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Effect of herbicides and their combinations on weed growth and yield of transplanted rice

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ABSTRACT

A field experiment was carried out at Norman E. Borlaug Crop Research Centre of G.B.P.U.A.&T, Pantnagar U.S. Nagar, Uttarakhand during *Kharif* season of 2012 and 2013 to find out the efficacy of different herbicide combinations in transplanted rice. The experimental site was silty clay loam in texture, medium in organic carbon (0.66%), available phosphorus (27.5 kg/ha) and potassium (243.5 kg/ha) with P^H 7.3. *Echinochloa colona, Echinochloa crus-galli, Leptochloa chinensis, Alternanthera sessilis, Ammania baccifera, Caesulia axillaris* and *Cyperus iria* were the major weeds in experimental field. Bispyribac–sodium + ethoxysulfuron 25 + 18.75 g/ha having statically similar with pretilachlor 750 g/ha *fb* ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha and bispyribac-sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha resulted in significantly lowest total weed density, dry matter accumulation and highest weed control efficiency, respectively. The maximum grain yield was recorded with twice hand weeding at 25 and 45 DAT, which was statistically at par with bispyribac–sodium + ethoxysulfuron 25 +18.75 g/ha, pretilachlor 750 g/ha *fb* ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha, bispyribac–sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha and pretilachlor 750 g/ha *fb* ethoxysulfuron 18.75 g/ha over the weedy check.

Key words: Grain yield, Herbicide combinations, Ready mix, Transplanted rice, Weed Control efficiency

Rice is the most important staple food crop of millions of mankind from dawn of civilization (Chakravarti *et al.* 2012). Among the cereal crops, it serves as the principal source of nourishment for over half of the global population (Davla *et al.* 2013). In Indian agriculture, rice is the main source of livelihood for more than 150 million rural households. The total area of rice crop in India in 2015 was 43.95 m ha, production is 106.65 mt and average productivity is 2.4 t/ha (Government of India, Ministry of Agriculture 2015). Weed management is one of the major factors, which affects rice yield. Uncontrolled weeds cause grain yield reduction up to 76% under transplanted conditions (Rao *et al.* 2007). The final choice of any weed control measures will depend largely on its effectiveness and economics. Use of herbicides to keep the crop weed free at critical crop weed competition stages will help in minimizing the cost of weeding as well as managing the weeds below the damaging level. Hand weeding is very easy and environment-friendly but tedious and highly labour intensive. Farmers very often fail to remove weeds due to unavailability of labour at peak periods. Therefore, hand weeding become difficult at early stages of growth due to morphological similarity between grassy weeds and rice seedlings (Rahman *et al.* 2012). Most of the herbicides have effective options for selective weed control but a single herbicide cannot control all weeds of the community (Corbelt *et al.* 2004). Bispyribac-sodium is effective for controling many annual and perennial grasses, sedges, and broad-leaved weeds in rice (Rawat *et al.* 2012). The combined application of different herbicides with different mode of action is required for most effective weed management and avoiding development of herbicide resistance. Therefore, for enhancing the efficacy of herbicides, their sequential and combined application is necessary for controlling mixed weed flora in transplanted rice. Keeping this in view, a field experiment was carried out to evaluate the efficacy of pre- and post-emergence herbicides alone and in combinations in transplanted rice.

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MATERIALS AND METHODS

A field experiment was conducted at N.E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture & Technology Pantnagar, U.S. Nagar, Uttarakhand during *Kharif* seasons of 2012 and 2013. Twelve treatments, *viz.* bispyribac-sodium 25 g/ha, pretilachlor 1000 g/ha, penoxsulam 22.5 g/ha, pyrazosulfuron 20 g/ha, bispyribac-sodium +

ethoxysulfuron 25 + 18.75 g/ha, bispyribac-sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha, pretilachlor 750 g/ha *fb* ethoxysulfuron 18.75 g/ha, pretilachlor 750 g/ha *fb* ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha, pyrazosulfuron 20 g/ha *fb* manual weeding at 25 DAT, pretilachlor (6%) + bensulfuron (0.6%) 6.6% GR 660 g/ha (10 kg/ha), hand weeding at 25 and 45 DAT and weedy check. Experiment was laid out in randomized block design with three replications. All herbicides were applied using knapsack sprayer fitted with flat fan nozzle at spray volume of 500 l/ha. Twenty-eight days old seedling of rice variety "*Sarjoo 52*" were transplanted on July 12, 2012 and June 27, 2013 at a spacing of 20 x 10 cm. The crop was raised by following recommended packages of practices for rice. The data on weed density and weed dry weight were collected from each unit plot at 60 DAT. A quadrate of 0.5 x 0.5 m was placed randomly and weed species within the quadrate were identified and their number was counted. The average number of sample was multiplied by four to obtain the weed density/meter square. The weeds inside the quadrate were uprooted, cleaned and then oven dried. Dry matter of weeds was recorded and expressed in g/m^2.

The data on weed density and weed dry matter were analyzed after subjecting to square root transformation by adding 1.0 to original values prior to statistical analysis. Weed control efficiency (WCE) was calculated on the basis of weed biomass. Yield and yield attributes were recorded at the time of harvesting. Each experimental plot was threshed by Paddy thresher to determine grain yield and it is presented as t/ha.

RESULTS AND DISCUSSION

Major weed flora in weedy plots at 60 days stage of crop growth comprised of *Echinochloa colona, Echinochloa crus-galli* and *Leptochloa chinensis* among grassy weeds; *Alternanthera sessilis, Ammania baccifera* and *Caesulia axillaris* among broad-leaved weeds and *Cyperus iria* among sedge during 2012 and 2013.

Effect on weeds

All the weed control treatments caused significant reduction in the density of all the weeds over weedy check at 60 DAS during 2012 and 2013 (Table 1). Combination of post-emergence application of bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha was found to be very effective in reducing the density of *E. colona* which was at par with twice hand weeding at 25 and 45 DAT, bispyribac - sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha, penoxsulam 22.5 g/ha and bispyribac-sodium 25 g/ha, pretilachlor 750 g/ha *fb* ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha, pyrazosulfuron 20 g/ha *fb* MW at 25 DAT over the weedy check. All treatments except pyrozosulfuron 20 g/ha and pretilachlor (6%) + bensulfuron (0.6%) 6.6% GR 660 g/ha were superior to weedy check in suppressing the growth of *E. crus-galli* during both the years. Among the herbicidal treatments, pretilachlor 750 g/ha *fb* ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha showed the effective control of *L. chinensis* followed by bispyribac-sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha, pretilachlor 1000 g/ha, pretilachlor (6%) +

Table 1. Effect of different treatments on species- wise weed count in transplanted rice at 60 DAT (pooled of 2012 and 2013)

Treatment	Dose (g/ha)	Weed density (no./m^2)							Total weed density (no./m^2)
		E. colona	*E. crus-galli*	*L. chinensis*	*A. sessilis*	*A baccifera*	*C. axillaris*	*C. iria*	
Bispyribac-sodium	25	1.8(3.3)	1.4(1.3)	4.0(16.0)	3.2(9.3)	3.3(11.3)	1.8(2.7)	1.4(1.3)	6.7(45.2)
Pretilachor	1000	2.5(5.3)	1.9(3.3)	2.5(5.3)	4.4(18.7)	4.3(18.7)	3.6(12.7)	2.1(4.0)	8.2(68.0)
Penoxsulam	22.5	1.8(2.7)	1.8(2. 7)	2.8(7.3)	2.9(8.0)	3.1(9.3)	2.5(6.7)	2.6(6.0)	6.5(42.7)
Pyrazosulfuron	20	4.0(16.0)	3.2(10.0)	4.2(17.3)	3.3(11.3)	3.9(18.0)	3.0(9.3)	2.2(4.7)	9.3(86.6)
Bispyribac-sodium + ethoxysulfuron	25+18.75	1.2(0.7)	1.2(0.7)	3.9(14.7)	1.6(2.0)	2.0(3.3)	1.6(2.0)	1.0(0.0)	4.8(23.3)
Bispyribac-sodium + CME + MSM (RM)	20 + 4	1.6(2.0)	1.4(1.3)	2.4(5.3)	1.8(2.7)	2.8(8.0)	1.8(2.7)	1.6(2.0)	4.9(24.0)
Pretilachlor *fb* ethoxysulfuron	750/18.75	2.2(4.7)	1.4(1.3)	3.9(15.3)	1.9(3.3)	3.2(10. 7)	1.6(2.0)	1.0(0.0)	6.1(37.3)
Pretilachlor *fb* CME +MSM (RM)	750/4	1.9(3.3)	1.6(2.0)	2.1(4.5)	2.2(4.0)	2.8(7.7)	1.6(2.0)	1.0(0.0)	4.8(23.5)
Pyrazosulfuron *fb* MW at 25 DAT	20	2.1(4.0)	1.8(2.7)	3.0(8.7)	2.5(5.3)	3.1(11.3)	2.3(5.3)	1.2(0.7)	6.2(38.0)
Pretilachlor (6%) + bensulfuron (0.6%) 6.6% GR	660	2.8(7.3)	4.2(16.7)	2.7(6.7)	2.8(8.0)	3.3(12. 7)	2.4(6.7)	1.2(0.7)	7.7(58.8)
Hand weeding 25 and 45 DAT	-	1.4(1.3)	1.0(0.0)	1.4(1.3)	1.4(1.3)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.1(4.7)
Weedy check	-	4.8(23.3)	5.7 (48.7)	4.6(20.7)	4.7(21.3)	5.5(32. 7)	4.6(22.0)	4.5(20.0)	12.5(156.7)
LSD (P=0.05)		0.9	1.5	0.6	0.9	0.8	0.7	0.7	1.2

Values in the parentheses are the means of original values. Data are subjected to square root transformation $(\sqrt{x+1})$, CME+MSM- chlorimuron-ethyl + metsulfuron- methyl , RM- Readymix, DAT- Days after transplanting, MW- Manual Weeding bensulfuron (0.6%) 6.6% GR 660 g/ha and penoxsulam 22.5 g/ha, as compared to rest of the herbicidal treatments. Combination of bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha being at par with bispyribac-sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha, pretilachlor 750 g/ha *fb* ethoxysulfuron 18.75 g/ha, pretilachlor 750 *fb* chlorimuron-ethyl + metsulfuron-methyl 4 g/ha, pyrazosulfuron 20 g/ha *fb* MW at 25 DAT and hand weeding at 25 and 45 DAT proved effective against the density of *A. sessilis* and *C. axillaris* over the weedy check.

Combination of bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha treated plots recorded the significantly lower number of *A. baccifera* followed by bispyribac-sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha, pretilachlor 750 g/ha, *fb* ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha and hand weeding at 25 and 45 DAT as compared to remaining herbicidal treatments. Complete reduction of *C. iria* was recorded with bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha, pretilachlor 750 g/ha *fb* ethoxysulfuron 18.75 g/ha and pretilachlor 750 g/ha *fb* ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha as compared to rest of the herbicidal treatments.

Total weed density was significantly reduced with bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha which remained at par with bispyribac-sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha and pretilachlor 750 g/ha *fb* ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha as compared to other treatments. The better performance of this treatment might be attributed due to broad spectrum effect of bispyribac-sodium and ethoxysulfuron, which controls broad-leaved weeds and sedges effectively. Similar results were also reported by Hossain *et al.* (2014).

