequence reunited with each other forming different products. The product II was formed through such reunion of radicals followed by ring hydroxylation. The product V was also formed by a homolytic cleavage at the C(ring)-N, followed by the addition of one methyl radical. The fission between N-CH_3 of V followed by the addition of one hydrgen atom led to the formation of the product VI. Products III and IV were the results of the consecutive demethylation of II either through the homolytic cleavage of a methyl radical, or through the formation of hydroxyl methyl group followed by the formation of formyl group as stated by Sukul and Roy Chowdhury (1995).

Phototransformation of isoproturon on soil surfaces was not much influenced by any property of soil. The organic matter present in black and alluvial soil acted as a photo quencher or as photo screen to protect isoproturon from the direct photolysis. The organic or humic substances generated hydroxyl group and methyl radical on irradiation under sunlight. These reactive species chemically acted upon the isoproturon molecules transforming them into different products. Demethylated products and

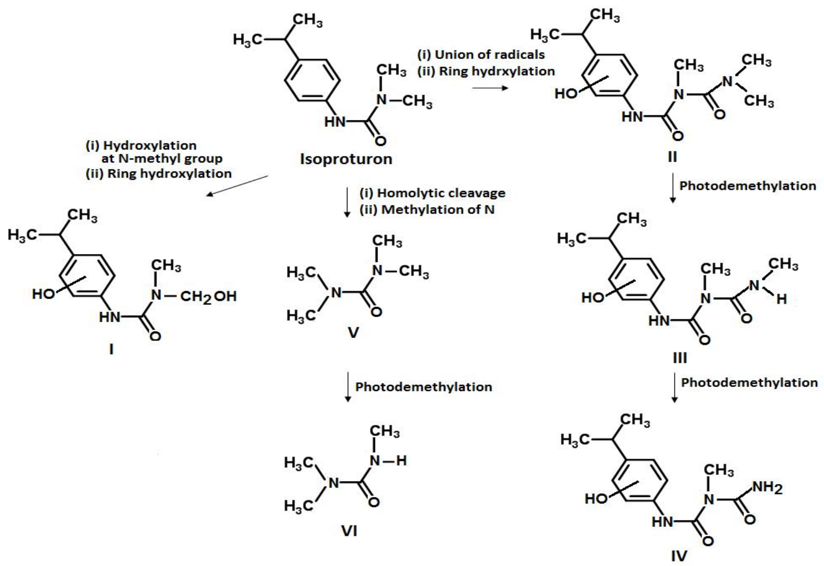

Figure 3. Pathways for the phototransformation of isoproturon in soil under sunlight [I: 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-hydroxymethyl urea; II: 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-(*N*,*N*-dimethylcarbamoyl)urea; III: 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-(*N*-methylcarbamoyl)urea; IV: 3-(4-isopropyl-2/3-hydroxyphenyl)-1-methyl-1-carbamoyl urea; V: *N*-dimethyl-*N′*-methyl urea; VI: *N*-dimethyl-*N′*-dimethyl urea]

aniline derivatives of isoproturon, which are generally formed during the photolytic process in aqueous phase or even in soil were not found in the present experiment. Terminal *N*-methyl substituted derivatives were formed (products II, III and IV), the toxicity of which are unknown.

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Herbicides effect on fish mortality and water quality in relation to chemical control of alligator weed

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ABSTRACT

Effect of three herbicides namely 2,4-D, metsulfuron-methyl and glyphosate was evaluated on fish mortality and water quality in relation to control of aquatic form of alligator weed (*Alternanthera philoxeroides;* Family, Amaranthaceae). All herbicides caused fish mortality and affected water quality after application, but it was highest in 2,4-D treated tanks followed by glyphosate and metsulfuron-methyl. Herbicide did not cause fish mortality at 1 DAA (days after application) but it caused at 7 DAA and increased corresponding to increase in concentration and days. Fish mortality was recorded lowest in herbicides treated tanks that were having only water but no weeds. Significantly higher fish mortality occurred in 2,4-D treated tanks having weeds. This reflected that fish mortality was more due to decaying of weeds, which decreased dissolved oxygen drastically in the water tanks. Herbicides did not affect fish development because growth and weight of fish was highest in water tanks treated with herbicides having no weeds. All the herbicides significantly decreased pH in treated tanks than control at 0 and 1 DAA, however, it was resumed towards normalisation in due course. The decrease in pH was least in the tanks having weeds and treated with metsulfuron-methyl followed by glyphosate and 2,4-D. Further, decrease in pH was less in water tanks having no weeds than having weeds. All the herbicides significantly decreased the dissolved oxygen (DO) at 0 day in water tanks with and without weeds except metsulfuron-methyl in the tanks having no weeds. Decrease in DO was more prominent in 2,4-D treated tanks followed by glyphosate and metsulfuron-methyl. Dissolved oxygen was least affected in tanks having no weeds.

Key words: Alligator weed, Chemical control, Fish mortality, Water quality

Alligator weed, *Alternanthera philoxeroides* (Family: Amaranthaceae) is a native of the Panama river system in North-Eastern Argentina and is believed to have been introduced in India from Indonesia and Myanmar. It is a noxious weed in Brazil (Abud 1985), Australia (Krake *et al.* 1999, Milvain *et al.* 1995), New Zealand, UK (Arthington *et al.* 1986) and USA (Rhodes 1983) and is capable of infesting terrestrial wet lands and aquatic habitats. From India, it was first reported in 1965 from Bihar (Maheswari 1965) and since than has spread to all states of India and in some states, it has assumed the alarming situation. It has been found to affect drainage systems severely In Jabalpur in India (Sushilkumar and Bhan 1996), Guwahati and Jorhat (Assam) and in Shilong (Meghalaya), this weed was found abundantly on the roadside as terrestrial weed in high moisture regime area, thus threatening local biodiversity (Sushilkumar *et al*. 2009). In many countries, this weed has been proclaimed as a state-prohibited, which reflects its seriousness in terms of its threat to public interest. In USA, it has become a menace in navigation and United State army had to spend huge money to clear the path for navigation from the infestation of this weed. Alligator weed has been reported to cause major blockages of water flow in water ways such as irrigation canals, rivers and drainage system. It is capable to readily establishes and covers extensive surface area of lakes and ponds.

Few herbicides have been tried to control alligator weed in other countries among which 2,4-D, glyphosate and metsulfuron-methyl have been used widely (Melvain *et al.* 1995, Langeland 1986, Sandberg and Burkhalter 1983, Sutton 1974). The use of herbicide in aquatic system is increasing worldwide, but so far Govt. of India has not recommended any herbicides for weed control in aquatic situations owing to fear of their non-target effect and very less information about the impact of herbicides on the aquatic ecosystem. Metsulfuron-methyl is a sulfonylurea group herbicide and used as alone or in a mixture to control broad-leaf weeds in cereal crops while glyphosate is a commercial formulation of N-{phosphonomethyl} glycine, which contains thenisopropylamine salt that makes it more soluble in water and its use more convenient in aquatic system, whereas 2,4-D is a broad-spectrum

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non-selective herbicide that effectively controls most of the annual and perennial herbaceous plant and deep root perennial species.

A common concern about the use of herbicides is about their effect on water quality and aquatic fauna especially fish besides non-target effects on other microorganism. To address this concern, in the present study, effects of herbicides, *viz.* 2,4-D, glyphosate and metsulfuron-methyl have been reported and discussed on fish mortality and growth and on water quality while doing chemical control of the alligator weed. The effect of herbicides on alligator weed control and on its regrowth has been dealt by Sushilkumar *et al.* (2008b) in other studies.

MATERIALS AND METHODS

The experiment was conducted during 2004-2005 at Directorate of Weed Research, Jabalpur in water tanks having surface area of 2.54 m^2 with one meter deapth. Shoots of alligator weed with 40 cm length were cut from naturally infested ponds and brought to the institute for establishment in water tanks. A 10 cm layer of soil was placed on the floor of each tank along with 4 kg FYM before filling the water. In each water tank, 2500 cut shoots were put, based on the survey of per meter square population in the severely infested pond. The cut shoots were allowed to establish for one month. This formed a shoot and leave mat above the water surface and interwoven root mat beneath the water as occurred in natural conditions. Twenty number of fish fingerlings of species *Rohito labio*, having average total length (7.20 cm) and weight (9.91 g) were released in each tank before 7 days of spray of herbicides to acclimatize them. Fresh fish was added in case of any mortality during period of the acclimatization.

On such established alligator weed mat, herbicides were sprayed in different concentrations by knapsack sprayer with flat fan nozzle at the rate of 500 litre per hectare. The herbicide treatments included 2,4-D ethyl ester at 1.5, 2.0 and 2.5 kg/ha, glyphosate at 1.5, 2.5 and 3.0 kg/ha and metsulfuron-methyl at 0.016, 0.020 and 0.024 kg/ha. In control, tanks were sprayed with water only. To see the effect of herbicides on water only, a treatment was kept without weed and herbicides were sprayed on water surface only. The fish mortality was counted daily by observing any dead fish over the water surface and amidst the nat of alligator weed. Total number of dead fish was computed at an interval of 0, 1, 7, 14, 21, 30 and 60 days after application (DAA) of herbicides. All the live fishes were removed after 60 days from the tanks and their total length, standard length and weight were measured to see the overall growth in tanks treated with herbicides having weeds, no weeds and control without herbicides. The experiment was replicated thrice in a completely randomized block design. The water samples were taken from treated and untreated water tanks at 0, 1, 7, 14, 21, 30 and 60 DAS for water quality, which was determined by following AOAC methods (1970).

RESULTS AND DISCUSSION

Effect of herbicides on fish mortality

Herbicide did not cause fish mortality at 0 and 1 days after application (DAA), but it started to cause mortality after 7 days, which increased correspon-ding to increase in herbicide concentration and days. Metsulfuron-methyl in all concentrations proved to be the best herbicide followed by glyphosate and 2,4-D. It was found that mortality of fishes was significantly less in those herbicides treated tanks having no weeds. However, significantly higher fish mortality occurred corresponding to increase in dose of 2,4-D. Fish mortality was recorded 20, 26 and 46% at 1.5, 2.0 and 2.5 kg/ha doses of 2,4-D at 60 days, respectively, while it was about half in glyphosate and even less in metsulfuron-methyl treated tanks (**Table 1**). Only 10% fish mortality was observed in 60 days in the tanks having no weeds, but was sprayed with the herbicides. No fish mortality was recorded in control at 30 DAA but about 6.60% mortality was observed at 60 DAA.

The length and weight of fishes were found significantly high in all the herbicide treated tanks than the control. This clearly reflected that growth of fish is drastically affected in the water bodies having cover of weeds over the water surface. Length and

Table 1. Effect of herbicides on fish mortality at different days after application (DAA)

Herbicide	Dose (kg/ha)	Progressive fish mortality (%) at different DAA						
		0	1	7	14	21	30	60
2,4-D	1.5	0.0	0.0	6.6	13.2	13.2	13.2	20.0
	2.0	0.0	0.0	6.6	26.5	26.5	26.5	26.6
	2.5	0.0	0.0	9.9	36.5	39.8	39.8	46.6
	2.5*	0.0	0.0	10.0	10.0	10.0	10.0	10.0
Glyphosate	2.0	0.0	0.0	6.6	6.6	6.6	6.6	13.3
	2.5	0.0	0.0	6.6	6.6	6.6	6.6	16.6
	3.0	0.0	0.0	13.2	13.2	13.2	13.2	23.3
	3.0*	0.0	0.0	10.0	10.0	10.0	10.0	10.0
Metsulfuron-methyl	0.02	0.0	0.0	5.0	5.0	5.0	5.0	6.6
	0.02	0.0	0.0	5.0	5.0	5.0	5.0	10.0
	0.02	0.0	0.0	8.3	8.3	8.3	8.3	10.0
	0.02*	0.0	0.0	10.0	10.0	10.0	10.0	10.0
Control		0.0	0.0	0.0	0.0	0.0	0.0	6.6
LSD (p= 0.05)		0.0	0.0	8.9	19.7	22.5	22.5	19.7

*Spray of herbicides on water surface in tank having no weeds weight of fishes were significantly higher in the water tanks having no weeds, but treated with highest dose of herbicides than the water tanks having weeds and treated with herbicides (**Table 2**). Significantly higher fish mortality was recorded between 14 to 21 days coincide with the decomposition of weeds due to action of herbicides. This implies that alone herbicide is not responsible for fish mortality became it did not cause significant mortality than the control. More fish mortality was caused due to lowering of water quality by the action of herbicides due to decomposition of weeds. Deivasigamani (2015) found that glyphosate showed significantly lesser fish mortality than 2,4-D Na salt with mortality percentage of 23.0, 16.0 and 20.0 and 46.0, 33.33 and 20.00 for common carp, mrigal and rohu, respectively at 96 h. Satya *et al.* (2016) did not observe mortality of fingerlings with all the tested herbicides with different concentrations except spraying of glyphosate at 10 ml/L + 2,4-D Na salt at 2.5 g/lit. In our experiment, reason of more mortality of fish in high dose of 2,4-D (2.5 kg/ha) may attributes of its ester property, which caused fast deterioration of weed by 14 days leading to decrease in dissolve oxygen. However, the same dose of 2,4-D when applied only on water without weed did not cause significant mortality of fish. This further suggests that in large water body, fish mortality may not be due to direct effect of herbicides, instead mortality of fish may be due to decrease of water quality parameters due to decomposition of weeds by action of herbicides.