Effect on weed dry matter

Different weed control treatments significantly reduced the biomass of different weed species over the weedy check during both the years at 60 DAT (Table 2). Significantly, total lowest weed dry matter was recorded in bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha being at par with pretilachlor 750 g/ha *fb* ready mix of chlorimuron-ethyl 4 g/ha and bispyribac-sodium + ready mix of chlorimuron-ethyl +metsulfuron-methyl 20 + 4 g/ha over rest of the herbicidal treatments. The broad spectrum effect of bispyribac-sodium, penoxsulam and effective control of broad-leaf weeds and sedges by ethoxysulfuron might be the reason for reducing weed biomass in these treatments. Pretilachlor 750 g/ha *fb* ethoxysulfuron 18.75 g/ha and bispyribac-sodium + chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha were at par with each other indicating the significant effect of sequential application of pre-emergence and post-emergence herbicides. These were significantly superior to alone application of bispyribac-sodium, pretilachlor 1000 g/ha and pyrazosulfuron-ethyl 20 g/ha.

The better performance of herbicide combinations indicates their superiority over alone application. The highest weed density and dry matter were recorded in weedy check. This suggests that without proper management of weeds in transplanted

Table 2. Effect of different treatments on weed dry weight, weed control efficiency and grain yield of transplanted rice (pooled of 2012 and 2013)

Treatment	Weed dry weight (g/m^2)	WCE (%)	No. of grains/ panicle	Grain yield (t/ha)
Bispyribac-sodium (25 g/ha)	6.2(39.6)	67.5	169	5.38
Pretilachor (1000 g/ha)	7.9(66.4)	45.6	152	5.14
Penoxsulam (22.5 g/ha)	5.8(35.2)	71.1	170	5.64
Pyrazosulfuron (20 g/ha)	8.6(75.8)	37.9	146	4.75
Bispyribac-sodium + ethoxysulfuron (25 + 18.75 g/ha)	3.5(15.7)	87.1	193	6.11
Bispyribac-sodium + CME + MSM (RM) (20 + 4 g/ha)	4.2(18.6)	84.8	180	5.97
Pretilachlor *fb* ethoxysulfuron (750/18.75 g/ha)	4.7(23.1)	81.1	176	5.86
Pretilachlor fb CME +MSM (RM) (750/4 g/ha)	3.9(16.8)	86.2	186	6.02
Pyrazosulfuron *fb* MW at 25 DAT (20 g/ha)	5.2(26.9)	77.9	172	5.66
Pretilachlor (6%) + bensulfuron (0.6%) 6.6% GR (660 g/ha)	7.4(56.5)	53.7	161	5.17
Hand weeding 25 and 45 DAT	2.6(9.1)	92.5	199	6.23
Weedy check	10.9(122.0)	-	135	3.52
LSD (P=0.05)	0.7		14.7	0.44

Values in the parentheses are the means of original values. Data are subjected to square root transformation $(\sqrt{x+1})$; CME+MSM-chlorimuron-ethyl +metsulfuron-methyl, RM- Readymix, DAT- Days after transplanting, MW-Manual Weeding rice, the weed growth will be at peak and hamper crop growth. Among herbicidal treatments, highest weed control efficiency (81.7%) was recorded with bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha followed by pretilachlor 750 g/ha *fb* chlorimuron-ethyl + metsulfuron-methyl 4 g/ha and bispyribac-sodium + chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha than rest of the herbicidal treatments, while the lowest weed control efficiency was recorded with alone application of pyrazosulfuron20 g/ha and pretilachlor 1000 g/ha than other treatments.

Effect on crop

Pooled data revealed that the average number of grains/panicle and grain yield were affected significantly by different treatments. It was observed that significantly highest grain yield (6.11 t/ha) was recorded with bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha which was at par with pretilachlor 750 g/ha *fb* chlorimuron-ethyl + metsulfuron-methyl 4 g/ha, bispyribac-sodium + ready mix of chlorimuron-ethyl + metsulfuron-methyl 20 + 4 g/ha and pretilachlor 750 g/ha *fb* ethoxysulfuron 18.75 g/ha as compared to rest of the herbicidal treatments (Table 2). Uncontrolled weeds in weedy check plots caused an average reduction in grain yield to the extent of 42.4% when compared with bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha mainly due to highest density and dry matter accumulation by weeds in weedy check plots. Ethoxysulfuron being an ALS inhibitor also significantly increased the grain yield when applied in combination with other herbicides. The results were in conformity with the findings of Dewangan (2011). Chlorimuron-ethyl + metsulfuron-methyl 4 g/ha (RM) also proved to increase the grain yield when applied in combination with other herbicides as post-emergence by suppressing weed population and reducing the weed biomass. Similar results were reported by Upasani *et al.* (2012).

It was inferred that combination of bispyribac-sodium + ethoxysulfuron 25 + 18.75 g/ha was found most effective in controlling weeds with the highest weed control efficiency and grain yield.

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Nitrogen and weed management effect on soil microbial properties in rice-based cropping system under conservation agriculture

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ABSTRACT

A study was carried out to evaluate the influence of tillage-residue management, N-levels and weed management on the population of bacteria, fungi and actinobacteria in soil under rice-wheat-greengram system during 2014-15 to 2015-16 at Jabalpur, India. Results showed that tillage-residue management had significant influence on microbial properties of soil. Zero tillage with preceding crop residue retention followed in all three crops in a system markedly improved soil microorganism communities by stimulating the growth of bacteria, fungi and actinobacteria. After two years of the study, conservation agriculture based practice, *i.e.* zero tillage with preceding crop residue retention increased population of bacteria by 65-83%, fungi by 28-32% and actinobacteria by 22-37% compared with conventional tillage with or without preceding crop residue. No significant differences in the population of bacteria and fungi were found between N-levels in 2014-15, while significant improvement was observed in 100% recommended dose of N in 2015-16. Improvement in bacterial and fungal population due to 100% recommended dose of N was 4 and 7% over 125% recommended dose of N, respectively. There was no significant change in microbial activities due to different weed management practices. These results suggest that zero tillage with preceding crop residue retention, recommended dose of N was the best practice for improving soil biological properties under rice-wheat-greengram system.

Key words: Actinobacteria, Bacteria, Fungi, N-levels, Residue management, Tillage, Weed management

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L. emend Fiori and Paol.) cropping system is the major system in India, which is fundamental to national food security. During summer season, inclusion of greengram (*Vigna radiate* L. R. Wilczek) in rice-wheat system is a remunerative option to sustain the productivity. Soil microorganisms play a vital role in biogeochemical cycling, which underpin the mechanisms of utilizing soil organic matter (Bowles *et al.* 2014). Tillage is a major factor which influences microbial activity and community structure in soil. Several studies confirmed that intensive conventional tillage practices reduce microbial biomass by decreasing or reversing C accumulation and breaking down soil structure (Lupwayi *et al.* 2012). In contrast, conservation agriculture, *i.e.* zero-till with preceding crop residue retention and crop rotation has been shown to increase microbial biomass and activity (Singh *et al.* 2015). Conservation tillage caused accumulation of soil microbial biomass in surface soil compared with conventional tillage. However, in other studies, tillage did not alter the soil microbial community structure (Helgason *et al.* 2009). Nitrogen fertilization induces alteration in soil microbial composition (Zeng *et al.* 2016). Improvements in productivity of crops can be achieved by combating weeds. Generally, herbicides are not harmful when applied at recommended rates (Selvamani and Sankaran 1993), but some herbicides may affect non-target organisms including microorganisms (Latha and Gopal 2010). Some herbicide may even stimulate the growth and activities of the microbial activities (Wardle and Parkinson 1990). Chemical or integrated methods of weed management should be tested in respect to microbial activities. Thus, the present investigation was undertaken to find out the effect of tillage-residue, N-levels and weed management on soil microflora of rice-wheat-greengram cropping system.

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MATERIALS AND METHODS

An experiment was initiated in 2013-14 at the ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh situated. Data presented in this article on rice (rainy season)-wheat (winter season)-greengram (summer season) were collected in the two subsequent years (2014-15 and 2015-16). The soil of the experimental site was classified as Typic

Chromusters (USDA classification). The treatments included four tillage-residue management practices, *viz.* zero tillage with preceding crop residue retention (ZT+RR), zero tillage with preceding crop residue burnt (ZT+RB), conventional tillage with preceding crop residue incorporation (CT+RI) and conventional tillage with preceding crop residue burnt (CT+RB); two N-levels, *viz*. 100% recommended dose of nitrogen (RDN) and 125% RDN, and three weed management options, *viz.* unweeded, herbicide and integrated for all crops in the system. Thus, 24 treatment combinations were laid out in a thrice replicated split-split plot design, keeping tillage-residue management in main plots, N-levels in sub-plots and weed management in sub sub-plots. Weed management practices included unweeded check, *i.e.* no weed management practices were applied; herbicide, *i.e*. pendimethalin 1000 g/ha as pre-emergence (PE) followed by (*fb*) bispyribac-Na 25 g/ha at 25 DAS in rice; mesosulfuron + iodosulfuron (12 + 2.4 g/ha) at 25 DAS in wheat; pendimethalin 1000 g/ha as PE *fb* imazethapyr 100 g/ha at 25 DAS in greengram; and integrated weed management (IWM), *i.e*. *Sesbania* co-culture + pendimethalin 1000 g/ha as PE *fb* 2,4-D at 25-30 DAS *fb* hand weeding (HW) at 45 DAS in rice; sulfosulfuron 25 g/ha at 25 DAS *fb* HW at 45 DAS in wheat; pendimethalin 1000 g/ha as PE *fb* HW at 25 DAS in greengram. Site-specific application of glyphosate was done at 1.0 kg/ha on the weeds in zero tillage plots and other weed management practices were applied as per treatments.

Enumeration of microorganisms

The soil samples were collected from 0-15 cm surface soil in all the plots at the time of harvest of rice, wheat and greengram. The soil samples were soaked into 90 ml deionized water at the rate of 10 g. Later this mixture was shaken for 10 min. and kept for 5 min. Thereafter, 1 ml of the supernatant was diluted twice and inoculated in the diluted water at the constant temperature (30 ºC). All samples were performed in triplicate, and were used for enumeration of microorganisms. The viable microbial counts were analyzed by the standard technique of serial dilution and dour plating. Enumeration of bacteria and fungi was carried out in soil extract agar medium (James 1958) and Rose Bengal agar medium (Parkinson *et al*. 1971). The Kenknight's agar medium (Wellingtonn and Toth 1963) was used for enumeration of actinomycetes. After allowing for development of discrete microbial colonies during incubations under suitable conditions, the colonies were counted and the number of viable bacteria, fungi and actinobacteria [expressed as colony forming units (cfu)] per gram dry weight of soil was estimated by taking into account the soil dilutions.

RESULTS AND DISCUSSION

Bacteria

Population dynamics of bacteria was markedly influenced by tillage-residue management and N-levels (Table 1). The highest population was recorded when zero-till with preceding crop residue retention was adopted in all the crops in the system. ZT+RB was comparable with ZT+RR in rice 2014, while CT+RI and ZT+RB did not significantly differ compared with ZT+RR in wheat 2014-15. ZT+RR led to significantly higher bacteria population in greengram 2015. In 2015-16, population of bacteria was higher in the rhizosphere of rice, wheat and greengram when ZT was done in the presence of preceding crop residue. Increasing bacterial population was due to continuous ZT with application of preceding crop residue which served as a continuous energy source for microorganisms. No significant difference was observed in bacterial population due to N-levels in rice 2015, however the population of bacteria was significantly improved under 100% RDN from wheat 2015-16. Additional N fertilizer can decrease soil pH, leading to leaching of magnesium and calcium and mobilization of aluminium, which may slow the growth of bacteria due to magnesium or calcium deficiency or aluminium toxicity. Liu *et al.* (2015) also found slow growth of bacterial biomass with increasing dose of N. Weed management practices did not influence the bacteria population significantly throughout both cropping cycles (Table 1).

Fungi

Population of fungi was influenced significantly due to tillage-residue management and N-levels while weed management had no significant influenced (Table 2). Maximum fungal population was recorded in ZT+RR, which was followed by ZT/CT with residue burnt in rice 2014. The population of fungi in rhizosphere was also significantly augmented in ZT+RR in wheat 2014-15 and greengram 2015. During rice 2015, the population of fungi was increased in ZT+RR, and the lowest population was noted in CT+RB. A similar trend was observed in wheat 2015-16 and greengram 2016. Sharma *et al.* (2012) reported that fungal population was increased with decrease the soil disturbance. Soil microbes typically are C-limited (Smith and Paul 1990) and the lower microbial biomass can be explained with low

Table 1. Effect of tillage-residue, N-levels and weed management practices on bacterial population

Treatment	Bacteria (10^6 cfu/g dry weight of soil)					
	Rice 2014	Wheat 2014-15	Greengram 2015	Rice 2015	Wheat 2015-16	Greengram 2016
Tillage-residue management						
ZT+RR	16.2	17.8	18.5	32.5	46.8	54.3
ZT+RB	15.3	17.2	17.9	29.5	40.4	45.9
CT+RI	14.7	16.8	17.3	25.3	26.8	27.7
CT+RB	14.4	16.1	16.6	24.3	24.3	22.4
LSD (P=0.05)	1.2	1.1	0.8	0.9	1.6	0.7
N-levels						
100% RDN	15.2	17.0	17.6	27.9	35.5	38.3
125% RDN	15.1	16.9	17.5	27.9	33.6	36.9
LSD (P=0.05)	NS	NS	NS	NS	0.6	0.6
Weed management						
Unweeded	15.3	17.1	17.8	28.0	35.3	37.9
Chemical	15.0	16.9	17.3	27.8	34.2	37.2
IWM	15.1	17.0	17.7	27.9	34.3	37.7
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

Table 2. Influence of tillage-residue, N-levels and weed management on fungal population

Treatment	Fungi (10^3 cfu/g dry weight of soil)					
	Rice 2014	Wheat 2014-15	Greengram 2015	Rice 2015	Wheat 2015-16	Greengram 2016
Tillage-residue management						
ZT+RR	14.4	14.8	15.1	25.1	30.1	32.0
ZT+RB	14.1	14.4	14.6	22.7	26.1	27.0
CT+RI	13.2	13.9	14.3	20.0	23.0	24.1
CT+RB	13.6	14.1	14.1	19.0	22.1	23.0
LSD (P=0.05)	0.9	0.6	0.7	1.9	1.8	2.2
N-levels						
100% RDN	14.1	14.3	14.7	22.5	26.5	27.5
125% RDN	13.6	14.3	14.3	20.9	24.1	25.5
LSD (P=0.05)	NS	NS	NS	1.63	0.7	0.8
Weed management						
Unweeded	14.0	14.4	14.8	21.8	25.4	26.8
Chemical	13.7	14.2	14.2	21.5	25.3	26.3
IWM	13.8	14.3	14.5	21.8	25.3	26.5
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

organic C in the soil (Mathew 2012). In zero-till soils, the accumulation of preceding crop residues on the soil surface results in enrichment of soil organic matter in the surface layer, and as a consequence, increases the abundance of microorganisms. N-levels did not exert any change in the fungal population in 2014-15, however the effect of N-levels was significant in 2015-16. Recommended dose of N improved the population of fungi in 2015-16 over 125% RDN. N additions have shown suppressive effect on microbial growth in several field studies (Nohrstedt *et al.* 1989). A number of mechanisms have been proposed for the slow multiplication in fungal biomass under N enrichment. Osmotic potentials in soil solution could become toxic owing to the introduction of additional ions via additional dose of N fertilizer. In this way, N additions could directly influence microbial growth.

Actinobacteria

Population of actinobacteria varied among tillage-residue management practices (Table 3). Compared with conventional tillage, zero tillage increased the abundance of actinobacteria. During rice 2014 and wheat 2014-15, ZT with/without preceding crop residue retention had significantly higher actinobacterial population than CT with/without preceding crop residue incorporation. However, actinobacterial population in ZT+RR was significantly higher in subsequent seasons after wheat 2014-15. ZT+RR led to actinobacterial population significantly higher over rest of tillage-residue management practices. Lowest population of actinobacteria was observed in CT+RB throughout cropping cycle in both years. Govindan and Chinnusamy (2014) also recorded higher actinobacterial population in rice based system under CA. The favourable effect of zero tillage and preceding crop residue retention on soil microbial populations are mainly due to increased soil aeration, optimum temperature and moisture fluctuations, and higher carbon content in surface soil. There was no significant change in actinobacterial population due to N-levels, and weed management practices.

Table 3. Actinobacterial population as influenced by tillage-residue, N-levels and weed management practices

Treatment	Actinobacteria (10^4 cfu/g dry weight of soil)					
	Rice 2014	Wheat 2014-15	Greengram 2015	Rice 2015	Wheat 2015-16	Greengram 2016
Tillage-residue management						
ZT+RR	14.8	16.0	17.1	20.4	25.0	29.1
ZT+RB	14.3	15.6	16.0	18.1	21.2	25.0
CT+RI	13.4	14.7	14.8	17.0	19.9	23.3
CT+RB	13.1	14.7	14.5	16.4	18.5	20.0
LSD (P=0.05)	1.0	0.7	0.9	1.3	1.6	0.8
N-levels						
100% RDN	14.1	15.3	15.7	18.2	21.4	24.4
125% RDN	13.7	15.2	15.5	17.8	20.9	24.3
LSD (P=0.05)	NS	NS	NS	NS	NS	NS
Weed management						
Unweeded	14.1	15.5	15.7	18.1	21.5	24.6
Chemical	13.8	14.8	15.5	17.8	20.7	24.0
IWM	13.8	15.4	15.6	18.1	21.3	24.4
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

It was concluded that continuous practice of ZT with preceding crop residue retention improved soil microbial biomass. N fertilization made no change in soil microbial activities in the first cropping cycle but there was improvement in second cropping cycle when the 100% RDN was applied over 125% RDN. This study also showed that there was no influence of weed management practices on microbial activities. Direct seeding in rice-wheat-greengram system under zero-till in the presence of preceding crop residue along with recommended dose of N and application of recommended practice of weed management proved to be a promising technology for improving soil biological properties.

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Management of complex weed flora with herbicides in direct-seeded rice under lateritic soil

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ABSTRACT

Efficient weed management, restricting weed growth and weed density particularly within the critical growth period, could induce essential growth dynamics with subsequent yield advantage. Field investigation on weed density and weed dry weight in drilled rice was conducted at the Agronomy Farm, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (Maharashtra) in *Kharif* season to evaluate the effect of different herbicide and herbicide combination during 2012 to 2015. The lowest weed population and dry weight of grasses, sedges and broad-leaved weeds were recorded in weed free check followed by pendimethalin *fb* manual weeding and pendimethalin *fb* bispyribac-Na *fb* manual weeding. The treatment weedy check recorded the highest dry weight of weeds. The highest weed control efficiency (89.5%) and weed control index (95.0%) were recorded by weed free check followed by pendimethalin *fb* manual weeding (84.4 and 92.8%) and pendimethalin *fb* bispyribac-Na *fb* manual weeding (76.6 and 89.9%).

Key words: Direct-seeded rice, Weed density, Weed growth, Weed management, Yield

Konkan region is one of the important rice growing belt of Maharashtra having the highest productivity of 2.75 t/ha milled and 3.83 t/ha unmilled rice (brown rice). The Konkan region produces of 15.26 lakh tones unmilled (brown rice) and 10.53 lakh tones milled rice from 3.83 lakh ha area (Anonymous 2014).The production and productivity of rice is affected by several biotic and abiotic stresses. Weed competition is one of the most important limiting factors in rice production. Weed can suppress the crop growth accounting 15-90% yield loss unless controlled efficiently (Jha *et al.* 1997). Manual weeding is considered as best method but it is time consuming and uneconomical. Therefore, it has given importance to the use of herbicides to get timely as well as effective weed control. In direct-seeded rice, it is important to keep the field weed free for first 30-45 DAS to avoid any loss in yield because dry weight of weeds increased greatly from 30 DAS in direct-seeded rice (Huh *et al.* 1995). Therefore, use of pre-emergence or early post-emergence herbicides is effective and economical at initial stages to prevent or inhibits the growth of weeds. There is need to combine different weed management techniques, not only to minimize the overall weed competition but also to reduce the total cost involved in weeding operations. Keeping these views into account, the present study was done to generate data regarding efficiency of herbicides in different combinations.

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MATERIALS AND METHODS

A field experiment was conducted during 2012 to 2015 at Department of Agronomy, College of Agriculture at Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (MS) to evaluate the effect of herbicide combination on weed density, weed dry matter and weed control efficiency in direct-seeded rice. The experiment was laid out in randomized block design with three replication consisted of ten treatments *i.e.* bispyribac-Na at 25 g/ha 20 DAS (3-4 leaf stage), pendimethalin (PE) at 1000 g/ha 0 to 2 DAS *fb* bispyribac-Na at 25 g/ha 20 DAS (3-4 leaf stage), oxadiargyl at 100 g/ha 0 to 2 DAS *fb* bispyribac-Na at 25 g/ha 25 DAS, pyrazosulfuron at 20 g/ha 0 to 3 DAS *fb* bispyribac-Na at 25 g/ha 25 DAS, pendimethalin (PRE) at 1000 g/ha 0 to 3 DAS *fb* bispyribac-Na at 25 g/ha. 25 DAS *fb* manual weeding at 45 DAS, pendimethalin (PRE) at 1000 g/ha 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS, bispyribac-Na at 20 g/ha + chlorimuron + metsulfuron at 4 g/ha 20 DAS, three mechanical weeding (cono/rotary weeder) at 20, 40 and 60 DAS, weed free check (HW at 20, 40 and 60 DAS) and weedy check. The soil of the experimental plot was sandy clay loam in texture, acidic in pH (5.80) and medium in organic carbon content (1.38). It was low in available nitrogen (282.1 kg/ha), medium in available phosphorus (10.8 kg/ha), and high in available potassium (235.9 kg/ha).