Table 2. Weight, standard length and total length of fish in different treatment after 60 days after application

Herbicides	Dose (kg/ha)	Standard length (cm)	Total length (cm)	Total weight (g)
2,4-D	1.5	8.67	10.9	13.7
	2.0	9.43	11.2	13.9
	2.5	9.45	11.8	16.5
	2.5*	10.02	13.9	23.8
Glyphosate	2.0	9.05	11.4	13.3
	2.5	9.70	12.1	17.1
	3.0	8.95	11.3	18.7
	3.0*	11.64	14.44	29.0
Metsulfuron- methyl	0.016	9.56	12.1	14.5
	0.020	9.16	11.6	15.8
	0.024	9.25	11.8	16.0
	0.024*	11.95	14.8	29.4
Control		7.92	10.0	9.40
LSD (p=0.05)		0.26	0.23	0.20

*Spray of herbicides on water surface in tank having no weed. Before spray of herbicides, average standard length, total length and weight of fish was 7.20 and 9.9 cm/fish and 19.4 g/fish

Table 3. Effect of herbicides on pH at different days after application (DAA)

Herbicides	Dose (kg/ha)	pH at different DAA							
		0	1	7	14	21	30	45	60
2,4-D	1.5	6.2	6.5	6.8	6.9	6.9	7.0	7.4	7.6
	2.0	6.2	6.3	6.5	6.6	6.8	6.9	7.0	7.4
	2.5	6.0	6.2	6.4	6.5	6.7	6.8	6.9	7.1
	2.5*	6.9	6.9	7.0	7.0	7.1	7.4	7.7	7.8
Glyphosate	2.0	6.5	6.7	6.9	7.0	7.0	7.2	7.4	7.6
	2.5	6.4	6.6	6.7	6.9	6.9	7.1	7.2	7.5
	3.0	6.3	6.4	6.5	6.8	6.8	7.0	7.1	7.4
	3.0*	7.0	7.0	7.1	7.1	7.2	7.6	7.8	7.9
Metsulfuron-methyl	0.016	6.7	6.9	7.1	7.2	7.2	7.4	7.6	7.8
	0.020	6.6	6.8	6.9	7.1	7.1	7.3	7.5	7.5
	0.024	6.5	6.6	6.7	7.0	7.0	7.2	7.3	7.6
	0.024*	7.0	7.0	7.1	7.2	7.2	7.6	7.9	7.9
Control	-	7.2	7.2	7.4	7.5	7.5	7.7	7.9	8.1
LSD p=0.05)		0.16	0.17	0.16	0.18	0.18	0.16	0.16	0.16

*Spray of herbicides on water surface in tank having no weed

Effect of herbicides on water quality

Herbicides influenced water quality in terms of pH, dissolve oxygen (DO), and biological oxygen demand (BOD) corresponding to increase in concentrations and time after spray.

Effect on pH: It was observed that pH was decreased in tanks having weeds than the control corresponding to increase in concentrations of herbicides, but pH decrease was less in tanks having only water. All the herbicides significantly decreased pH than control at 0 and 1 DAA. The decrease in pH was minimum in metsulfuron-methyl treated tanks followed by glyphosate and 2,4-D. However, pH tend to be increased corresponding to increase in time but it varied herbicide to herbicide. In tanks treated with higher dose of 2,4-D (2.5 kg/ha) having weeds, pH increased from 6.0 at 0 DAS to 6.9 at 45 DAA, while in tanks having no weeds, the pH increased from 6.9 at 0 DAA to 7.0 at 7 DAA. In control, pH increased from 7.2 to 8.1 by 60 days (**Table 3**). This suggests that pH decrease was high in the presence of weed, while in the absence of weeds, decrease was low. This might be due the release of chemical contents of plants in the water due to deterioration of weeds by action of herbicides.

Effect on dissolve oxygen: Decrease in dissolve oxygen (DO) level may be fatal for the aquatic life. Fishes are most susceptible with decrease in DO level. All the herbicide treatments significantly decreased the DO at '0' day in the tanks having or not having weeds except metsulfuron-methyl in tanks having no weeds. The fast decaying of weed biomass after herbicides application started at 5 to 10 days, which was responsible for more lowering the DO and mortality of fish. Decrease in DO was more pronounced in 2,4-D treated tanks followed by glyphosate and metsulfuron-methyl. A decrease trend of DO was observed in all the treatments including control corresponding to increase in time from the date of application. DO was least affected in tanks having no weeds (**Table 4**). This further confirms that decrease in DO was mainly due to the decaying of weed owing to the action of herbicides. DO was brought down below 4 ppm in 2,4-D 2.5 kg/ha treated tanks at 14 DAS, which might have resulted high increase in fish mortality from 10 to 37% due to oxygen depletion (**Table 1**). Decaying of alligator weed was observed slow in metsulfuron-methyl treated tanks than the 2,4-D and glyphosate, which might have resulted less decrease in DO hence, less mortality of fish.

Effect on BOD: Biological oxygen demand (BOD) is also an important water quality parameter for existence of aquatic life particularly microbes, which are essential for aquatic ecology. Less BOD has been considered better for aquatic ecosystem. BOD increased significantly at '0' day in all the treatments than control including water tanks having no weeds. This increase of BOD even in the tanks having no weed reflects that BOD is directly affected by herbicides. BOD increase was highest in 2,4-D followed by glyphosate and metsulfuron-methyl and was at par with control in metsulfuron-methyl treated tanks at 1 DAA, but it increased with the increase in time (**Table 5**).

In general, there was deterioration of water quality parameters with increase of time in herbicide treated and untreated tanks with weed or without weed. This might be due to water stagnation in the tank up to longer duration. It was presumed that water quality deterioration might be less in large aquatic body treated with herbicides in patches. Sushilkumar *et al.* (2005) did not observed mortality of fishes when glyphosate was sprayed in half part of full lotus infested pond, leaving other part unsprayed in a fish culture pond. Reduction in water quality due to lower dissolved oxygen might have been the primary cause for fish mortality in all the herbicides treated tanks having weeds. Olaleye and Akinyemiju, (1996) have also reported the effect of glyphosate on fish composition and abundance during control of water hyacinth in delta of Nigeria. Kannan and Kathiresan (2002) observed minimum fish mortality in the glyphosate treated water tanks followed by 2,4-D in relation to water hyacinth control. They observed lowest dissolve oxygen (2.5 ppm) in tubs sprayed with 2,4-D 1.0 kg/ha at 15 DAA. They also observed reduction in pH and DO by paraquat (0.90 kg/ha), 2,4-D (1.00 kg/ha) and glyphosate (2.20 kg/ha) compared to the untreated control.

Table 4. Effect of herbicides on dissolve oxygen (DO) at different days after application

Herbicides	Dose Kg/ha	DO (mg/l) at different DAA							
		0	1	7	14	21	30	45	60
2,4-D	1.5	6.4	6.0	5.6	5.2	4.8	3.6	2.4	2.3
	2.0	5.6	5.6	4.8	4.4	3.2	2.4	2.0	1.9
	2.5	4.8	4.8	4.0	3.6	2.4	1.6	1.2	1.1
	2.5*	7.0	7.0	6.9	6.5	6.5	5.8	5.6	4.5
Glyphosate	2.0	7.2	7.2	6.4	5.6	5.6	4.8	4.0	3.2
	2.5	6.4	6.4	5.6	5.6	4.8	4.0	3.2	2.4
	3.0	6.4	6.4	4.8	4.8	4.0	3.2	2.4	1.6
	3.0*	7.0	7.0	6.9	6.6	6.6	5.6	5.9	4.8
Metsulfuron-methyl	0.016	8.0	8.0	7.2	6.4	6.4	5.6	4.8	4.0
	0.020	7.2	7.2	6.4	6.4	5.6	4.8	4.0	3.2
	0.024	7.2	7.2	5.6	5.6	4.8	4.0	3.2	2.4
	0.024*	8.1	8.1	8.0	7.2	7.0	6.8	6.3	5.3
Control		8.2	8.2	8.1	8.0	7.5	7.2	6.5	5.8
LSD (p=0.05)		0.16	0.21	0.17	0.19	0.20	0.16	0.18	0.17

*Spray of herbicides on water surface in tank having no weeds

Table 5. Effect of herbicides on BOD of water at different days after application (DAA)

Herbicides	Dose Kg/ha	BOD (mg/l) at different DAS							
		0	1	7	14	21	30	45	60
2,4-D	1.5	100	110	130	150	170	190	200	210
	2.0	100	110	140	165	180	190	210	220
	2.5	120	130	150	180	190	200	215	240
	2.5*	60	90	100	120	130	150	160	170
Glyphosate	2.0	100	104	126	148	168	180	190	200
	2.5	100	106	128	150	170	184	198	204
	3.0	100	108	130	156	174	190	200	210
	3.0*	90	100	110	124	136	148	158	162
Metsulfuron-methyl	0.016	90	100	116	130	146	158	160	170
	0.020	90	100	118	134	150	160	164	172
	0.024	90	100	120	138	156	168	172	178
	0.024*	90	100	110	124	136	148	158	162
Control		60	100	110	120	130	140	150	160
LSD (P=0.05)		6.48	3.25	2.71	2.83	2.46	2.43	4.42	2.83

*Spray of herbicides on water surface in tank having no weeds

In our experiment, all treatments influenced the pH of treated water and also affected dissolved oxygen content. The slight reduction in water quality in the herbicides treated tanks can be attributed to the metabolic processes and to the decaying of organic matter after its death. Sushilkumar, *et al*, (2005) reported that 2,4-D, glyphosate (2.0 kg/ha) and metsulfuron-methyl (0.012 kg/ha) influenced the water quality in a fish culture pond at Jabalpur, India. The pH was significantly reduced in all the treatments over control but it was least affected by metsulfuron-methyl and maximum by glyphosate and 2,4-D. Detailed study done after the spray of glyphosate in large area in fish culture pond, they found that pH and DO did not change significantly up to 7 days but increased after 15 days corresponding to the decaying of treated weed biomass. Maximum and longer control in context of regrowth of alligator weed was also found by metsulfuron-methyl as has been reported by Sushilkumar *et al.* (2004, 2008). Metsulfuron-methyl at 16 and 24 g/ha was found effective to control aquatic and terrestrial form of alligator weed in tropical situations as it persisted for about 2 months in the soil sediments (Sushilkumar *et al.* 2008b).

Results unequivocally revealed metsulfuron-methyl as most promising herbicide to control alligator weed in context to less deterioration of water quality parameters as well as less fish mortality. Therefore, metsulfuron-methyl may be recommended to control alligator weed.

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Short communication

Lolium, an emerging grassy weed of wheat in Haryana and its chemical control

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Wheat (*Triticum aestivum*L.) is the second most important grain crop of India after rice and thus crucial for the food security of the country. Wheat competes with several grassy and broad-leaf weeds during its growth period depending upon the adopted agronomic practices, soil types, underground water quality, weed control techniques and cropping system. For realizing potential crop yield, proper weed management is essential. Survey of weed flora of wheat fields has shown moderate to heavy infestation of new grassy weed of *Lolium* spp. in North-Eastern districts of the state under high moisture conditions which have threatened wheat cultivation in some fields (AICRPWC 2014 and 2015).

To study the infestation level of this new emerging weed species, a systematic survey of wheat fields was done in 11 districts, *viz*. Ambala, Kurukshetra, Karnal, Panchkula, Yamuna Nagar, Jind, Panipat, Kaithal, Sirsa, Fatehbad and Hisar districts of state. Twenty fields in each district were surveyed during January - March, 2015, as this period depicted most appropriate representation of majority of weed species and the weeds have cumulative effects of all agronomic practices, soil type, fertilizer and irrigation application and weed control measures adopted during initial crop growing period. The road map of Haryana state was followed and routes were planned to establish sampling localities as equidistantly as possible (about 10 kms) avoiding inhabited areas. Four observations on density of individual weeds were recorded per field at one spot by using quadrant (0.5 x 0.5 m), 80-100 meters deep inside the fields. Pooled average values of observations of relative density were thus calculated as per method suggested by Misra (1968) and Raju (1977). To test the efficacy of various herbicides, a field experiment was conducted at farmers' field in V. Danoura, Distt. Ambala (Haryana) by keeping a plot size of 150 m^2 with three replications during *Rabi* 2004-15 and 2015-16.Wheat variety HD2967 was planted on 15.11.2014 and 20.11.2015, during first and second years, respectively. Herbicides pendimethalin alone at 1500 g/ha, pendimethalin + metribuzin 1500 + 175 g/ha (TM) and pendimethalin 35% + metribuzin 3.5% (RM) at 1925 g/ha were applied as pre-emergence using 500 litres of water/ha. Isoproturon at 1000 g/ha was applied 5 days after first irrigation by mixing in 10 kg urea while post-emergence herbicides sulfosulfuron at 25 g/ha, mesosulfuron + iodosulfuron (RM) at 14.4 g/ha and pinoxaden at 50 g/ha were applied at 40 DAS using 375 litres of water. All herbicide sprays were done by knapsack sprayer using flat fan nozzle. In field experiment, data on density and dry weight of weeds was recorded using 0.5 x 0.5 meter quadrant from four places in a plot at 75 DAS which was subjected to $(\sqrt{x+1})$ transformation before analysis. Data on percent control of *Lolium* spp. was recorded at 120 DAS which was subjected to arc $\sin^{-1}$ transformation before analysis.

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Survey of *Lolium* infestation

Maximum population of *Lolium* 49.1 plants/m^2 occurred in Yamuna Nagar district with a frequency of 55%, followed by Panchkula (41.32 plants/m^2), Ambala (32.2 plants/m^2), Kurukshetra (27.5 plants/m^2) and Karnal 24.0 plants/m^2. In south western districts of Hisar, Sirsa and Fatehabad although infestation occurred but with less density in a range of 1.45-3.5 plants/m^2 and only at 10-15% locations surveyed (**Figure 1**).

Chemical control in wheat

Weed flora present in the experimental field consisted of grassy weeds *Lolium* spp. (70%), *Phalaris minor* (20%) and broad-leaf weeds *Chenopodium album*, *Rumex dentatus* and *M. indica* (10%) All herbicides except pinoxaden and sulfosulfuron proved effective against *Lolium* spp. in wheat (**Table 1**). These herbicides proved effective against *P.minor* (data not given). Pre-emergence

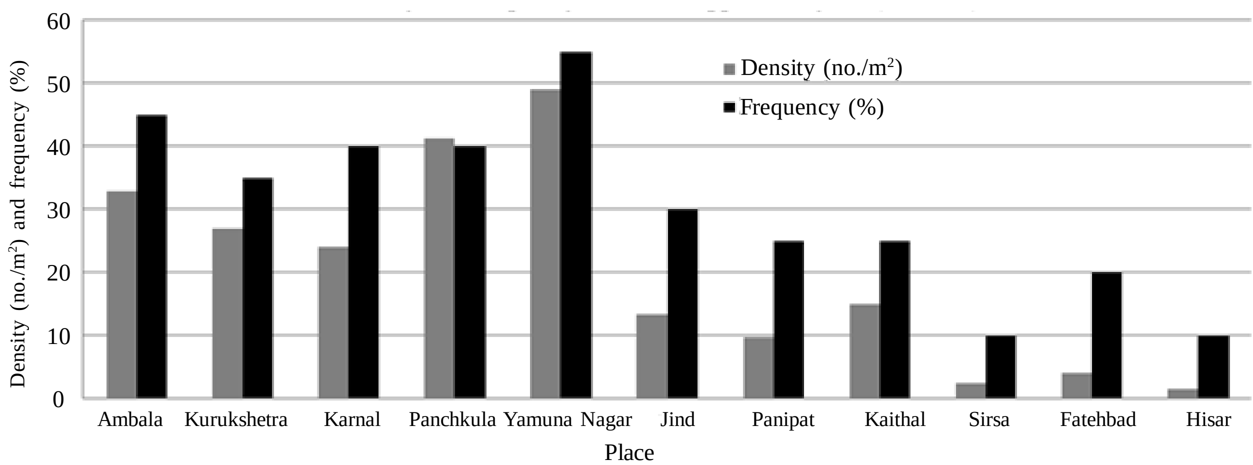

Figure 1. Density and frequency of *Lolium* spp. in wheat in Haryana

Table 1. Effect of different herbicides on density, dry weight , WCE (%) of *Lolium* spp. and grain yield of wheat

Treatment	*Lolium* spp. (no./m^2) 75 DAS		*Lolium* dry wt. (g/m^2) 75 DAS		WCE (%) 75 DAS		Visual control (%) 120 DAS		Grain yield (t/ha)	
	2014-15	2015-16	2014-15	2014-15	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimethalin (1500 g/ha) PE	1.9 (2.7)	1.9 (2.7)	2.17 (3.7)	2.27(4.2)	91.7	87.8	79.5 (95)	71.9 (90)	4.25	4.80
Pendimethalin + metribuzin (TM) (1500 + 175 g/ha) PE	1.7 (2.0)	1.5 (1.3)	2.10 (3.4)	1.72(2.0)	92.3	94.2	82.3 (97)	77.2 (95)	4.40	4.86
Pendimethalin + metribuzin (RM) (1925 g/ha) PE	1.6(1.7)	1.7 (2.0)	2.0 (3.0)	1.78(2.2)	93.3	93.6	79.5 (95)	77.2 (95)	4.42	4.88
Sulfosulfuron (25 g/ha)35 DAS	7.3 (52)	7.1 (50.3)	6.99 (47.9)	5.98(34.7)	-6.4	0	0(0)	0(0)	3.82	4.06
Pinoxaden (50 g/ha)35 DAS	7.5 (55.7)	6.7 (44.7)	6.76 (44.8)	5.95(34.4)	0.44	0.86	0(0)	0(0)	4.03	4.12
Mesosulfuron + iodosulfuron (RM) (14.4 g/ha)35 DAS	2.3 (4.7)	1.7 (2.0)	2.60 (5.8)	1.83(2.7)	87.1	92.2	69.5 (88)	74.8 (90)	4.48	4.90
Isoproturon (1000 g/ha) 25 DAS	0.6 (2.7)	1.6 (1.7)	2.52 (5.4)	1.68(2.0)	87.9	94.2	67.4 (85)	81.8 (97)	4.02	3.20
Weedy	7.2 (50.7)	6.8 (45.7)	6.78 (45.0)	5.99(34.7)	0	0	0(0)	0(0)	3.25	0.12
LSD (p=0.05)	0.6	0.64	0.1	0.69	-	-	7.4	11.1	0.15	0.12

PE-Pre-emergence

application of pendimethalin alone at 1500 g/ha or in conjunction with metribuzin at 1500 +175 g/ha as tank mixture provided 90-97% control of *P.minor* with only 1.3-4.2 plants/m^2. Isoproturon applied at 1000 g/ha as urea mix after first irrigation proved very effective with 1.7-5.4 plants/m^2 exhibiting 85-97% control of *Lolium*. Ready mix combination of pendimethalin (35%) + metribuzin (3.5%) caused significant reduction in density and dry weight of *Lolium* during both years of study. The herbicides pinoxaden and sulfosulfuron at their applied rates proved effective against *P.minor* but did not cause any inhibition of *Lolium*. Grain yield of wheat followed the same trend as density and dry weight of weeds. Weed control efficiency with use of pendimethalin at 1500 g/ha was 91.7 and 87.8% during 2014-15 and 2015-16, respectively which slightly increased by use of metribuzin as tank mixture or in ready mixture with pendimethalin. Grain yield was maximum (4.48 and 4.90 t/ha) during 2014-15 and 2015-16, respectively in plots treated with mesosulfuron+iodosulfuron (RM) at 14.4 g/ha which was at par with pendimethalin +metribuzin (TM) and pendimethalin+metribuzin(RM) applied as pre-emergence due to excellent control of *Lolium* as well as *P.minor* present in the experimental field.

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Short communication

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

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Key words: Maize, Pre- and post-emergence herbicides, Weed control efficiency, Weed density

Maize (*Zea mays* L.) is one of the most versatile cereal crops having wider adaptability under diverse soil and climatic conditions. There are various causes of low productivity of maize and severe weed infestation is one of the major ones. Initial slow growth and wider row spacing of crop provide enough opportunity for the weeds to emerge and offer severe competition. Weeds, if left uncontrolled mitigates the benefits obtainable from different agricultural inputs. Hence, management of weeds is considered to be an important factor for achieving higher productivity. Even though herbicides are effective in controlling weeds, application of single pre-emergence (PE) or post-emergence (PoE) herbicide does not provide satisfactory weed control for desired period (Malviya and Singh 2007). Keeping this in view, an experiment was carried out to study the efficacy of sequential application of pre- and post-emergence herbicides in controlling weeds in maize.

A field experiment was conducted at Agricultural College Farm, Bapatla during *Kharif* 2015. The soil of experimental site was clay loam in texture, slightly alkaline in reaction, low in organic carbon and nitrogen, medium in available phosphorous and high in available potassium. The experiment was laid out in a randomized block design with three replications involving eight treatments. Treatments comprised of atrazine (1.0 kg/ha), halosulfuron-methyl (90 g/ha) and pendimethalin (1.0 kg/ha), and their combinations, hand weeding twice at 20 and 40 DAS, weed free and weedy check (**Table 1**). The maize hybrid '*30-V-92*' was dibbled manually at spacing of 60 × 20 cm using 25 kg seed/ha during last week of August, 2015. Thinning and gap filling was done at 10 days after seeding (DAS) by keeping one seedling/hill. Atrazine and pendimethalin were applied as PE and halosulfuron-methyl was applied as PoE application. Recommended dose of 120:60:60 kg/ha nitrogen, phosphorus and potassium were applied in the form of urea, single super phosphate (SSP) and muriate of potash (MOP).

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Weed density

Among the herbicides tested, pre-emergence application of atrazine 1.0 kg/ha *fb* halosulfuron-methyl 90 g/ha as post-emergence recorded the lowest weed density of 4.6 and 5.7/m^2 at 30 and 60 DAS, respectively, which was found statistically at par with pendimethalin 1.5 kg/ha PE followed by (*fb*) halosulfuron-methyl 90 g/ha as POE and was significantly superior to PE application of atrazine 1.0 kg/ha, PE application of pendimethalin 1.5 kg/ha PE *fb* halosulfuron-methyl 90 g/ha PoE (**Table 1**). The weedy check recorded the highest weed density of 12.3 and 14.2/m^2 at 30 and 60 DAS, respectively over the rest of the treatments. Persistence of atrazine for longer period might have resulted in less weed population in weedy check treatment. Similar trend was observed at harvest stage also as that of the 30 and 60 DAS. These results were in agreement with the findings of verna *et al.* (2009) and Kumar *et al.* (2013).

Weed biomass

Weed free recorded the lowest weed biomass (0.7, 0.7 and 0.7 g/m^2 at 30, 60 DAS and at harvest, respectively) and was significantly lower compared to all the other treatments. With regard to herbicide treatments, the lowest weed biomass (4.6 and 6.3 g/m^2 at 30 and 60 DAS, respectively) was recorded with atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 90 g/ha PoE, which was at par with pendimethalin 1.5 kg/ha PE *fb* halosulfuron-methyl 90 g/ha PoE. Atrazine 1.0 kg/ha PE, pendimethalin 1.5 kg/ha PE *fb* halosulfuron-methyl 90 g/ha PoE were significantly inferior to weedy check (**Table 1**). These results were in agreement Srividya e*t al.* (2011).