The seed of rice variety *'Ratnagiri-1'* treated with thiram at the rate of 3 g/kg of seed was used for sowing. Sowing was done by opening small furrows of about 3 cm depth with the help of marker at a distance of 20 cm between the lines on onset of monsoon. The rice seed rate of 60 kg/ha was used and covered with the soil. The recommended dose of fertilizer was applied to all the plots. The uniform representative samples of weeds at 60 and 90 DAS were randomly collected from each plot and dried. Data were analyzed statistically harvesting and yield data using standard methods of Panse and Sukhatme (1984).

RESULTS AND DISCUSSION

The major weed flora observed during the experimentation were, *viz. Cyperus rotundus, Isachne globosa, Ludwigia octovalis, Cloem viscose, Echinochloa colona, Ischemum rugosum, Amaranthus sessils, Mimosa pudica, Physalis minima, Ageratum coneyzoides* and *Celocia argentea.*

Application of pendimethalin *fb* manual weeding remained at par with weed free check and pendime-thalin *fb* bispyribac-Na *fb* manual weeding recorded significantly lower density of monocots than the remaining treatments during the year 2013, 2014 and in pooled results. However, pendimethalin *fb* manual weeding showed the lowest weed density over rest of the weed control measures tried except weed free check, bispyribac-Na, pendimethalin *fb* bispyribac-Na, pyrazosulfuron *fb* bispyribac-Na and bispyribac-Na + (chlorimuron + metsulfuron), which were at par with each other during 2012 (Table 1) .

Weed density of broad-leaved weeds at 60 DAS was not significantly influenced due to different weed control measures during all individual years of experimentation except 2014 and in pooled means. Weed free check recorded significantly lowest weed density of broad-leaved weeds except pendimethalin *fb* manual weeding. The weed free check resulted in the highest weed control efficiency followed by pendimethalin *fb* manual weeding and pendimethalin *fb* bispyribac-Na *fb* manual weeding.

At 90 DAS, weed free check (3 HW) reduced the density of monocots significantly over all other weed control measures tried, except use of pendimethalin *fb* manual weeding and pendimethalin *fb* bispyribac-Na *fb* manual weeding during 1st year and in pooled results while, pendimethalin *fb* manual weeding during 2nd year (Table 2). However, during 3rd year, use of pendime-thalin *fb* bispyribac-Na *fb* manual weeding recorded the lowest weed density of monocots than all other weed control measures, except weed free check and pendimethalin *fb* manual weeding. Similar effective lower density of grasses, sedges and broad leaved weeds in rice field was documented by Sharma *et al.* (2007) and Walia *et al.* (2012).

Effect on weed dry weight

During the first year (2012) of the experiment, use of pendimethalin *fb* manual weeding significantly reduced the growth of monocots as compared to use of bispyribac-Na, pendimethalin *fb* bispyribac-Na,

Table 1. Effects of herbicide combinations on weed density (0.25/m²) and weed control efficiency (four year pooled mean) at 60 DAS

Treatment	Grasses and Sedges					Broad-leaved weeds					WCE %				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	33.00 (5.68)	29.00 (5.16)	44.33 (6.64)	19.67 (4.45)	15.71 (4.00)	00.00 (0.71)	00.00 (0.71)	15.00 (3.93)	1.33 (1.18)	3.46 (1.98)	52.9	41.2	58.4	50.0	35.9
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	53.00 (6.56)	21.33 (4.32)	23.33 (4.88)	21.33 (4.66)	14.02 (3.80)	1.67 (1.26)	3.00 (1.68)	11.00 (3.38)	4.00 (2.12)	2.73 (1.80)	21.9	50.7	75.9	39.7	44.0
Oxadiargyl (PRE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	26.33 (4.64)	23.33 (4.41)	17.00 (4.13)	20.00 (4.52)	13.13 (3.67)	1.00 (1.10)	00.00 (0.71)	14.67 (3.89)	2.33 (1.57)	1.96 (1.57)	61.0	52.7	77.8	46.8	49.6
Pyrazosulfuron (PRE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	33.00 (5.68)	34.67 (5.88)	32.33 (5.70)	25.00 (5.03)	18.61 (4.34)	0.00 (0.71)	0.00 (0.71)	15.00 (3.91)	4.33 (2.18)	1.89 (1.54)	52.9	29.7	66.8	30.2	31.5
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	57.00 (4.43)	2.67 (1.74)	15.67 (4.00)	9.33 (3.06)	6.36 (2.54)	4.00 (1.63)	1.00 (1.17)	9.33 (3.13)	3.67 (1.83)	1.61 (1.42)	12.9	92.6	82.5	69.0	73.4
Pendimethalin (PRE) 1000 g/ha *fb* manual weeding 25-30 DAS	76.67 (2.60)	0.67 (1.00)	16.00 (4.05)	8.67 (3.02)	4.07 (2.14)	3.00 (1.50)	3.33 (1.79)	6.67 (2.67)	0.67 (1.00)	1.38 (1.36)	86.2	91.9	84.1	77.8	81.8
Bispyribac-Na 20 g/ha + almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	55.00 (7.41)	26.00 (5.02)	45.67 (6.78)	19.33 (4.42)	11.48 (3.46)	7.33 (2.04)	0.0 (0.71)	13.67 (3.76)	3.00 (1.72)	3.33 (1.93)	11.0	47.3	58.4	46.8	50.5
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	21.33 (4.45)	12.00 (2.88)	28.67 (5.37)	13.00 (3.57)	8.59 (2.95)	15.00 (3.59)	3.67 (1.85)	11.00 (3.37)	2.33 (1.68)	2.07 (1.60)	48.1	68.24	72.2	63.5	64.4
Weed free check (HW at 20,40 and 60 DAS)	87.67 (2.85)	3.00 (1.86)	16.00 (4.03)	4.67 (2.24)	3.48 (1.99)	0.67 (1.00)	0.0 (0.71)	5.33 (2.39)	0.67 (1.00)	0.78 (1.12)	88.1	93.9	85.0	87.3	85.8
Weedy check	57.00 (7.45)	47.67 (6.71)	116.00 (10.78)	34.00 (5.86)	23.74 (4.92)	12.67 (2.53)	1.67 (1.39)	26.67 (5.26)	8.00 (2.87)	6.18 (2.58)					
LSD (P=0.05)	- (2.20)	- (1.86)	- (0.78)	- (0.89)	- (0.79)	- (N.S.)	- (N.S.)	- (0.55)	- (N.S.)	- (N.S.)					

Figures in parentheses are $\sqrt{x+0.5}$ transformed values; PE - pre-emergence; POE - post-emergence pyrazosulfuron *fb* bispyribac-Na, weedy check and remained at par with rest of the treatments. However, during other years and in pooled results, the use of pendimethalin *fb* manual weeding recorded significantly lower weed growth than rest of the treatments except pendimethalin *fb* bispyribac-Na *fb* manual weeding and weed free check. Various weed control measures tried did not significantly influence growth of broad-leaved weeds during individual years as well as in pooled results at 60 DAS (Table 3 and 4). Walia *et al.* (2012) also reported similar results in drilled rice.

Table 2. Effects of herbicide combinations on weed density at 90 DAS (no. 0.25/m^2) and weed control efficiency (four year pooled mean)

Treatment	Grasses and sedges					Broad-leaved weeds					WCE %				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	26.00 (5.04)	46.67 (6.81)	42.33 (6.50)	18.00 (4.26)	33.25 (5.81)	00.00 (0.71)	00.00 (0.71)	15.67 (4.02)	6.67 (2.66)	5.58 (2.47)	16.1	71.5	56.4	50.7	58.9
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	17.33 (4.09)	19.33 (4.22)	22.67 (4.81)	22.67 (4.79)	20.50 (4.58)	3.00 (1.50)	3.67 (1.81)	11.67 (3.51)	5.67 (2.45)	6.00 (2.55)	34.4	86.0	74.2	43.3	72.0
Oxadiargyl (PRE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	17.67 (3.87)	26.00 (4.76)	18.33 (4.32)	21.00 (4.61)	20.75 (4.60)	2.67 (0.89)	0.33 (0.88)	15.00 (3.94)	6.00 (2.54)	6.00 (2.55)	34.4	83.9	74.9	46.0	71.7
Pyrazosulfuron (PRE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	23.33 (4.74)	76.33 (8.73)	27.67 (5.28)	28.33 (5.31)	38.92 (6.27)	0.00 (0.71)	0.67 (1.00)	15.33 (3.95)	6.33 (2.59)	5.58 (2.45)	24.7	53.0	67.7	30.7	52.9
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	1.00 (1.17)	32.33 (5.32)	15.67 (4.00)	9.00 (3.07)	14.50 (3.83)	8.67 (2.98)	4.00 (2.02)	12.00 (3.53)	5.67 (2.47)	7.58 (2.84)	68.8	77.8	79.2	70.7	76.6
Pendimethalin (PRE) 1000 g/ha *fb* manual weeding 25-30 DAS	3.00 (1.71)	5.33 (2.06)	17.67 (4.26)	7.33 (2.79)	8.33 (2.96)	7.33 (2.65)	6.67 (2.58)	7.67 (2.83)	4.00 (2.09)	6.42 (2.61)	66.7	92.7	80.9	77.3	84.4
Bispyribac-Na 20 g/ha + almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	19.00 (4.32)	39.33 (6.26)	39.67 (6.30)	18.67 (4.34)	29.17 (5.45)	0.00 (0.71)	1.00 (1.10)	15.00 (3.94)	6.33 (2.59)	5.58 (2.46)	38.7	75.4	58.9	50.0	63.2
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	12.67 (3.15)	30.00 (5.31)	20.67 (4.68)	10.33 (3.23)	18.42 (4.31)	5.67 (2.24)	3.67 (1.55)	10.00 (3.24)	4.33 (2.15)	5.92 (2.50)	40.8	79.5	76.9	70.7	74.2
Weed free check (HW at 20,40 and 60 DAS)	0.67 (1.00)	3.00 (1.82)	18.00 (4.10)	4.33 (2.18)	6.50 (1.96)	1.00 (1.10)	1.00 (1.10)	9.00 (3.08)	2.67 (1.76)	3.42 (1.96)	94.6	97.6	79.7	86.0	89.5
Weedy check	21.00 (4.56)	156.67 (12.03)	105.67 (10.29)	40.33 (6.37)	80.92 (8.95)	10.00 (2.81)	7.33 (2.17)	27.33 (5.27)	9.67 (3.18)	13.58 (3.72)					
LSD (P=0.05)	- (1.46.)	- (2.25)	- (0.62)	- (0.90)	- (0.75)	- (2.11)	- (N.S.)	- (0.40)	- 0.64	- 0.58					

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

Table 3. Effects of herbicide combinations on weed dry weight (g) at 60 DAS (0.25/m^2) and weed control index (four year pooled mean)