Weed control efficiency

The highest weed control efficiency (90.0, 90.0 and 90.0% at 30, 60 DAS and at harvest, respectively) was recorded with weed free treatment. Among various herbicides tested, atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 90 g/ha PoE recorded the highest weed control efficiency (69.4 and 68.1% at

Table 1. Weed density and weed biomass as influenced by different weed management treatments in maize

Treatment	Weed density (no./m^2)*			Weed biomass (g/m^2)*		
	30 DAS	60 DAS	At Harvest	30 DAS	60 DAS	At Harvest
Atrazine 1.0 kg/ha (PE 2 DAS)	5.8(33)	8.0(64)	7.2(52)	6.6(44)	9.2(85)	8.9(79)
Halosulfuron-methyl 90 g/ha (PoE 20 DAS)	6.8(46)	9.3(85)	8.8(77)	9.1(81)	10.6(111)	9.4(87)
Pendimethalin 1.5 kg/ha (PE 2 DAS)	6.1(37)	8.3(69)	7.7(59)	6.9(47)	9.6(98)	9.2(84)
Atrazine 1.0 kg/ha (PE) *fb* halosulfuron-methyl 90 g/ha (PoE)	4.6(21)	5.7(32)	5.2(27)	4.6(20)	6.3(39)	7.0(49)
Pendimethalin 1.5 kg/ha (PE) *fb* halosulfuron-methyl 90 g/ha (PoE)	4.7(23)	6.0(32)	5.4(28)	4.8(22)	6.6(44)	7.3(54)
Hand weeding at 20 and 40 DAS	3.6(13)	4.8(23)	4.6(21)	3.6(13)	5.2(27)	6.5(43)
Weedy check	*12.3(152)	14.2(2023)	10.9(120)	*13.0(168)	16.7(279)	13.1(173)
Weed free	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)
LSD (p=0.05)	1.0	1.0	1.0	1.1	1.4	1.6

*The data are $\sqrt{X+0.5}$ transformed. The figures in parentheses are the original values; DAS = Days after seeding; *fb* = Followed by

Table 2. Weed control efficiency as influenced by different weed management treatments in maize

Treatment	Weed control efficiency (%)			
	30 DAS	60 DAS	At harvest	Yield (t/ha) kernel yield
Atrazine 1.0 kg/ha (PE 2 DAS)	59.2(73.2)	56.4(69.2)	47.6(54.5)	5.14
Halosulfuron-methyl 90 g/ha (PoE 20 DAS)	45.7(51.2)	50.6(59.6)	44.2(48.6)	4.78
Pendimethalin 1.5 kg/ha (PE 2 DAS)	57.8(71.6)	53.6(64.7)	45.2(50.4)	4.99
Atrazine 1.0 kg/ha (PE) *fb* halosulfuron-methyl 90 g/ha (PoE)	69.4(87.6)	68.1(85.9)	57.4(70.6)	6.49
Pendimethalin 1.5 kg/ha (PE) *fb* halosulfuron-methyl 90 g/ha (PoE)	68.7(86.7)	66.8(84.5)	55.9(68.2)	6.26
Hand weeding at 20 and 40 DAS	74.1(92.3)	72.0(90.3)	60.4(75.3)	6.74
Weedy check	*0.0(0.0)	0.0(0.0)	0.0(0.0)	3.20
Weed free	90.0(100.0)	90.0(100.0)	90.0(100.0)	7.43
LSD (p=0.05)	6.0	5.2	8.9	0.90

*The data are arc sine transformed. The figures in parentheses are the original values; DAS = Days after seeding; *fb* = Followed by

30 and 60 DAS, respectively), which was at par with pendimethalin 1.5 kg/ha PE *fb* halosulfuron-methyl 90 g/ha PoE at 30 and 60 DAS (**Table 2**). These results were in line with the findings of Kumar *et al*. (2013).

Yield

Among the various weed control treatments, the highest grain yield (7.43 t/ha) was recorded with weed free, which was at par with hand weeding at 20 and 40 DAS. With regard to herbicide treatments, pre-emergence application of atrazine 1.0 kg/ha + halosulfuron-methyl 90 g/ha as PoE recorded the highest grain yield (6.49 t/ha) and it was comparable with pendimethalin 1.5 kg/ha PE *fb* + halosulfuron-methyl 90 g/ha PoE and significantly superior to atrazine 1.0 kg/ha (PE) *fb* halosulfuron-methyl 90 g/ha (PoE), hand weeding at 20 and 40 DAS and pendimethalin 1.5 kg/ha (PE) *fb* halosulfuron-methyl 90 g/ha (PoE) treatments (**Table 2**).

Among the chemical weed control treatments, the lowest weed density, biomass and the highest weed control efficiency were recorded with pre-emergence application of atrazine 1.0 kg/ha + post-emergence application of halosulfuron-methyl 90 g/ha and PE application of pendimethalin 1.5 kg/ha + PoE application of halosulfuron-methyl 90 g/ha treatments. However, these two treatments were statistically at par with each other.

SUMMARY

Experiment was carried out during *Kharif*, 2015 at Agricultural College Farm, Bapatla. Among the herbicides tested, pre-emergence application of atrazine 1.0 kg/ha + post-emergence application of halosulfuron-methyl 90 g/ha registered the lowest density (no./m^2) and biomass of weeds (g/ha) and highest weed control efficiency (%) and yield of maize and this was statistically at par with pre-emergence application of pendimethalin 1.5 kg/ha + post-emergence application of halosulfuron-methyl 90 g/ha.

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Short communication

Integrated weed management in *Bt* cotton

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Key words: *Bt* cotton, Economics, Herbicide, Weed management, Yield

Cotton is one of the major commercial crop and also called 'White Gold'. Of many problems faced by the cotton growers, the most troublesome one is the control of weeds particularly during early stages of crop growth. Venugopalan *et al*. (2009) reported a reduction in yield due to weeds in cotton crop to the extent of 50 to 85%. Farmers are facing problem of timely weed management in cotton crop and also increased cost of production due to scarcity of labours, increased labour wages *etc*. To overcome these problems farmers are using the herbicides which are available in market, without considering the lable claim of herbicides, its safe dose of application, persistency, phyto-toxicity and other technical details, which many leads creating problem to other crop or succeeding crop, adverse effect on soil micro flora and fauna, and environmental pollution.

Weeds in cotton field can be effectively killed or their growth can be minimised at the germination stage itself by the use of suitable herbicide. They are capable of giving the crop a relatively better weed free situation in the early stage of crop. Pre-emergence use of pendimethalin and oxyflurofen will control the weeds in early stages and thereby ensure efficient utilization of inputs put in by the farmers. The weeds (annual and perennial), which appear in the later period of crop growth could be controlled by combining cultural methods and post-emergence application of herbicides like quizalofop-ethyl and pyrithiobac-sodium. Thus, herbicides would solve the weed problem quite efficiently and economically. The present investigation aimed at identifying suitable integrated weed management in *Bt* cotton was conducted during *Kharif* 2014 at Post Graduate Instruction Farms, MPKV, Rahuri.

The experiment was conducted at Post Graduate Institute Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra) during *Kharif* season, 2014. The experiment was laid out in randomized block design consisted of three replications of ten treatments, *viz*. one hoeing at 15 days after seeding (DAS) + two hands weeding (HW) at 30 and 45 DAS, three inter cultivations with mechanical weeder at 20, 40 and 60 DAS, pendimethalin pre-emergence application (PE) at 1.0 kg/ha followed by (*fb*) one HW at 45 DAS, oxyfluorfen PE at 0.1 kg/ha *fb* one HW at 45 DAS, pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium post emergence application (PoE) at 75 g/ha at 45 DAS + one inter cultivation through mechanical weeder at 60 DAS, pendimethalin PE at 1.0 kg/ha *fb* quizalofop-ethyl PoE at 50 g/ha at 45 DAS + one inter cultivation through mechanical weeder at 60 DAS, oxyfluorfen PE at 0.1 kg/ha *fb* pyrathiobac-sodium PoE at 75 g/ha at 45 DAS + one inter cultivation through mechanical weeder at 60 DAS, oxyfluorfen PE at 0.1 kg/ha *fb* quizalofop-ethyl PoE at 50 g/ha at 45 DAS + one inter cultivation through mechanical weeder at 60 DAS, weedy check and weed free check. The *Bt* cotton cultivar '*Malika (NCH-207)*' was sown. The gross and net plot size were 6.3 x 5.4 m and 4.5 x 3.6 m, respectively. The soil of experimental site was clayey in texture. The soil was low in available nitrogen (194 kg/ha), phosphorous (17.45 kg/ha) and very high in potassium (483 kg/ha), soil pH 8.15 and electrical conductivity (0.23 dS/m). The recommended fertilizer dose (125:65:65 N, P_2O_5 and K_2O kg/ha) was applied through urea and single super phosphate as half of nitrogen and full of phosphorous and potassium at the time of sowing and half of nitrogen at 30 DAS. Along with the growth and yield parameters of cotton crop, total weed density, weed biomass were periodically recorded by following standard methodology, weed control efficiency, weed index, weed persistence index herbicide efficiency index and crop resistance index were calculated by using standard formulae. The pre-emergence herbicides, *viz*. pendimethalin and oxyflurofen were sprayed very next two DAS and post-emergence herbicide, *viz*. pyrathiobac-sodium and quizalofop-ethyl were applied 45 DAS as per treatments by using hand operated knapsack sprayer, fitted with flat fan nozzle.

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Weed density

The significantly lowest weed density was recorded with pendimethalin PE 1.0 kg/ha *fb* pyrathiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing with mechanical weeder at 60 DAS, oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing with mechanical weeder at 60 DAS and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS, which were at par with weed free.

The pendimethalin or oxyflurofen, PE herbicides component of integrated weed management, might have effectively hindered the germination of weed seeds in initial stage and reduced the weed dynamics of grasses, sedges and broad-leaved weeds effectively. PoE of pyrithiobac-sodium at 45 DAS might have taken care in controlling most of the later germinated broad-leaved weed species effectively and supplemented with one hoeing through mechanical weeder resulted in significantly lowering the weed density. These results were in close conformity with the results of Giri *et al.* (2006), Kaleem *et al.* (2006) and Mahar *et al.* (2007).

Weed biomass

The treatment weed free check registered significantly lowest weed biomass over the rest of treatments but it was at par with pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder 60 DAS, oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS. The integrated effect of PE and PoE application of herbicides as well as hoeing through mechanical weeder resulted in keeping weed density and biomass below the critical level of competition. These results were in agreement with those reported by Panwar *et al.* (1999) and Patel *et al.* (2013).

Weed control efficiency

The significantly higher weed control efficiency was recorded in weed free check treatment (100%). This was followed by pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder 60 DAS (74.26%) , oxyfluorfen PE 0.1 kg/ha *fb* pyrathiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS (71.07%) and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS (69.63%) at harvest. Pendimethalin or oxyflurofen PE and pyrithiobac-sodium PoE might have effectively reduced the weed density resulting in high weed control efficiency, this could be explained based on the fact that, maximum uptake and better assimilation of herbicides was pronounced as soon as weeds emerged. Less weed intensity and its lower biomass in integrated weed control treatments and mechanical weed control treatment compared to weedy check resulted in higher WCE with these treatments. The results were close conformity with the findings of Hiremath *et al.* (2013).

Weed index

Among the weed control treatments, application of pendimethalin PE 1.0 kg/ha *fb* pyrathiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder 60 DAS (5.23%), oxyfluorfen PE 0.1 kg/ha *fb* pyrathiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS (5.65%) and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS (5.95%), recorded significantly minimum weed index as compared to rest of the treatments. The significantly maximum weed index (62.84%) was noticed in weedy check treatments. Lower weed index was due to higher *Bt* seed cotton yield in the corresponding treatments and vice versa. This might be due to sequential herbicidal application with one supplemented hoeing through mechanical weeder. The results were close conformity with the findings of Hiremath *et al.* (2013).

Herbicide efficiency index

The data revealed that, numerically maximum value of herbicide efficiency index was rest with application of pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder 60 DAS (4.40%) but it was at par with oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS (3.52%). This data reveals that PE and PoE herbicides application was effective along with integrated management as compared to application of pre-emergence herbicide alone.

Weed persistence index

Among the weed control treatments, significantly minimum weed persistence index value was observed at harvest with treatment PE application of application of pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder 60 DAS, (1.38%) but it was at par with oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45

DAS + one inter culturing through mechanical weeder at 60 DAS (1.42%), and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS, (1.44%).

Crop resistance index

Among the weed control treatments, crop resistance index at harvest significantly maximum with PE application of application of pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS (6.41), but it was at par with oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS (4.67) and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS, (4.52).

Seed cotton yield

The seed cotton yield under weed free check treatment (2.72 t/ha) was significantly higher than rest of treatments. However, it was at par with pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder 60 DAS (2.58 t/ha), oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS (2.56 t/ha) and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS (2.56 t/ha). This might be due to low weedy situation during initial stage and further control of latter germinated of weeds by application of post-emergence herbicides at 45 DAS with supplemented inter cultivation through mechanical weeder at 60 DAS and thus, reducing the weed competition during critical initial to peak growth period of the crop. In fact, inter cultivation operation carried out at 60 DAS almost maintained weed free condition throughout remaining period of crop growth period. These results were in conformity with those reported by Hiremath *et al.* (2013).

Lint yield

The lint yield was significantly higher in weed free check (980 kg/ha) than rest of treatments. However, it was at par with pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS (945 kg/ha), oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS (933 kg/ha) and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS (922 kg/ha). This might due to higher accumulation of photosynthates in leaves, stem and reproduction parts, resulted in better development of bolls and thereby increase lint yield in integrated weed control and weed free treatments. Similar results were reported by Hiremath *et al.* (2013).

Stalk yield

The stalk yield under weed free check treatment (4.08 t/ha) was significantly higher than rest of treatments except pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one

Table 1. Effect of different weed control treatments on weed dynamics in *Bt.* cotton

Treatment	Weed density (no./m^2)			Weed biomass (g/m^2)	WCE (%)	Weed index	Herbicide efficiency index	Crop resistance index	Weed persistence index
	20 DAS	60 DAS	At Harvest						
One hoeing at 15 DAS + two hand weeding at 30 and 45 DAS	4.4(19.1)	5.1(25.5)	8.0(63.5)	8.2(67.4)	69.63	5.95	-	4.52	1.44
Three inter culturing through mechanical weeder at 20, 40 and 60 DAS	5.6(30.7)	6.1(37.1)	8.6(73.3)	8.7(75.7)	64.94	43.28	-	3.46	1.56
Pendimethalin PE 1.0 kg/ha *fb* one HW at 45 DAS	5.0(24.6)	5.3(27.6)	8.6(74.0)	8.3(69.2)	64.62	30.87	1.71	4.20	1.47
Oxyfluorfen PE 0.1 kg/ha *fb* one HW at 45 DAS	5.5(29.9)	5.4(29.1)	8.8(76.8)	8.7(70.3)	63.27	34.14	1.67	4.05	1.61
Pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS	4.1(16.3)	5.1(25.8)	7.4(53.8)	7.2(52.2)	74.26	5.23	4.40	6.41	1.38
Pendimethalin PE 1.0 kg/ha *fb* quizalofop-ethyl PoE 50 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS.	5.1(25.9)	6.0(36.0)	8.1(65.9)	8.5(71.2)	68.47	40.05	1.38	4.01	1.60
Oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS	4.3(17.8)	4.4(18.9)	7.8(60.5)	8.0(64.1)	71.07	5.65	3.52	4.67	1.42
Oxyfluorfen PE 0.1 kg/ha *fb* quizalofop-ethyl PoE 50 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS	5.9(34.5)	6.1(36.8)	8.4(70.9)	8.6(73.7)	66.09	42.88	1.06	3.65	1.55
Weedy check	9.0(80.9)	11.9(140.9)	14.5(209.1)	11.7(137.0)	0.00	62.84	0.00	1.00	100
Weed free check	0.00	0.00	00	0.00	100.00	0.00	-	0.00	0.00
LSD (p=0.05)	0.54	0.76	0.70	0.98	1.62	0.37	0.18	0.29	0.06

$\sqrt{x+0.5}$ Transformed values. Original values are in parentheses; HW-Hand weeding; DAS-Days after sowing; *fb*- Followed by; PE-Pre-emergence; PoE - Post-emergence

Table 2. Effect of weed control treatments on plant growth attributes, yield attributes, seed cotton, lint, stalk yield and economics of *Bt*. cotton

Treatment	Seed cotton yield (t/ha)	Lint yield (kg/ha)	Stalk yield (t/ha)	Cost of cultivation (x10^3 `/ha)	Net returns (x10^3 `/ha)	B : C Ratio
One hoeing at 15 DAS + two hand weeding at 30 and 45 DAS	2.56	922	3.84	54.32	54.01	1.99
Three inter culturing through mechanical weeder at 20, 40 and 60 DAS	1..3	531	2.30	40.39	24.47	1.60
Pendimethalin PE 1.0 kg/ha *fb* one HW at 45 DAS	1.86	651	2.79	46.82	31.89	1.68
Oxyfluorfen PE 0.1 kg/ha *fb* one HW at 45 DAS	1.78	628	2.67	45.68	29.61	1.64
Pendimethalin PE 1.0 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS	2.58	945	3.87	42.27	66.70	2.57
Pendimethalin PE 1.0 kg/ha *fb* quizalofop-ethyl PoE 50 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS.	1.63	570	2.45	40.79	28.16	1.69
Oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS	2.56	933	3.84	41.13	67.24	2.63
Oxyfluorfen PE 0.1 kg/ha *fb* quizalofop-ethyl PoE 50 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS	1.55	546	2.32	40.90	24.55	1.60
Weedy check	1.00	353	1.51	36.64	5.86	1.15
Weed free check	2.72	980	4.08	55.84	59.21	2.06
LSD (p=0.05)	0.17	64	0.54		13.92	

HW-Hand weeding; DAS-Days after sowing; *fb*- Followed by; PE- Pre-emergence; PoE - Post-emergence

interculturing through mechanical weeder at 60 DAS (3.87 t/ha), oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder at 60 DAS (3.84 t/ha) and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS (3.84 t/ha). This might due to higher accumulation of photosynthates in leaves, stem and reproduction parts. Similar result were reported by Hiremath *et al.* (2013).

Economics

Significantly the highest net returns (` 67239/ha) with maximum B:C ratio (2.63) was accrued with oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS compared to rest of the treatments, but was found at par with pendimethalin 1.0 kg/ha PE *fb* pyrathiobac sodium PoE 75 g/ha at 45 DAS + one interculturing through mechanical weeder 60 DAS which recorded next best net returns (` 66696/ha) and B:C ratio (2.57). The highest net returns and maximum B:C value was observed with oxyfluorfen PE 0.1 kg/ha *fb* pyrathiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS and pendimethalin PE 1.0 kg/ha *fb* pyrathiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder at 60 DAS might be due to higher gross returns and comparatively less cost of production compared to treatment Weed free check and one hoeing at 15 DAS + two hand weeding at 30 and 45 DAS. These results were in conformity with those reported by Hiremath *et al.* (2013).

SUMMARY

Application of pendimethalin PE 1.0 kg/ha or oxyfluorfen PE 0.1 kg/ha *fb* pyrithiobac-sodium PoE 75 g/ha at 45 DAS + one inter culturing through mechanical weeder 60 DAS in *Bt*. cotton recorded significantly lowest total weed density, weed biomass, weed index and weed persistence index while higher WCE, herbicide efficiency index, crop resistance index also higher seed cotton, lint, stalk yield, net returns and B:C ratio.

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Short communication

Flurochloridone -A promising herbicide for weed management in carrot

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Carrot (*Daucus carota* L.) is an important vegetable crop grown in spring, summer and autumn for fresh market and processing under tropical, sub-tropical and temperate climate. It is a high value cash crop and rich source of vitamin-A, which helps people to improve the nutritional quality of their diets. Weed control in carrots is very important due to early slow crop growth and lack of competitiveness with weeds. Without weed control, yields are often reduced by more than 90% (Swanton *et al.* 2009). Manual weeding is widely practiced for controlling weeds which is costly and have certain limitations, *viz.* hike in high labor wages, timely unavailability of labour and soil physical conditions that often limit physical and mechanical weeding. Hence, there is a need to find out alternate methods of weed control. Herbicide based weed management is becoming popular among farmers on account of its lower cost and effective weed control. As limited herbicides are available for weed control in carrot, herbicide flurochloridone was evaluated against infestation of complex weed flora in carrot.

Present study, was conducted at Agriculture Research Farm Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh during *Rabi* seasons of year 2014-15 and 2015-16. The soil at the location was sandy loam in texture with normal (pH 7.4) reaction. The treatments comprised of flurochloridone at 500, 625 and 750 g/ha as pre-emergence and was compared with pendimethalin 1000 g/ha and metribuzin 525 g/ha. The efficacy of these treatments was assessed against two hand weeding and untreated treatments in a randomized block design replicated thrice. A water volume of 500 L/ha was used for the application of the herbicide using flat fan nozzle fitted in a plot sprayer. The carrot crop was grown with recommended package of practices in the region. Three places in each treatment were selected at random and marked with pegs. Species wise weed count was recorded by placing 1 m^2 quadrate in marked area at 45 days after herbicide application (DAA). Hand weeding was taken up at 25 and 50 days after sowing. For quantifying weed biomass, the weed samples were sun dried for four days and then in hot air oven for drying at 60 ^{0}C and dry weight (g/m^2) was recorded separately for each species. The crop was harvested at maturity and fresh carrot yield was recorded in kg/plot and converted to t/ha. The data on density and biomass of different weeds were pooled and subjected to square root transformation before statistical analysis and significant difference were compared by critical difference at 5% level of probability.

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Weed flora

The dominant weed flora observed in experimental field comprised of both narrow-leaf weeds, *viz. Cyperus rotundus* and *Cynodon dactylon,* broad-leaf weeds *viz. Chenopodium album, Melilotus* spp. and *Trianthema portulacastrum*. Sporadic presence was observed of *Anagallis arvensis, Physalis minima* and *Parthenium hysterophorus.*

Effect on weed biomass and weed control efficiency

The pooled data of two years indicated that weed density and dry biomass of major weeds were significantly lower in herbicide treated crop as compare to untreated (**Table 1**). Pre-emergence application flurochloridone 750 g/ha was statistically at par with flurochloridone 625 g/ha in causing significant reduction in biomass of all weeds when compared to pendimethalin at 1000 g/ha and metribuzin at 525 g/ha. Pre-emergence application of herbicides gave effective control of weeds by inhibiting the germination of weeds and also killing the emerging weeds at early stages (Vyas *et al.* 2000). Application of herbicides at pre-germinating stage in crop was found to control poaceae weeds and broad-leaved weed effectively (Khare and Jain 1995). Dobrzanski and Palczynski (1998) also found same result in case of different root vegetables.