Treatment	Grasses and Sedges					Broad-leaved weeds					WCI %				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	24.67 (4.74)	3.84 (1.97)	14.67 (3.88)	6.31 (2.58)	12.37 (3.55)	00.00 (0.71)	00.00 (0.71)	12.50 (3.59)	0.25 (0.85)	3.19 (1.91)	30.2	65.7	12.8	59.2	33.7
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	19.67 (4.34)	2.75 (1.79)	12.33 (3.56)	6.67 (2.67)	10.35 (3.28)	0.33 (0.88)	0.27 (0.87)	6.33 (2.61)	1.51 (1.41)	2.11 (1.61)	43.4	73.0	40.1	49.2	46.9
Oxadiargyl (PRE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	15.00 (3.40)	3.53 (2.00)	14.00 (3.80)	8.45 (2.99)	10.25 (3.24)	0.33 (0.88)	0.00 (0.71)	5.17 (2.37)	0.98 (1.16)	1.62 (1.45)	56.6	68.5	38.5	41.4	49.4
Pyrazosulfuron (PRE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	27.33 (4.83)	4.09 (2.13)	10.00 (3.30)	8.61 (2.98)	14.51 (3.83)	0.00 (0.71)	0.00 (0.71)	3.23 (1.92)	2.37 (1.69)	1.40 (1.38)	22.7	63.5	57.6	29.9	32.2
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	10.67 (2.79)	0.44 (0.96)	5.00 (2.34)	3.39 (1.96)	4.87 (2.24)	0.33 (0.88)	0.09 (0.77)	2.33 (1.66)	0.95 (1.15)	0.93 (1.19)	68.9	95.3	76.5	73.0	75.3
Pendimethalin (PRE) 1000 g/ha *fb* manual weeding 25-30 DAS	1.00 (1.22)	0.12 (0.78)	6.50 (2.64)	1.60 (1.42)	2.31 (1.67)	0.33 (0.88)	0.36 (0.91)	4.17 (2.14)	0.00 (0.71)	1.22 (1.30)	96.2	95.7	65.8	90.1	83.9
Bispyribac-Na 20 g/ha + almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	10.33 (3.18)	2.42 (1.57)	13.83 (3.78)	6.23 (2.55)	8.20 (2.94)	3.33 (1.53)	0.00 (0.71)	7.00 (2.73)	1.31 (1.31)	2.91 (1.83)	61.3	78.4	33.2	53.2	52.6
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	4.33 (2.09)	4.37 (2.00)	12.67 (3.61)	4.13 (2.14)	6.38 (2.59)	1.33 (1.34)	0.44 (0.96)	4.17 (2.13)	0.87 (1.17)	1.70 (1.48)	84.0	57.0	46.0	68.9	65.6
Weed free check (HW at 20,40 and 60 DAS)	2.00 (1.52)	0.42 (1.03)	6.83 (2.70)	3.30 (1.94)	3.14 (1.91)	0.33 (0.88)	0.00 (0.71)	2.12 (2.26)	0.23 (0.83)	0.67 (1.08)	93.4	96.2	71.3	78.1	84.8
Weedy check	32.67 (5.70)	10.80 (3.25)	17.50 (4.22)	12.69 (3.63)	18.42 (4.34)	2.67 (1.45)	0.40 (0.98)	13.67 (6.87)	3.41 (1.92)	5.04 (2.35)	-	-	-	-	-
LSD (P=0.05)	- (2.39)	- (1.05)	- (0.45)	- 0.70	- (0.85)	- (N.S.)	- (N.S.)	- (N.S)	- (N.S.)	- (N.S.)					

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

The pooled data indicated that, the highest weed control index on the basis of weed dry weight was recorded under weed free check (84.8 and 95.0 at 60 and 90 DAS, respectively) followed by pendimethalin *fb* manual weeding and pendimethalin *fb* bispyribac-Na *fb* manual weeding at all the stages of observations. These results were in conformity with the findings of Walia *et al.* (2012) and Ganie *et al.* (2013).

Effect on yield and yield attributes

Weed free check (three hand weeding) recorded significantly higher plant height over all other treatments followed by pendimethalin (PE) at 1000 g/ha 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS while in respect of number of tillers, weed free check (HW at 20, 40, and 60 DAS) recorded significantly higher number of tillers except pendimethalin (PE) at 1000 g/ha 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS. Weed free check (HW at 20, 40, and 60 DAS) also recorded significantly higher weight of filled grains per panicle as compared to bispyribac-Na at 25 g/ha 20 DAS, oxadiargyl at 100 g/ha 0 to 2 DAS *fb* bispyribac-Na at 25 g/ha 25 DAS, pendimethalin (PE) at 1000 g/ha 0 to 3 DAS *fb* bispyribac-Na at 25 g/ha

Table 4. Effects of herbicide combinations on weed dry weight (g) at 90 DAS (0.25/m^2) and weed control index (four year pooled mean)

Treatment	Grasses and Sedges					Broad-leaved weeds					WCI %				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	33.50	102.00	25.38	2.67	39.48	00.00	00.00	18.70	2.27	1.66					
	(5.76)	(9.87)	(5.08)	(1.77)	(6.32)	(0.71)	(0.71)	(4.36)	(1.66)	(1.47)	68.5	16.4	24.2	56.8	32.1
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	20.00	23.67	18.04	2.87	12.71	1.33	1.00	9.10	2.65	2.26					
	(4.30)	(4.00)	(4.29)	(1.83)	(3.53)	(1.39)	(1.17)	(3.06)	(1.77)	(1.65)	81.1	79.8	53.4	51.7	75.3
Oxadiargyl (PRE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	36.83	86.33	20.37	2.82	32.64	1.17	0.33	9.47	2.11	1.69					
	(6.02)	(8.27)	(4.56)	(1.81)	(5.45)	(1.22)	(0.88)	(3.14)	(1.61)	(1.48)	66.3	29.0	48.7	56.9	43.4
Pyrazosulfuron (PRE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	28.83	66.33	29.78	3.16	25.96	0.00	0.33	6.18	2.68	1.40					
	(5.13)	(7.98)	(5.50)	(1.91)	(5.04)	(0.71)	(0.71)	(2.56)	(1.78)	(1.37)	74.4	45.4	38.2	48.9	54.9
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	1.00	12.33	10.81	1.08	4.44	1.67	1.00	3.70	2.08	1.70					
	(1.15)	(3.22)	(3.35)	(1.25)	(2.18)	(1.45)	(1.22)	(2.04)	(1.58)	(1.48)	97.6	89.1	75.1	72.4	89.9
Pendimethalin (PRE) 1000 g/ha *fb* manual weeding 25-30 DAS	2.50	1.33	12.90	2.18	2.41	1.50	1.33	6.19	1.99	1.93					
	(1.53)	(1.27)	(3.65)	(1.64)	(1.69)	(1.38)	(1.34)	(2.90)	(1.55)	(1.56)	96.4	97.8	67.2	63.5	92.8
Bispyribac-Na 20 g/ha + almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	17.50	112.67	21.61	2.67	34.34	0.00	0.33	13.16	2.77	1.69					
	(4.16)	(10.43)	(4.68)	(2.67)	(5.84)	(0.71)	(0.88)	(3.64)	(1.81)	(1.48)	84.5	7.4	40.3	52.4	40.5
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	10.50	53.00	18.26	2.60	17.60	15.17	0.67	7.20	1.99	5.14					
	(3.24)	(6.51)	(4.31)	(1.76)	(4.11)	(3.36)	(1.05)	(2.75)	(1.54)	(2.28)	77.2	56.0	56.3	59.9	62.5
Weed free check (HW at 20,40 and 60 DAS)	1.67	1.00	11.32	2.31	2.10	0.17	0.33	3.48	1.24	0.93					
	(1.26)	(1.22)	(3.43)	(1.67)	(1.60)	(0.81)	(0.88)	(1.97)	(1.30)	(1.19)	98.4	98.9	74.6	69.0	95.0
Weedy check	74.50	116.67	32.90	5.59	46.96	38.33	5.33	25.32	5.85	13.65					
	(8.47)	(10.78)	(5.77)	(2.45)	(6.79)	(5.28)	(2.12)	(5.07)	(2.51)	(3.54)	-	-	-	-	-
LSD (P=0.05)	-	-	-	-	-	-	-	-	-	-					
	(1.61)	(1.52)	(0.45)	(0.42)	(1.31)	(3.42)	(1.19)	0.70)	(0.52)	(1.25)					

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

Table 5. Effects of herbicide combinations on growth and yield attributes of rice (four year pooled mean)

Treatment	Height (cm)					No. of tillers					Panicle length (cm)					Weight of filled grain /panicles				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	52.40	65.7	83.3	69.9	67.8	37.3	96.0	62.0	40.3	58.9	18.4	19.3	19.3	18.8	18.9	1.03	2.97	1.98	2.07	2.07
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	57.0	71.5	89.7	75.0	73.3	31.0	64.0	61.7	44.3	46.6	18.1	21.5	20.2	19.4	19.8	1.47	3.70	2.52	2.19	2.19
Oxadiargyl (PRE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	59.7	63.5	88.2	74.7	71.5	50.0	72.7	64.0	43.3	57.5	19.7	20.3	20.3	19.7	20.0	2.01	4.18	2.40	2.06	2.06
Pyrazosulfuron (PRE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	51.4	66.9	86.8	73.9	69.8	47.0	56.0	63.0	44.7	52.7	18.5	19.3	18.4	18.9	18.8	2.11	2.64	2.00	2.23	2.23
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	63.7	72.6	91.3	79.3	76.6	48.3	62.7	66.0	51.3	54.2	19.3	19.6	31.4	19.9	20.0	2.01	3.38	3.19	2.08	2.08
Pendimethalin (PRE) 1000 g/ha *fb* manual weeding 25-30 DAS	59.7	69.7	93.2	78.9	75.4	60.7	75.3	69.0	50.0	63.7	19.9	20.5	21.5	20.1	20.5	2.25	3.35	3.08	2.24	2.24
Bispyribac-Na 20 g/ha + almix 4 g/ha at 20 DAS (chlorimuron+metsulfuron)	49.5	76.1	83.3	72.2	70.3	35.3	60.0	60.7	46.3	50.6	18.9	21.4	19.0	18.9	19.6	2.09	3.17	2.48	2.26	2.26
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	55.7	71.5	89.5	74.4	73.0	36.7	76.0	62.0	47.0	53.6	18.2	20.7	20.4	19.4	19.7	1.52	3.52	2.48	2.21	2.21
Weed free check (HW at 20,40 and 60 DAS)	60.8	76.4	91.0	80.6	77.7	51.7	80.0	68.0	56.3	64.0	19.3	20.4	20.7	20.0	20.1	2.22	3.68	2.63	2.27	2.27
Weedy check	54.6	61.2	79.3	62.9	64.5	32.0	66.0	56.0	45.7	45.3	19.5	18.7	16.8	17.7	18.5	2.00	2.20	1.90	1.90	1.86
LSD (P=0.05)	NS	NS	1.01	1.75	0.77	N.S.	N.S	0.80	0.63	2.62	N.S.	N.S	0.33	N.S.	N.S.	N.S.	0.88	0.45	0.08	0.08

Table 6. Effects of herbicide combinations on yield and yield attributes of rice (four year pooled mean) and weed index

Treatment	Grain yield (t/ha)					Straw yield (t/ha)					WI (%)				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	1.95	2.31	2.86	2.78	2.23	2.04	2.42	4.91	3.35	2.93	33.6	56.1	27.7	17.1	42.6
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	1.79	5.04	3.52	2.78	3.04	2.00	5.30	5.47	3.39	3.79	38.9	4.2	11.2	16.9	21.8
Oxadiargyl (PRE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	1.80	4.06	3.68	2.89	3.10	1.91	4.30	5.29	3.54	3.76	38.9	22.9	7.3	13.7	20.0
Pyrazosulfuron (PRE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	1.64	3.28	2.92	2.58	2.61	1.91	3.68	4.19	3.06	3.21	44.1	37.6	26.2	23.0	32.8
Pendimethalin (PRE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	2.57	4.64	3.92	3.20	3.58	2.89	5.01	5.82	3.86	4.40	12.5	11.9	1.1	4.4	7.7
Pendimethalin (PRE) 1000 g/ha *fb* manual weeding 25-30 DAS	2.32	5.23	3.94	3.21	3.68	2.41	5.65	5.55	3.88	4.38	21.0	0.6	0.5	4.3	5.3
Bispyribac-Na 20 g/ha + almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	1.13	3.83	2.77	2.73	2.62	1.22	4.14	4.67	3.32	3.34	61.5	27.2	30.0	18.5	32.6
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	1.79	3.75	3.56	2.51	2.90	1.91	4.05	5.29	3.13	3.59	39.1	28.7	10.2	25.2	25.2
Weed free check (HW at 20,40 and 60 DAS)	2.94	5.26	3.96	3.35	3.88	3.04	5.68	5.96	4.02	4.68	-	-	-	-	-
Weedy check	0.33	1.09	2.0	2.49	1.48	0.38	1.18	3.43	2.92	1.98	88.7	79.1	49.6	25.8	61.9
LSD (P=0.05)	0.16	0.21	0.07	0.16	0.08	0.11	0.117	0.15	0.17	0.10	-	-	-	-	-

25 DAS *fb* manual weeding at 45 DAS and weedy check. Similar results of higher yield attributes of direct-seeded rice were reported by Veeraputhiran and Balasubramanian (2013) and Chauhan *et al*. (2013).