Table 1. Effect of weed management treatments on weed density and biomass of major weeds associated with carrot at 45 DAA (pooled data)

Treatment	Dose (g/ha)	Weed density (no./m^2)					Dry weed biomass (g/m^2)				
		C. dectylon	*C. rotundus*	*T. portulacastrum*	*C. album*	*Melilotus sp.*	*C. dectylon*	*Cyprus rotundus*	*T. portulacastrum*	*C. album*	*Melilotus* sp.
Flurochloridone	500	3.28(1.94)	3.00(1.87)	3.78(2.07)	5.44(2.44)	4.17(2.16)	2.90(1.84)	2.71(1.79)	4.46(2.23)	7.18(2.77)	4.68(2.28)
Flurochloridone	625	1.06(1.25)	1.00(1.22)	1.22(1.31)	1.73(1.49)	1.45(1.39)	1.38(1.37)	1.39(1.37)	1.99(1.58)	3.34(1.96)	2.08(1.61)
Flurochloridone	750	0.95(1.20)	0.89(1.18)	1.06(1.25)	1.56(1.43)	1.28(1.33)	1.22(1.31)	1.22(1.31)	1.80(1.51)	3.10(1.90)	1.88(1.54)
Pendimethalin	1000	1.67(1.47)	4.06(2.13)	1.78(1.51)	2.06(1.60)	2.17(1.63)	1.98(1.57)	3.90(2.10)	2.70(1.79)	4.26(2.18)	2.74(1.80)
Metribuzin	525	1.50(1.41)	1.45(1.39)	1.73(1.49)	2.22(1.65)	2.06(1.60)	1.80(1.51)	1.88(1.54)	2.55(1.74)	4.07(2.14)	2.53(1.74)
Hand weeding	25&50 DAS	0.78(1.13)	0.78(1.13)	0.89(1.18)	1.39(1.37)	1.11(1.27)	1.07(1.25)	1.10(1.26)	1.62(1.46)	2.89(1.84)	1.71(1.49)
Untreated	-	13.1(3.68)	12.1(3.55)	14.8(3.92)	21.9(4.74)	16.9(4.18)	11.3(3.44)	10.7(3.34)	17.7(4.26)	28.5(5.39)	18.3(4.33)
LSD (p=0.05)		0.14	0.14	0.17	0.13	0.15	0.12	0.15	0.16	0.17	0.12

Figures in the parentheses are square root transferred ($\sqrt{x+0.5}$) values, DAS= Days after sowing, DAA= Days after application

Table 2. Effect of weed management treatments on weed control efficiency at 45 DAA and carrot yield (pooled data)

Treatment	Dose (g/ha)	Weed control efficiency					Carrot yield (t/ha)
		Cynodon dactylon	*Cyperus rotundus*	*Trianthema portulacastrum*	*Chenopodium album*	*Melilotus sp.*	
Flurochloridone	500	74.25	74.55	74.39	74.845	74.76	25.01
Flurochloridone	625	87.56	87.08	88.65	88.26	88.88	29.88
Flurochloridone	750	89.01	88.67	89.81	89.105	89.97	30.34
Pendimethalin	1000	81.92	67.11	84.68	85.04	85.19	27.50
Metribuzin	525	83.60	82.57	85.86	85.695	86.07	27.90
Hand weeding	25&50 DAS	90.40	89.78	90.86	89.86	90.81	31.14
Untreated	-	-		-	-	-	22.92
LSD (p=0.05)	-	-	-	-	-	-	1.50

DAA= Days after application, DAS= Days after sowing

Criterion for herbicide weed control efficiency (WCE) was taken as the % of reduction in weed biomass in particular treatment in comparison to untreated control. Amongst herbicides, maximum weed control efficiency was recorded in flurochloridone 750 g/ha, which was closely followed by flurochloridone 625 g/ha and both had higher WCE than pendimethalin and metribuzin against both narrow- and broad-leaf weeds.

Carrot yield

The highest carrot yield was recorded with two hand weeding (31.14 t/ha). It was at par to flurochloridone 750 g/ha (30.34 t/ha) and flurochloridone at 625 g/ha (29.90 t/ha). Both these treatments had significantly higher yield than pendimethalin 100 g/ha (27.53 t/ha) and metribuzin 70% WP (27.90 t/ha) (**Table 2**). All the herbicides treatment showed significantly higher carrot yield over the untreated treatment. This might be due to less crop-weed competition for moisture, light and nutrient and efficient utilization of resources by carrot in herbicide treated and hand weeded treatments resulting in higher assimilation of photosynthesis and higher carrot yields.

Thus, it was concluded that for effective control of weeds and higher yield of carrot, flurochloridone 625 g/ha as pre-emergence can be recommended under agro-climatic conditions of Varanasi.

SUMMARY

Field experiment was conducted during *Rabi* season of 2014-15 and 2015-16 at agricultural research farm of Banaras Hindu University, Varanasi (Uttar Pradesh) to study the bio-efficiency of flurochloridone on narrow and broad-leaved weeds in carrot. Flurochloridone 500, 625 and 750 g/ha, pendimethalin 1000 g/ha and metribuzin 525 g/ha were applied as pre-emergence. Maximum reduction in different weed species biomass was observed with flurochloridone 750 g/ha followed by flurochloridone 625 g/ha. Weed control efficiency was highest with flurochloridone at 750 g/ha for all the weed species. Carrot yield was maximum with two hand weeded treatment (31.14 t/ha) and was comparable to flurochloridone 750 g/ha and flurochloridone 625 kg/ha.

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Short communication

Three fungal pathogens associated with horse purslane (*Trianthema portulacastrum*) in North India

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Key words: Biological control, *Cochliobolus australiensis,* Fungal pathogens, Horse purslane

Weeds represent one of the major kinds of pests worldwide which reduce yield and the quality of crops through competition for essential inputs such as water, nutrients and sunlight. Of the total annual loss of agricultural products due to various pests in India, weeds roughly account for 37%, insects for 29%, diseases for 22% and other pests for 12% (Yaduraju 2006). It is widely accepted that sole dependence on herbicides for weed control is inopportune and that alternative and complementary control options should be developed. The application of plant pathogens is considered especially for parasitic weeds, difficult to control *via* chemical means, or for small-scale and specialized crops where the development of specific chemical solutions is too expensive (Auld and Morin 1995).

Trianthema portulacastrum L. (Aizoaceae), commonly known as horse purslane, santhi or santha, is one of the troublesome weed in Haryana, Punjab, Rajasthan, Uttar Pradesh and Delhi affecting important agricultural crops such as maize, sorghum, sugarcane, cotton, mungbean, potato, soybean, black gram, pearl millet, pigeon pea (Kumar and Aneja 2016). The biological control of weeds by plant pathogens has gained acceptance as a practical, environmentally safe and beneficial method. The use of fungal pathogens as biological control agents for weeds is provoking increasing interest worldwide. Some commercial products are already available in developed countries as potential mycoherbicides to control terrible weeds (Aneja *et al.* 2013). In the present study, survey to find out the natural enemy associated with the horse purslane that may be used as potential mycoherbicide agents against *T. portulacastrum* was conducted during 2012-2015,

Preparation of *Trianthema* extract dextrose agar medium (TEDA)

A specific and economic growth medium was prepared growing. This medium was found to be very suitable with the supplementation of dextrose for growing pathogens that are specific to horse purslane. The plant extract of *T. portulacastrum* was prepared by boiling and dextrose was added into the extract as a supplement and sterilized by autoclaving at 121 ^{O}C at 15 lbs pressure for 15 minutes.

Infected leaves with different types of symptoms were collected in sterilized polythene bags and brought to the laboratory for the study of symptoms, isolation, identification and pathogenicity tests of the pathogen/s involved.

Isolation and identification of the fungal pathogens

Leaf surfaces of horse purslane were washed with distilled and sterilized distilled water in order to remove epiphytic fungi and adherent soil particles**.** The infected leaves were cut into 1.0-1.5 cm fragments, surface sterilized with 70% ethanol by dipping for 1-2 minutes and then rinsed in sterile distilled water for 3 to 4 times. These fragments were transferred on to the *Trianthema* extract dextrose agar (TEDA) medium supplemented with streptomycin sulphate. Petri-plates were incubated at 25 °C for 3 to 4 days (Aneja *et al.* 2014). After appearance of fungal growth on leaf surface, fungus was sub cultured and purified on *Trianthema* extract dextrose agar (TEDA) and Potato Dextrose Agar (PDA). Isolated pathogens were morphological characterized and identification was confirmed by molecular characterization.

Pathogenicity test

The pathogenicity was determined under *in vitro* conditions. The leaves were washed with sterile distilled water and wiped with a cotton swab dipped in 70% alcohol. Some of the leaves before inoculation were injured by pricking on adaxial surface with a flamed needle. Mycelial discs of 8 mm taken from 5 days old culture were placed on injured and uninjured portions. The inoculated leaves were kept in sterilized moist chambers and incubated at 25 °C. Regular observations were made for the appearance of symptoms for 3 days of incubation.

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A total of three fungal pathogens namely, *Cochliobolus australiensis, Cochliobolus spicifer* and *Colletotrichum gloeosporioides* were reported on this weed (**Table 1**). Molecular identification of *C. australiensis* was confirmed from Macrogen Inc., Advancing through Genomics, Korea and sequence was submitted to the National Center for Biotechnology Information (NCBI) with accession number KM999998. *C. spicifer* (IMI no. 503552) and *C. gloeosporioides* (IMI no. 503551) were identified by Commonwealth Agricultural Bearux International (CABI), International Mycological Institute (IMI) Egham, England.

Cochliobolus australiensis

Effuse velvety, grey to blackish-brown growth with pale dark brown, smooth, septate hyphae. Conidiophores appear as single, flexuous, geniculate, septate, smooth, cylindrical, reddish-brown, up to 150 µm long, 3-7 µm wide. Conidiogenous cells are polytretic, integrated, terminal and intercalary, sympodial, cicatrized, bearing verruculose conidiogenous nodes. Conidia are straight, ellipsoidal or oblong, rounded at the ends, pale brown to mid reddish-brown, usually 3- rarely 4- or 5-distoseptate, 14-40 × 6-11 µm (**Figure 1**).

Cochliobolus spicifer

It produced olive green to dark brown coloured colonies (**Figure 2. A**). Conidiophores appear solitary or in small groups, flexuous, mid to dark brown, up to 300 µm long, 4-9 µm thick. Conidiogenous cells are polytretic, integrated, terminal, sympodial, cylindrical, and prominently cicatrized. Conidia are straight, oblong or cylindrical, round at ends, golden brown when mature except for a small area just above the scar which remains hyaline, smooth, constantly three-pseudoseptate, 20-40 x 9-14 µm (mostly 30-36 x 11-13 µm); hilum 2-3 µm wide (**Figure 2**).

Colletotrichum gloeosporioides

Symptoms are dark blackish brown coloured start at the margins and enlarge over the leaf. Fungus produces orange white colored colonies with white margins on the potato dextrose agar medium. The fungus produces hyaline, one-celled, ovoid to oblong, slightly curved or dumbbell shaped conidia, 10-15 µm in length and 5-7 µm in width (**Figure 3**). The waxy acervuli that are produced in infected tissue are sub-epidermal, typically with setae, and simple, short, erect conidiophores.

Figure 1. *Cochliobolus australiensis* (A) Leaf spots; (B) Fungal growth on PDA plate, (C) 4-5 septate conidia of the fungus

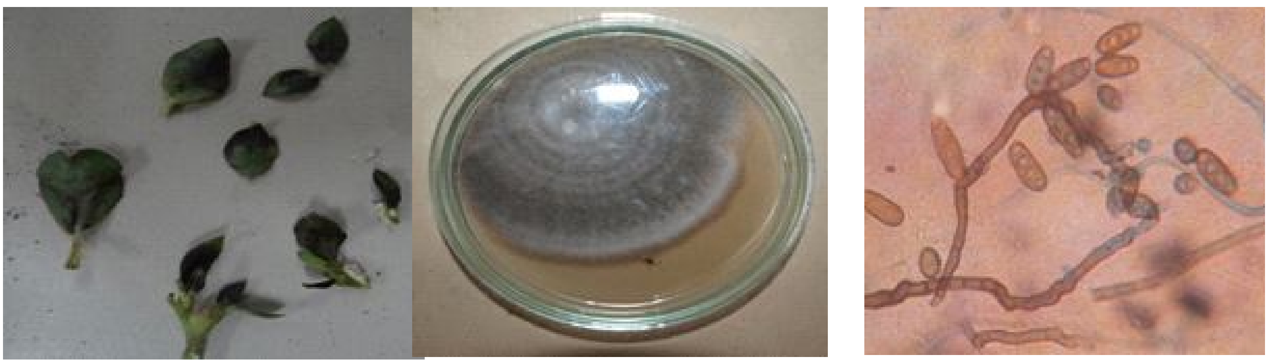

Figure 2. *Cochliobolus spicifer* (A) Leaf spots, (B) Growth on PDA plate, (C) 2-3 septate golden brown conidia of the fungus

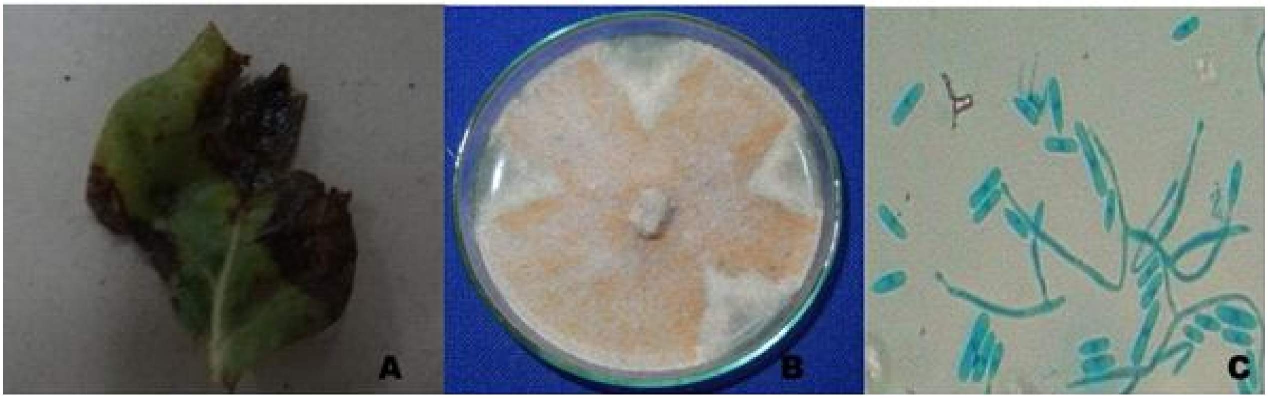

Figure 3. ***Colletotrichum gloeosporioides*** **(A) Leaf spots, (B) Growth on PDA plate, (C) Single cell conidia of the fungus**

Table 1. Total fungal pathogens isolated from *Trianthema portulacastrum*

Fungus	Symptoms	Samples collected from	IMI number	Accession number	Gene Bank submitted name	Isolates
Cochliobolus australiensis	Leaf spot	Jyotisar	-	KM999998	*Cochliobolus australiensis* strain VKR	D-TP
Cochliobolus spicifer	Leaf spot	Kurukshetra	503552	-	-	DT-1
Colletotrichum gloeosporioides species complex	Leaf spot	Kurukshetra	503551	-	-	CT-1

Pathogenicity test

Typical disease symptoms were produced on both injured and uninjured leaves in *in-vitro* and the inoculated pathogen was re-isolated and found similar to the original isolate in cultural characteristics thus confirming the pathogenicity of all the phytopathogens to *T. portulacastrum* and completing the Koch's postulates.

Molecular characterization of fungal pathogens

PCR amplification of 18S rRNA gene with universal primers for the fungal plant pathogen, *viz. Cochliobolus* sp. (D-TP) produced an amplification product of approximately 557 bp. The sequence similarity search of the sequenced products obtained were analysed through BLAST that confirmed the identification of these isolates namely, *Cochliobolus australiensis.* The alignment of retrieved sequences from NCBI database with 18S rRNA of the fungal isolate D-TP showed maximum homology with *Cochliobolus australiensis*. The gene sequences of the fungal pathogen have been submitted to NCBI under the accession number KM999998.

Out of three isolated fungal pathogens, two has been reported first time from *T. portulacastrum,* namely *Cochliobolus australiensis* and *Cochliobolus spicifer. Colletotrichum gloeosporioides* was reported previously by Darshika and Daniel (1992).

SUMMARY

A number of phytopathogenic fungi are known to be associated with horse purslane. Three new fungal pathogens have been found to be associated with horse purslane, which may be used for the preparation of mycoherbicide. There may be possibility to prepare cultural blends with suitable adjuvants. One of the fungal pathogen, *Gibbago trianthema,* has shown the potential to be used as successful biological control agent. New phytopathogenic fungal genera reported during this study, can be further exploited for the biological control of horse purslane.

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Short communication

Weed manager (App for mobile): Harnessing innovations in Indian farming

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Key words: Agriculture, Mobile App, Weed manager, Weed management

India is an agriculture based developing country and it is the primary occupation of 65–70% Indian population. To achieve higher agriculture production, farmers should be well aware of latest technologies and current information on day-to-day agricultural affairs. The data on farming are available through many sources such as print media, audio and visual aids, newspaper, TV, internet, mobile *etc*., but the formats and structures of data are dissimilar.

A mobile App is a software based programme that contains formally encoded knowledge of experts in a given problem area or domain and is able to provide help to a non-specialist to problem solving in that domain (Patterson 2004). In agriculture, expert systems were developed in various disciplines (Olmo and Recasens 1995, Schulthess *et al.* 1996, Chakrabarti and Chakraborty 2007, Ravisankar *et al.* 2010, Ahmed Rafea 2010) that combine the experimental knowledge and experience with intuitive reasoning skills of specialists to aid in making the best decisions. The Apps are not only useful for stakeholders located at remote area where desktop PCs are not available, but would also be available to farmers and all other stakeholders for extracting information from the web.

Presently, mobile communication technology has become the world's most common way of transmitting voice, data, images and services due to advantages of affordability, wide ownership, voice communications and instant and convenient service delivery. The cost of acquisition of a typical mobile phone is lower than that of a PC. It is also easy to learn how to use a mobile phone, even for computer-illiterate people. This fact makes a mobile device most appropriate medium to introduce technology to users who are not compute friendly. The objective of the present study was to develop App for mobile phones which provide weed management related information to different stakeholders.

The first step in building a mobile App is knowledge acquisition. Methodology is mainly based on the principal of knowledge level which means developing a knowledge model at the farmer's level problem solving approach. Android Operating System has the largest share among the smart phones in India. Therefore, initially Apps are being developed for Android operating mobiles. In the light of existing problem and need of the user–friendly mobile app for farmers, agriculture officials, students and Industry professionals, a mobile App named '*Weed Manager'* was developed by the ICAR–Directorate of Weed Research, Jabalpur. With the help of scientists of ICAR-Directorate of Weed Research, Jabalpur, data were collected on crops/cropping systems, dominant weeds, herbicides availability in the market and crop –wise recommendations of herbicides for weed control. Data were also obtained from the data repository maintained at ICAR-Directorate of Weed Research as well as from the published information. Further, some other related information was collected from literature (Naidu 2012) where information about weeds scientific names, common names along with weed images was documented.

The knowledge engineer coded the information in the form of rules or some other representation scheme. System editor (software expert) served as intermediate between the domain expert and the mobile that emulates their expertise. The software expert acquired the information about the weeds in the form of facts and rules through consultation and document analysis and then prepared a knowledge base for the system. The process was repeated till the sufficient knowledge was collected to build the expert system. The basic requirement to operate this app is to have an Android device with net connectivity, and the software of '*Weed Manager'* to be downloaded from the Directorate website (ww.dwr.org.in). After completion of download, setup file has to be run for the installation in a device. An icon ( ) will appear on mobile screen after complete installation. Data flow in the App (**Figure 1**) along with step-by-step data flow in *Weed Manager* is presented (**Figure 2**).

Decision making to control weed is challenging. Broad-spectrum of weeds found in fields, and

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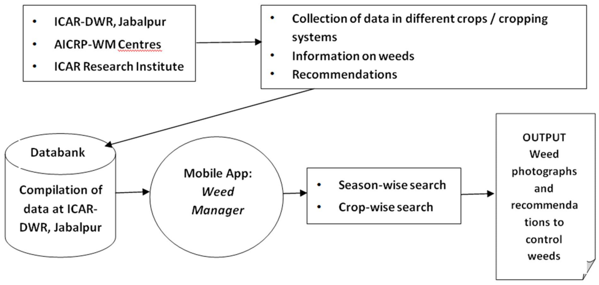


Figure 1. Data flow diagram

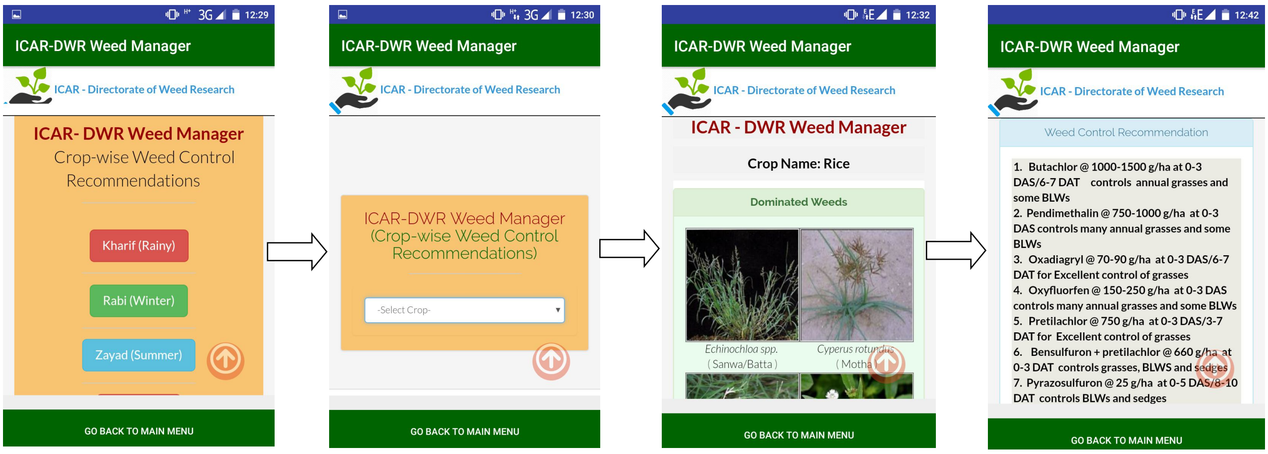


Figure 2. Step-by step data flow

availability of a number of herbicides in the market make the selection of a suitable herbicide difficult. *Weed Manager* can assist in making right decision to manage such weeds in various crops. It provides advice for the control of weeds specific to the crop and informs the best herbicide with optimum dosage and method of application.

It is a menu–driven App, where crops are grouped by season. User can select crop based on season like rainy, winter or summer (*i.e. Kharif*, *Rabi* and *Zayad*). After selecting season, user can choose the crop. A screen will appear with dominated weeds details along with weed management recommendations for that particular crop.

Evaluation of App

The performance of the App was evaluated using the data obtained from different users. Data were collected through the pre-tested questionnaire from the users who have downloaded the App. Questionnaires were sent to all users. Questionnaire included the opinion of users on different points *viz.* general information, working of the App, quality/ reliability of information provided, satisfaction level/ easiness provided in the app, *etc*. along with suggestions for improvement.

Total 156 filled proforma were received. Most of the users (42%) were academicians who used this App for accessing weed management information for their academic purposes including research and extension. Around 28% users were student who are doing their research work on weed management. Only 11% farmers were using App to get information which helped them to reduce the yield losses due to weeds (**Figure 3**). The reason for less number of farmers as App users, could be the language of the

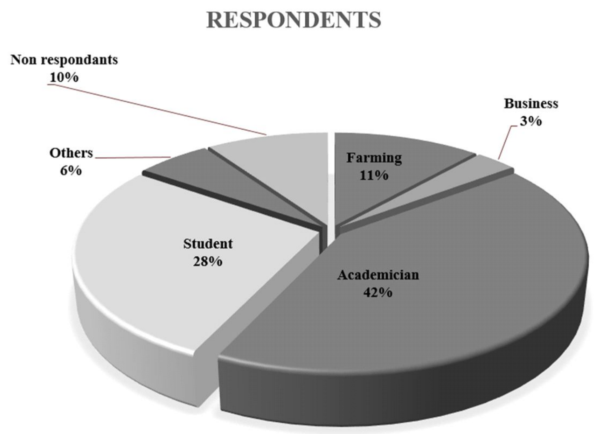
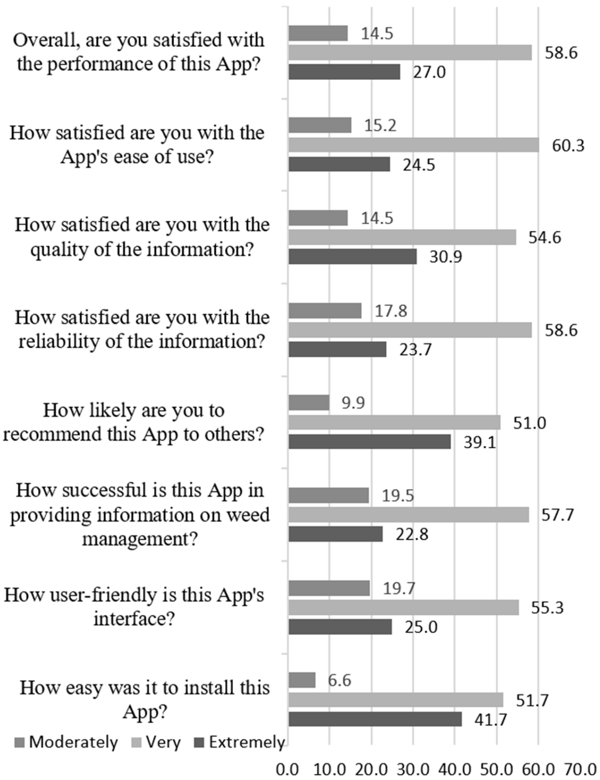


Figure 3. Distribution of respondents

App (English). Most of the farmers can not read and understand English. Therefore, considering their problem, efforts are being made to translate the information provided in the App in Hindi. In future, it is planned to translate the information in regional languages also.