Consequently, weed free check (Table 6) (HW at 20,40, and 60 DAS) produced significantly higher grain and straw yield as 3.88 and 4.68 t/ha, respectively over rest of the treatments except pendimethalin (PRE) at 1000 g/ha 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS (3.68 and 4.38 t/ha) and pendimethalin(PE) at 1000 g/ha 0 to 3 DAS *fb* bispyribac-Na at 25 g/ha 25 DAS *fb* manual weeding at 45 DAS (3.58 and 4.40 t/ha), which were at par with each other (Table 6). Weed free check (HW at 20, 40, and 60 DAS) also indicated higher per cent increment of grain yield (162.8%) over weedy check followed by pendimethalin (PE) at 1000 g/ha 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS (148.9%). Compared to best treatment of weed free check (HW at 20, 40, and 60 DAS), the weed index (WI) which indicate the increase in grain yield was maximum under pendimethalin (PRE) at 1000 g/ha 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS (5.26%) closely followed by pendimethalin (PRE) at 1000 g/ha 0 to 3 DAS *fb* bispyribac-Na at 25 g/ha. 25 DAS *fb* manual weeding at 45 DAS (7.70%). Similar results of higher yield attributes of direct-seeded rice was reported by Veeraputhiran and Balasubramanian (2013) and Naseeruddin and Subramanyam (2013).

The combination of chemical and cultural/ physical control measures (pendimethalin *fb* manual weeding and pendimethalin *fb* bispyribac-Na *fb* manual weeding) were effective for weed control in drilled rice than the application of chemical herbicides, cultural or mechanical control alone.

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Herbicide combinations for weed control in direct-seeded rice

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ABSTRACT

A field experiment was conducted during *Kharif* season of 2012 and 2013 at College farm, Professor Jayashankar Telangana State Agriculture University, Rajendranagar, Hyderabad to assess the bioefficacy of different herbicides and their integration with cultural methods to control weeds and relative influence on profitability in direct dry-seeded rice cultivation. Integrated weed management (pendimethalin *fb* bispyribac-sodium followed by manual weeding at 45 days after sowing) gave highest net returns with higher B:C ratio during both the years of study. Among cultural methods, three hand weedings (weed free condition) and three mechanical weedings recorded lower weed biomass and higher weed control efficiency.

Key words: Direct-seeded rice, Herbicides, Herbicide combinations, Weed biomass, Weeds

Direct dry-seeding of rice has potential for attaining better water and other resources utilization. Heavy weed infestation and shifts in weed population are major constraints in the sustainability of direct dry-seeded rice (dry-DSR). An appropriate weed management strategy has always been a major focus and key element to make dry-DSR a success. Such a strategy is of utmost significance to improve rice yield, quality and to minimize production costs as well. Traditionally, weeds are controlled through cultural/chemical methods. Manual weeding, though effective is getting increasingly impractical due to labour scarcity, rising wages and its dependence on weather conditions. Moreover, allowing weeds to reach sufficient size to be pulled out and the presence of perennial weeds that fragment/break on pulling are other related concerns (Rao *et al.* 2007). Thus, herbicide usage seems essential for weed management in dry-DSR. Although dry-DSR has been under practice in many regions of the world, yet its adoption has been limited by the unavailability of a successful local weed control strategy. The present study was designed to assess the bio-efficacy and economics of sole and sequential application of pre and post-emergence herbicides and their integration with manual/mechanical weeding for selective and season-long weed management in dry-DSR in Southern Telangana Zone of Telangana State.

MATERIALS AND METHODS

Field experiment was conducted at college farm, Rajendranagar, Hyderabad during *Kharif* season of 2012 and 2013. Hyderabad is situated at 17^0 19’ N latitude, 78^0 28’ E longitude 542 m above mean sea level. The total rainfall was770.5 mm and 658.9 mm during 2012 and 2013, respectively. The soil of the experimental site was clay loam with P^H 7.85 and electrical conductivity of 0.21 ds/m. The soil was low in organic carbon (0.52%). The experiment was laid out in randomized block design with three replications. The net plot size was 5 x 4 m. Seeds of rice *cv*. ‘*MTU-1010*’ were sown during the first week of August using a seed rate of 75 kg/ha by maintaining 22.5 cm distance between crop rows on a non-flooded, non-puddled aerobic soil. Fertilizer dose of 150-60-60 Kg N, P_2O_5 and K_2O was applied. Fertilizers used were urea (46% N), superphosphate (16% P_2 O_5) and muriate of potash (60% K_2O), entire phosphorus, ½ of potash and 1/3 of nitrogen were applied at the time of sowing. The remaining 2/3rd nitrogen was applied in two splits at tillering and panicle initiation and remaining potash was applied at panicle initiation, respectively.

Herbicides pendimethalin, oxadiargyl, pyrazosulfuron were applied as pre-emergence and these were followed by bispyribac-sodium as post-emergence. In addition, bispyribac-sodium was applied as post-emergence in combination with chlorimuron-ethyl + metsulfuron-methyl. Weedy check and weed free treatments were maintained for comparison. Spray volume was calibrated using water prior to treatment application. Herbicides were applied using a knapsack sprayer fitted with flood jet nozzle. Plant protection measures for insect pests and diseases and for iron deficiency were taken to grow healthy crop.

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Data on weed density and biomass was recorded at 60 DAS by two randomly selected quadrats (50 x 50 cm) from each experimental unit. Data on rice yield attributes was recorded from 15 randomly selected plants from each plot and averaged. Weed data were square root transformed before statistical analysis. The data were analyzed according to RBD by standard ANOVA at P < 0.05 level of significance.

RESULTS AND DISCUSSION

Weed density and weed biomass

Weed flora of the experimental site was comprised of *Trianthema portulacastrum*, *Digera arvensis*, *Echinochloa colonum*, *Echinochloa crus-galli*, *Dactylactenium aegyptium*, *Dinebra arabica*, *Cyperus rotundus* and *Cynodon dactylon*. All the treatments significantly suppressed weed density as compared to control.

Different weed control treatments significantly influenced the weed biomass in dry-DSR. Significantly, lower weed biomass was observed with all treatments compared to control in both the years and highest weed biomass in weedy check (170.2 g/m^2) indicating the essentiality of weed control in dry-DSR. Significantly, lowest weed biomass (12.5 g/m^2) was observed with weed free treatment wherein hand weeding was done at 20, 40 and 60 DAS followed by three mechanical weedings (31.5 g/m^2). Among different treatments, pendimethalin *fb* bispyribac-sodium *fb* manual weeding recorded significantly lowest weed biomass during both the years, indicating the importance of integrated weed management for effectively managing the weeds (Table 2). Similar results were obtained by Singh *et al.* (2011). The treatments pendimethalin *fb* bispyribac-sodium bispyribac-sodium + (chlorimuron-ethyl + metsul-furon-methyl) and pendimethalin *fb* manual weeding recorded weed biomass, which was at par with each other (85.6, 89.5 and 84.6 g/m^2, respectively).

Sequential application of oxadiargyl *fb* bispyribac-sodium and pyrazosulfuron-ethyl *fb* bispyribac-sodium recorded weed biomass (71.8 g and 69.7 g/m^2, respectively). Sole application of bispyribac-sodium could not control weeds effectively resulting in higher weed biomass (109.5 g/m^2) compared to other sequential application of herbicides and integrated weed management practices during 2012 and 2013.

Grain yield

Significantly lowest rice grain yield (1.06 t/ha) was recorded under weedy check. Highest grain yield was under weed free condition (3.95 t/ha), which was at par with pendimethalin *fb* bispyribac-sodium *fb* manual weeding (3.67 t/ha) and three mechanical weedings (3.72 t/ha) and all these three treatments were significantly superior in recording higher grain yield compared to all the other herbicide treatments during 2012 and 13. Walia *et al.* (2008) also observed that it was difficult to raise weed free DSR with the application of only one herbicide (Table 2).

Among the treatments, pyrazosulfuron-ethyl *fb* bispyribac-sodium recorded a grain yield (3.02 t/ha) that was at par with oxadiargyl *fb* bispyribac-sodium (2.81 t/ha), which differed significantly from bispyribac-sodium + (chlorimuron-ethyl + metsulfuron-methyl 2.53 t/ha) and pendimethalin *fb* manual weeding (2.63 t/ha). All these treatments recorded significantly superior grain yield than sole application of bispyribac-sodium (1.85 t/ha) in both the years. Pendimethalin (PE) *fb* bispyribac-sodium

Table 1. Weed biomass (60 DAS) and weed control efficiency of dry-DSR as influenced by different weed management practices

Treatment	WCE (%)		Weed biomass (g/m^2)	
	2012	2013	2012	2013
Bispyribac-Na (25 g/ha) 20 DAS (3-4 leaf stage)	35.7	35.7	10.51 (109.5)	11.4 (129.2)
Pendimethalin *fb* bispyribac-Na (1000 *fb* 25 g/ha) 0-2 *fb* 25	49.7	49.7	9.30 (85.6)	10.1 (101.0)
Oxadiargyl *fb* bispyribac-Na (100 /25 g/ha) 0-2 *fb* 25	57.8	57.8	8.53 (71.8)	9.2 (84.7)
Pyrazosulfuron *fb* bispyribac-Na (20/25 g/ha) 0-3 *fb* 25	59.1	59.1	8.40 (69.7)	9.1 (82.2)
Pendimethalin *fb* bispyribac-Na *fb* manual weeding (1000 *fb* 25 g/ha) 0-2 *fb* 20 DAS (3-4 leaf stage) *fb* 45 DAS	73.4	73.4	6.79 (45.2)	7.37 (53.3)
Pendimethalin *fb* manual weeding (1000 g/ha) 0-2 *fb* 25-30 DAS	50.3	50.3	9.25 (84.6)	10.04 (100)
Bispyribac + (chlorimuron + metsulfuron) (20 + 4 g/ha) 20 DAS	47.4	47.4	9.51 (89.5)	10.3 (105.6)
Three mechanical weedings (cono / rotary weeder) 20, 40 and 60 DAS	81.5	81.5	5.69 (31.5)	6.17 (37.2)
Weed free (HW at 20, 40 and 60 DAS)	92.7	92.7	3.67 (12.5)	3.97(14.8)
Weedy check	-	-	13.08 (170.2)	14.2 (200.8)
LSD (P=0.05)			0.56	0.61