Feed back of users on specific questions are depicted as the horizontal bar diagram (**Figure 4**).

Mobile applications in general and in agriculture in particular hold significant potential for advancing agricultural development. It can provide the most



*Numbers are in percentage

Figure 4. Views of the users in relation to different questions on quality, reliability, easiness and other aspects of the App

affordable ways to millions of people to access information previously unavailable to them.

Weed Manager is capable to transfer crop specific weed management technology to stakeholders efficiently. The services of App will ensure door-step delivery of information on weed management. Further, modification and additions to current system will be a continuous process based on the information and feedback received from the users.

SUMMARY

Agricultural system in India is an amalgamation of various sub-systems where information need is very critical at various stages starting from input supply and production till finally reaching to consumer doorsteps. The farming system faces a plethora of problems including weed management and to solve these problems, *Weed Manager* – a mobile App can provide real time weed management information to farmers and other agriculture stakeholders to improve decision making ability to manage weeds to increase their production and productivity.

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Short communication

Comparative efficacy of fumes of some weeds and oleo-gum resin of guggul (*Commiphora wightii*) on air microflora

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Key words: Bacteria, Fumigants, Guggule, Microbes, Utilization, Weeds

With rapid industrialization and urbanization, environmental pollution has become a serious problem. There are various types of pollution *e.g.* air, water, soil and sound. Chemical fumigation is used as an adjunct for environmental cleaning of indoors, hospital isolation rooms and other critical areas. For healthy living and to check unwanted microflora, often people use cleaning products, which have substantial risk particularly with the products containing volatile organic compounds (Nazaroff and Weschler 2004).Various chemical fumigants, *viz.* formaldehyde gas, hydrogen peroxide, chlorine dioxide *etc.* (Knapp and Battissi 2001) are used to manage air pollution. Although, chemical fumigation is effective, but possess many hazardous effects, which may be responsible for serious illness. It is evident that fumigation with formaldehyde causes sulfhydryl poisoning, protein aggregation and cancer (Rengaramanujum *et al.* 2009). The acute renal, liver, myocardial and skeletal muscle injury can also be developed in cases of severe intoxication by chemical fumigation (Arora *et al.* 1995). Moreover, these chemicals as fumigants also cause damage to the surfaces and equipments.

Plants produce many bio-chemical compounds for biological functions, including defense against insects, fungi and herbivores. The use of different plant fumes for air purification or to kill germs is well documented in our ancient literature (Saxena *et al.* 2007). Smoke produced from natural substances has been used extensively in many societies world over. Ancient ayurvedic physicians have recommended for treatment of several diseases or purification of air indoors or outdoors by use of plant products' smoke. Hence, considering the hazardous effect of chemical fumigants, plants bio-chemicals may be the lucrative alternative to use in indoors, hospitals *etc*. to combat the notorious microorganism present in the air.

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Collection of plants

Aerial parts of *Vernonia cinerea* (Compositae), *Tridax procumbanens* (Asteraceae) and *Lantana camara* (Verbenaceae) were collected from Non-wood Forest Produce Nursery of Tropical Forest Research Institute, Jabalpur and air dried. Oleo-gum resin of *Commiphora wightii* (Burseraceae) was collected from ravines area of district Morena (Madhya Pradesh).

Testing of microbial activity

An experiment was conducted in three different laboratory rooms having dimensions of 25 x 25 (625 sq ft). Bio-fumigation was carried out by burning the mixture of selected plant species dried powder with fumigation catalyst, *viz.* cow dung cake and wooden chips in ratio of 0.5:1:1 as per method described by Rengaramanujum *et al.* (2009) in an earthen pot placed in the centre of table at a height of 125 cm from the floor level. The Petri-dishes containing sterile nutrient agar medium were placed at three different distance, *viz.* 1.0, 1.5 and 2.0 m apart from the table. Petri-dishes were kept open before and after fumigation for 15 minutes. Petri-dishes were incubated at 37 ^{0}C after exposure in the air. The microbial colony count was recorded in Petri-dishes at each distance before and after fumigation after 24 and 48 hours. The experiment was carried out in three replications and the results were expressed in terms of mean cfu/15 min. These were labeled as, L1 (1.0 m), L2 (1.5 m) and L3 (2.0 m).

The effect of fumes of different weeds and guggul resin on air micro-flora of the laboratory are given in **Table 1**. There was significant (p=0.05) decrease in bacterial population after fumigation (**Figure 1**). The bacterial count was found maximum at 2.0 m distance in all the treatments after fumigation. Minimum bacterial count was observed in *C. wightii* oleo-gum resin (0.33 cfu/15 min) followed by *T. procumbanens* (0.67 cfu/15 min) at

Table 1. Mean of bacteria colonies (cfu/15 m) before and after fumigation with fumes of weeds and guggul oleo-gum resin

Species	Bacteria colony recorded before fumigation Mean		Bacteria colony recorded after fumigation at three distance (m) L1 (1.0 m)		L2 (1.5 m)		L3 (2.0 m)		Mean 24 h	Mean 48 h
	24 hrs	48 hrs	24 hrs	48 hrs	24 hrs	48 hrs	24 hrs	48 hrs		
V. cinerea	25.3 ± 4.16	30.33± 3.51	1.67±0.58	8±1.73	3.33±0.58	5.6±2.08	5±2.00	8±4.36	3.33±1.67	7.20±1.39
T. procumbens	16.7 ± 2.08	32.00±4.00	0.67±1.15	4±1.00	1.33±0.58	4±1.00	4±1.00	8.66±2.08	2.00±1.76	5.55±2.69
L. camara	18.3±8.39	26.67±8.14	2.00±1.00	4.33±1.53	4.67±3.21	7±3.46	9±3.61	14.66 ± 6.43	5.22±3.53	8.66±5.36
C. wightii	25.7±9.02	36±5.29	0.33±0.58	2.67±0.58	3.67±1.15	8±4.00	6.33±4.16	9±3.00	3.44±3.01	6.56±3.40
LSD (p=0.05)	NS	NS	NS	2.75	NS	NS	NS	NS	2.01	NS

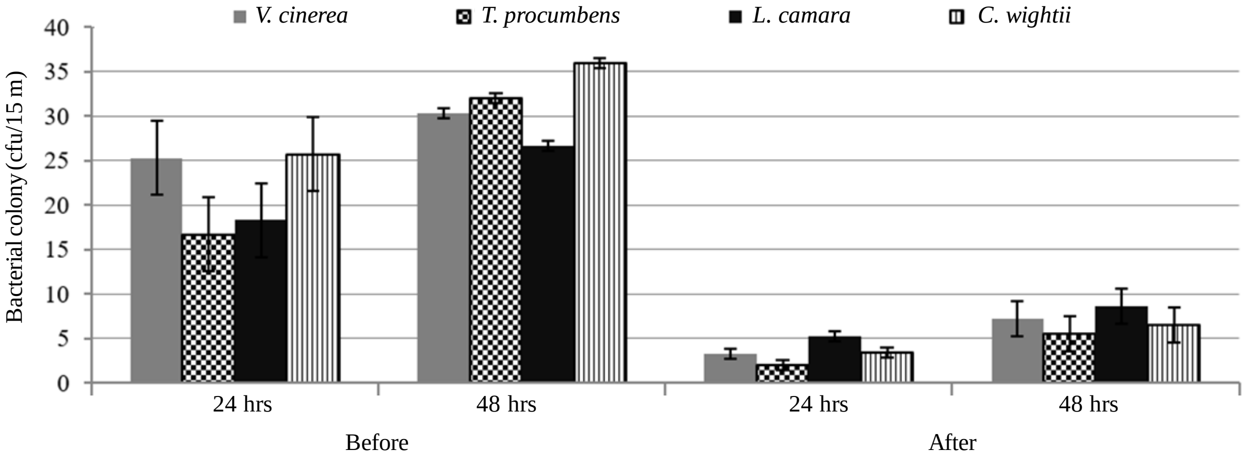

Figure 1. Air bacterial colonies before and after fumigation (microbial count expressed in cfu/15 m)

1.0 m distance. There was no significant difference in bacterial colonies count among the oleo-gum resin of guggul and weeds at both the time durations of 24 and 48 h except at distance 1.0 m (48 h). However, mean values of bacterial colonies at three distances after 24 h showed significant difference while non-significant variation in bacterial colonies were recorded in Petri-dishes exposed with the fumes of *C.wightii, V. cinerea,* and *T. procumbens*. Per cent reduction of total microbial count after fumigation was observed as 92, 96, 88 and 99% and 73, 87, 84 and 93% after 24 and 48 h by *V. cinerea, T. procumbens, L. camara* and oleo-gum resin of *C. wightii,* respectively (**Figure 2**).

Maximum reduction was observed in oleo-gum resin fumes. However, fumes of weed species were also found effective for reducing bacteria population in the laboratory rooms.

The results indicated that weeds fumes are also effective to reduce microbial population in comparison to guggul (*C. wightii*) fumes, which is an important ingredient of Havan 'samigri' (composition of various ingredients) in Yagna and are used for air purification since ancient times. The reduction in the microbial load in the air might be due to the presence of medicinal volatiles or anti-microbial chemicals in the smokes. These results also supported the findings of Nautiyal *et al.* (2007), who studied the effect of Yagna fumes and medicinal plants smoke in reduction of airborne bacteria. Pattnaik (2010) reported antibacterial activity of leaf extract and essential oils of *L. camara* against the bacteria species of *Staphylococcus aureus, Bacillus subtilis, Escherichia coli* and *Salmonella gallinarum*. The antimicrobial effects of *T. procumbens* has also been demonstrated (Sanchez *et al.* 2005). Somasundaram *et al.* (2010) has reported antibacterial activity of *V. cinerea* extracts against most prevalent microbes like *S. aureus, P. aeruginosa, B. cereus, K. pneumonia, E. coli, A. niger* and *C. albicans.* Our observations are in accordance with the findings of several workers, who suggested the advantage of smoke/fumigation by burning incense, herbs and aromatic essence.

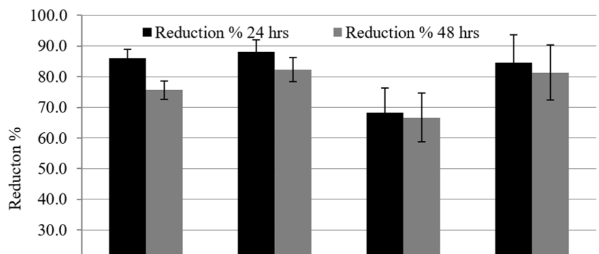

Figure 2. Percent reduction of Air-microflora after fumigation

Mohagheghzadeh *et al.* (2006) reviewed mono and multi-ingredient herbal remedies administered as smoke for the treatment of diseases, but no scientific study ever been conducted to elucidate the effect of fumes of dried power of weeds on air microflora. This study revealed that the dried powder of these weed species also have potential to reduce air microflora and can be used to prepare natural plant based fumigants.

SUMMARY

Presence of air microbes such as bacteria is reported to be associated with a number of illnesses. Chemical based cleaning products and fumigants available in the market have their limitations and sometimes pose severe ill effects on health of mankind. In order to explore the potential of weeds as bio-fumigant to reduce microflora in indoors, experiments were conducted with the fumes of three weeds namely purple fleabean *Vernonia cinerea* (Compositae), coat buttons *Tridax procumbens* (Asteraceae), *Lantana camara* (Verbenaceae) and oleo-gum resin of guggul *Commiphora wightii* (Burseraceae), an important ingredient of Yajnya 'Havan samigri' (composition of different herbal ingredients). The study revealed significant reduction in bacterial colonies (cfu/15 m) after fumigation in Petri-plates exposed to the air. Per cent reduction of bacterial count over control (before fumigation) was recorded as 79.7, 83.7, 67.3 and 82.3% and 76.7, 80.7, 61.0 and 77.3% by *V. cinerea*, *T. procumbens*, *L.camara* and *C. wightii* after 24 and 48 hours, respectively. The findings of the present study highlights that these weeds can be utilized as an ingredient in preparation of herbal fumigants for cleaning the indoors.

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