Data are square root transformed and values in parentheses are original values; DAS - days after sowing; Spray volume: 500 l/ha for PRE and 375 L/ha for POST herbicides; *fb* - followed by

Table 2. Yield attributes and grain yield of dry-DSR as influenced by different weed control treatments

Treatment	Productive tillers (no./m^2)		No. of filled grains/ panicle		1000-seed weight (g)		Grain yield (t/ha)	
	2012	2013	2012	2013	2012	2013	2012	2013
Bispyribac-Na (25 g/ha) 20 DAS (3-4 leaf stage)	240	301.0	48	62.4	18.0	19.1	1.85	2.29
Pendimethalin *fb* bispyribac-Na (1000 *fb* 25 g/ha) 0-2 *fb* 25	270	341.0	53	67.1	19.0	19.2	2.47	3.11
Oxadiargyl *fb* bispyribac-Na (100 /25 g/ha) 0-2 *fb* 25	275	336.0	55	68.5	19.0	19.8	2.81	3.44
Pyrazosulfuron *fb* bispyribac-Na (20/25 g/ha) 0-3 *fb* 25	282	357.0	56	69.9	20.0	20.1	3.02	3.81
Pendimethalin *fb* bispyribac-Na *fb* manual weeding (1000 *fb* 25 g/ha) 0-2 *fb* 20 DAS (3-4 leaf stage) *fb* 45 DAS	305	381.0	56	69.2	21.0	20.5	3.67	4.54
Pendimethalin *fb* manual weeding (1000 g/ha) 0-2 *fb* 25-30 DAS	271	333.0	55	66.8	19.5	19.5	2.63	3.21
Bispyribac + (chlorimuron + metsulfuron) (20 + 4 g/ha) 20 DAS	269	336.0	54	68.1	19.3	19.3	2.53	3.18
Three mechanical weedings (cono / rotary weeder) 20, 40 and 60 DAS	315	394.0	56	70.2	20.2	20.2	3.72	4.64
Weed free (HW at 20, 40 and 60 DAS)	320	405.0	58	72.8	21.0	20.6	3.95	4.98
Weedy check	175	241.0	32	41.6	15.5	18.7	1.06	1.54
LSD (P=0.05)	13.0	22.0	5.0	6.1	2.2	1.2	0.35	0.34

DAS (Days after sowing); Spray volume: 500 l/ha for PRE and 375 l/ha for POST herbicides; *fb* followed by

Table 3. Economics of different weed control treatments in dry-DSR cultivation

Treatment	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C ratio	
	2012	2013	2012	2013	2012	2013	2012	2013
Bispyribac-Na (25 g/ha) 20 DAS (3-4 leaf stage)	13.95	18.75	22.20	27.49	8.25	8.74	1.59	1.5
Pendimethalin *fb* bispyribac-Na (1000 *fb* 25 g/ha) 0-2 *fb* 25	15.72	20.53	29.70	37.38	13.97	16.85	1.89	1.8
Oxadiargyl *fb* bispyribac-Na (100 /25 g/ha) 0-2 *fb* 25	15.57	20.37	33.78	41.29	18.21	20.92	2.17	2.0
Pyrazosulfuron *fb* bispyribac-Na (20/25 g/ha) 0-3 *fb* 25	15.67	20.47	36.24	45.78	20.57	25.31	2.31	2.3
Pendimethalin *fb* bispyribac-Na *fb* manual weeding (1000 *fb* 25 g/ha) 0-2 *fb* 20 DAS (3-4 leaf stage) *fb* 45 DAS	17.42	22.23	41.70	54.49	24.27	32.27	2.39	2.5
Pendimethalin *fb* manual weeding (1000 g/ha) 0-2 *fb* 25-30 DAS	18.87	23.68	31.62	38.5	12.74	14.89	1.68	1.6
Bispyribac + (chlorimuron + metsulfuron) (20 + 4 g/ha) 20 DAS	15.87	20.67	30.36	38.21	14.49	17.54	1.91	1.9
Three mechanical weedings (cono / rotary weeder) 20, 40 and 60 DAS	17.70	22.50	38.70	55.69	28.53	33.19	2.18	2.5
Weed free (HW at 20, 40 and 60 DAS)	25.90	30.70	43.80	59.78	27.70	29.08	1.69	2.0
Weedy check	12.00	16.80	12.72	18.49	0.72	1.69	1.06	1.0
LSD (P=0.05)	-	-	-	-	2.72	3.15	-	-

DAS (Days after sowing); Spray volume: 500 l/ha for PRE and 375 l/ha for POST herbicides; *fb* followed by

and oxadiargyl (PE) *fb* bispyribac-sodium recorded grain yield which were at par with each other indicating the efficacy of sequential application of pre- and post-emergence herbicides in effective weed control and realizing higher yield in paddy. These results were in conformity with the findings of Mahajan and Timsina (2011).

Economics

Highest gross returns (` 59,784/ha) were realized due to maintenance of weed free situation at 20, 40 and 60 DAS followed by three mechanical weedings (and pendimethalin *fb* bispyribac *fb* manual weeding). However, higher cost of cultivation in weed free resulted in lower net returns (` 29084) and BC ratio (2.0). Pre-emergence application of pendime-thalin *fb* bispyribac *fb* manual weeding gave reasonably good B:C ratio (2.3 and 2.5) in both the years and it was at par with three mechanical weedings. Though three mechanical weedings were effective in dry-DSR (2.2 and 2.5), the impending problem of labour scarcity and non-availability in time may prohibit farmers relying on it. Oxadiargyl *fb* bispyribac and pyrazosulfuron *fb* bispyribac also performed better, registering a B:C ratio of 2.0 each (Table 3).

It was concluded that pre-emergence application of pendimethalin *fb* bispyribac-sodium along with one manual weeding at 45 DAS may be recommended for efficient weed management, realizing higher grain yield and good profit in dry-DSR cultivation.

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Interaction effect of nitrogen schedule and weed management on yield of direct-seeded rice

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ABSTRACT

A field experiment was conducted at Agricultural Research Farm, Institute of Agricultural sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, during rainy season of 2011 and 2012 to study the effect of nitrogen schedule and weed management in direct-seeded rice under irrigated condition. The experiment comprised of 24 treatments including all the combinations of four nitrogen schedule and six weed management. The results indicated that the minimum weed density, total weed dry weight and depletion of nutrient was recorded under nitrogen schedule of ¼ 2 WAS (week after sowing) + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WAS, which was statistically at par with $^1/_3$ 2 WAS + $^1/_3$ 4 WAS + $^1/_3$ 6 WAS and significantly lower than other nitrogen schedules. The maximum yield was recorded under nitrogen schedule at ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS + ¼ 8 WAS, which was statistically at par with $^1/_3$ 2 WAS + $^1/_3$ 4 WAS + $^1/_3$ 6 WAS and which was significantly superior over other treatments. Significantly lower weed density, dry weight and nutrient depletion were recorded under application of pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone (25 + 20 g/ha) and pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron (25 +18 g/ha), which were significantly superior over other treatments.

Key words: Direct-seeded rice (DSR), Interaction effect, Nitrogen schedule, Nutrient depletion, Weed management, Yield

Rice is the premier food crop of India and therefore, national food security system largely relies on the productivity of rice in different agro-ecosystems and physical conditions of soil. In South Asia, rice-based cropping systems account for more than 50% of the total land with rice grown in sequence of rice or upland crops like wheat, maize or legumes. Cultivation of rice by transplanting in rice-wheat is most popular in North India. This method requires puddling for field preparation to check percolation losses of water and control weeds effectively; however, destruction of soil structure that adversely affects growth and yield of succeeding crop in rotation is a major disadvantage and it is also a labor and water intensive method. Rice consumes about 3000-5000 litres of water to produce 1 kg grain, depending on the different rice cultivation methods. Under these situations, direct-rice seeding is one of the important alternate methods of rice establishment that avoid puddling and does not require submergence and thus reduce the overall water need for rice cultivation (Farooq *et al*., 2011). Nitrogen use efficiency (NUE) of rice is usually low due to leaching, volatilization and denitrification losses. Moreover, direct-seeded rice soils are often exposed to dry and wet conditions and difference in N dynamics and losses pathways often results in different fertilizer recoveries in aerobic soils. Split application is one of the strategies for efficient use of N fertilizers throughout the growing season by synchronizing with plant demand, reducing denitrification losses and improved N uptake for maximum straw and grain yield and harvest index in DSR (Lampayan *et al.* 2010). Recently, Mahajan and Timsina (2011) evaluated response of DSR to different nitrogen rates when applied in four splits.

Weeds pose major problem in rice production due to the prevalence of congenial atmosphere during *Kharif* rainy season. The aerobic soil conditions and dry-tillage practices, besides alternate wetting and drying conditions, are conducive for germination and growth of highly competitive weeds, which cause grain yield losses of 50-91%. The direct-seeded rice stimulates more weed growth than transplanted rice, thus their management becomes more complex. Weed control, particularly during the initial stages of crop establishment is very essential in realizing higher yield. Manual weeding has become difficult because of labor scarcity and increased cost (Rao *et al.* 2007). Single herbicide may not provide an effective control due to wide diversity of weed flora observed in rice

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field, thus tank mix of herbicides are very effective to reduce the weed density. The combination of herbicides with nitrogen schedule have been reported for better control of weeds and maximum crop growth and yield in DSR (Sharma 2007 and Chaudhary *et al*. 2011). Therefore, this study was conducted to assess the performance of different herbicides under nitrogen schedule on direct-seeded rice.

MATERIALS AND METHODS

A field experiment was conducted at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (Uttar Pradesh), during rainy (*Kharif*) season of 2012 and 2013. The soil was Gangetic alluvial having sandy clay loam in texture with normal soil reaction (7.39), low organic carbon (0.43%), low available N (205.51 kg/ha), and medium in available P_2O_5 (23.21 kg/ha) and K_2O (221.50 kg/ha). The total rainfall received during crop-growing season of 2012 and 2013 was 665.6 and 780.8 mm, respectively. The experiment was laid out in split-plot design with 24 treatment combinations (4 nitrogen schedules and 6 weed management including weed free and weedy check) and replicated three times. The nitrogen schedule was subjected to main plots, *viz*. ¼ basal + ¾ 4 week after sowing (WAS), $^1/_3$ 2 WAS + $^1/_3$ 4 WAS + $^1/_3$ 6 WAS, ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS + ¼ 8 WAS and ¼ basal + ½ 4 WAS + ¼ 6 WAS, while weed management was placed in sub plots, *viz*. weedy check, weed free, pendimethalin at 1.0 kg/ha, pendimethalin 1.0 kg/ha (PE) *fb* metsulfuron-methyl + chlorimuron (4 g/ha, POE), pendimethalin 1.0 kg/ha (PE) *fb* bispyribac + carfentrazone (25 + 20 g/ha, POE) and pendimethalin 1.0 kg/ha (PE) followed by bispyribac + ethoxysulfuron (25 + 18 g/ha POE). Recommended dose of N, P and K were applied at 120 kg N/ha, 60 kg P_2O_5/ha and 40 kg K_2O/ha. Full dose of phosphorus and potash were applied as basal application and nitrogen was applied as treatment wise. Dry seed of '*HUR 105*' variety of rice at 40 kg/ha was used for seeding of rice. Sowing was done manually with the help of spade at a spacing of row 20 cm. The herbicides were applied with the help of a hand-operated knapsack sprayer fitted with flat-fan nozzle. Weed density and weed dry weight data were collected at 20, 40, 60, 80 DAS and at harvest stage. The data on weeds were subjected to square-root transformation ($\sqrt{x + 0.5}$) to normalize their distribution. Weeds were cut at ground level, washed with tap water, sundried, dried at 70°C for 48 hr and then weighed. Grain yield and its attributes were also recorded during the course of investigation at crop maturity. The data recorded on various parameters of rice crop were analyzed following standard statistical analysis of variance procedure.

RESULTS AND DISCUSSION

Weed flora

Major weed flora species infesting in the direct-seeded rice as observed in weedy check plots were, grasses, sedges and broad-leaved weeds. The critical analysis of data on relative composition of weed species indicated that among grassy weeds, *Echinocloa colona* and *Echinocloa crus-galli* were dominant weed species. Major sedges consisted of *Cyperus rotundus*, *Cyperus iria* and *Fimbristylis miliaceae*. Predominant broad-leaved weeds included *Eclipta alba, Ammannia baccifera, Caesulia axillaris* and *Phylanthus niruri*.

Nitrogen schedule had no significant influences on the total density of different group of weeds (grasses, sedge and broad-leaved weed) at 20, 40 DAS and harvest stages while it influenced significantly at 60 and 80 DAS except the grasses. In grasses, it influenced significantly only at 60 DAS. This shows that germination of weed seeds was not influenced significantly by the time of application of nitrogen. However, total weed density, their dry weight and nutrient depletion by weeds influenced significantly due to application of different nitrogen schedule (Table 1). The pooled data revealed that minimum weed density, total weed dry weight and nutrient depletion by weeds were recorded under nitrogen schedule at ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WAS, which was statistically at par with $^1/_3$ 2 WAS + $^1/_3$ 4 WAS + $^1/_3$ 6 WAS and it was significantly lower than ¼ basal + $^3/_4$ 4 WAS, and ¼ basal + ½ 4 WAS + ¼ 6 WAS at all stages of observation except grass weeds. In grass weeds, the weed density was significantly reduced only at 60 DAS. This can be attributed to low vigorous growth of weeds due to skip of the application of nitrogen at the time of sowing, which resulted into suppression of total weed density, weed dry weight and nutrient depletion by weeds. Higher density of weeds, their dry weight and nutrient depletion by weeds were recorded under ¼ basal + ¾ 4 WAS, and ¼ basal + ½ 4 WAS + ¼ 6 WAS, which might have been due to the fact that under these treatments whole nitrogen doses were applied within month, which had better impact on emergence of weeds and growth, and poor crop growth resulted in higher weed dry weight and more nutrient depletion by weeds.

Table 1. Effect of nitrogen schedule and weed management on total weed density, total weed dry weight and nutrient depletion by weeds in direct-seeded rice (pooled over 2 year)

Treatment	Total weed density (m^2) at DAS					Dry weight of weeds (m^2) at DAS					N	P	K
	20	40	60	80	Harvest	20	40	60	80	Harvest	(kg/ha)	(kg/ha)	(kg/ha)
Nitrogen schedule													
$^1/_4$ basal + $^3/_4$ 4 weeks after sowing (WS)	9.22 (101.3)	9.49 (116.9)	11.48 (166.6)	11.10 (155.7)	10.58 (141.8)	3.64 (16.0)	4.60 (28.0)	10.34 (138.8)	11.61 (172.5)	12.04 (186.2)	3.96 (19.28)	1.84 (3.35)	4.56 (25.38)
$^1/_3$ 2 WS + $^1/_3$ 4 WS + $^1/_3$ 6 WS	8.66 (89.2)	8.26 (87.1)	9.95 (123.5)	9.58 (114.0)	9.10 (103.3)	3.35 (13.7)	3.66 (19.6)	8.12 (92.2)	8.95 (110.6)	9.36 (120.2)	3.16 (13.11)	1.59 (2.58)	3.85 (19.19)
$^1/_4$ 2 WS + $^1/_4$ 4 WS + $^1/_4$ 6 WS + $^1/_4$ 8 WS	8.41 (83.7)	8.06 (83.6)	9.50 (112.5)	8.98 (100.2)	8.77 (95.9)	3.18 (12.3)	3.41 (16.8)	7.63 (81.7)	8.47 (97.8)	8.77 (103.7)	3.00 (11.87)	1.48 (2.11)	3.67 (17.64)
$^1/_4$ basal + $^1/_2$ 4 WS + $^1/_4$ 6 WS	8.89 (94.1)	9.18 (108.4)	10.98 (151.5)	10.52 (140.1)	9.98 (125.7)	3.45 (14.4)	4.36 (25.4)	9.99 (131.3)	10.70 (148.9)	11.10 (159.6)	3.85 (18.71)	1.83 (3.44)	4.45 (24.46)
LSD (P=0.05)	0.38	0.59	0.45	0.72	0.36	0.21	0.30	0.62	0.60	NS	0.240	0.005	0.027
Weed management													
Pendimethalin at 1.0 kg/ha	10.79 (116.5)	12.76 (163.2)	14.68 (216.9)	14.14 (201.3)	13.56 (184.8)	4.14 (17.2)	5.97 (36.1)	13.23 (177.2)	14.71 (218.5)	15.27 (235.5)	4.91 (25.30)	2.21 (4.63)	5.75 (34.50)
Pendimethalin1.0 kg/ha *fb* metsulfuron-ethyl +chlorimuron (2 + 2 g/ha)	9.81 (96.0)	8.57 (73.7)	11.04 (12.4)	10.62 (113.5)	10.12 (102.6)	3.97 (15.8)	4.44 (20.2)	10.38 (109.6)	11.59 (136.6)	12.09 (148.7)	3.93 (16.08)	1.88 (3.25)	4.79 (23.93)
Pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone (25 + 20 g/ha)	8.97 (80.3)	7.09 (50.1)	9.04 (81.6)	8.56 (73.2)	8.12 (65.9)	3.71 (13.8)	2.73 (8.0)	6.54 (45.0)	7.45 (58.3)	7.92 (65.7)	2.55 (6.69)	1.36 (1.49)	3.32 (10.88)
Pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron (25 + 18 g/ha)	9.36 (87.5)	7.62 (57.9)	9.65 (93.1)	9.23 (85.3)	8.77 (76.6)	3.76 (14.2)	3.19 (10.7)	7.45 (58.6)	8.40 (74.8)	8.77 (80.9)	2.87 (8.57)	1.46 (1.78)	3.53 (13.07)
Weedy check	13.12 (172.2)	15.74 (249.1)	17.76 (317.0)	17.01 (291.6)	16.38 (270.1)	4.85 (23.6)	7.72 (59.8)	16.54 (275.7)	17.43 (306.4)	17.90 (323.7)	6.01 (37.84)	2.50 (6.07)	6.80 (47.63)
Weed free	0.71 (0.0)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.0)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
LSD (P=0.05)	0.34	0.39	0.37	0.38	0.36	0.15	0.24	0.51	0.50	0.51	0.175	0.008	0.025
N x S	NS	S	S	S	S	NS	S	S	S	S	S	S	S

Figures in parentheses are the original values; *fb* - Followed by; DAS - days after sowing

The pooled data indicated that all weed management treatments significantly lowered weed density, their weed dry weight and nutrient depletion than the weedy check (Table 1). Application of pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone 25 + 20 g/ha was at par with pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron 25 + 18 g/ha and it was significantly superior over others treatments in respect of minimizing weed density, their dry weight, and nutrient depletion by weeds at different stages of observation. This might be attributed to more bio-efficiency of bispyribac, which effectively controlled wide diversified weeds. In addition, carfentrazone (Rawat *et al*. 2013, Singh *et al*. 2013) and ethoxysulfuron (Hussain 2008) have been reported to provide effective control for broad-leaved weeds and sedges in rice, and also for lowering the weeds population. Sequential application of pendimethalin *fb* tank mix of bispyribac with carfentrazone or ethoxysulfuron lowered the weed count than weedy check and sole application of pendimethalin. Alone application of pendimethalin was least effective in minimizing the density of weeds, dry weight and nutrient depletion as compared to sequential application of herbicides. This may be due to control of weeds by pre-emergence herbicides in early stages and post-emergence herbicides effectively controlled the later emerging weeds, particularly sedges and broad-leaved weeds as reported earlier for sequential application of bispyribac + carfentrazone by Khaliq *et al.* (2012). The highest NPK depletion by weeds was recorded under alone application of pendimethalin. It was due to maximum total weed dry matter under this treatment as nutrient depletion is positively correlated with weed dry matter accumulation. This is in agreement with the findings of Singh *et al.* (2013).

Crop

Effect on yield attributes and yield: Nitrogen schedule and weed-management practices had significant effect on yield attributes but nitrogen schedule did not significantly influenced the test weight and harvest index (Table 2). Pooled data indicated that the maximum grain yield (4092.81 kg/ha) and yield attributes, *ie* effective tiller/m^2 (69.7), number of grains/panicle (111.2), panicle length (24.0 cm), weight of panicle (2.88 g), test weight (23.8 g) and harvest index (40.3%) recorded under nitrogen schedule at ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WAS were statistically at par with $^1/_3$ 2 WAS + $^1/_3$ 4 WAS + $^1/_3$ 6 WAS and it was significantly higher than remaining nitrogen schedule treatments. It clearly showed that skipping the nitrogen dose at sowing time and applying the same at two weeks after sowing was better for crop growth due to increases nutrient use efficiency, and also less chance of nitrogen losses due to leaching, immobilization and denitrification etc. The soil has sufficient amount of nitrogen for fulfill the initial requirement of crop. Nitrogen schedule with four split of ¼ of total nitrogen was given at 2 weeks after sowing (WAS) to 8 WAS of crop stage gave significantly higher yield than rest two nitrogen schedule where ¼ of total nitrogen was applied as basal and remaining at 4 and 6 WAS in N_1 and N_4 nitrogen schedule, respectively. Splits application maintained continuous supply of nutrients which might have favored the crop for good growth, yield attributes and finally the yield of rice. This might to be more favorable for higher grain attributes and grain yield. This confirms the earlier findings where nitrogen dose was reported better in splits (Sharma *et al.* (2007), Mahajan and Timsina (2011) and Rehman *et al.* (2013).

The highest yield attributes and yield was recorded in weed free plots. Among the weed management treatment, the maximum grain yield (4.62 t/ha) and yield attributes, effective tiller per m row length (70.13), number of grains/panicle (114.13), panicle length (24.52 cm), weight of panicle (2.87/g), test weight (24.19/g) and harvest index (42.43%) were recorded with application of pendimethalin 1 kg/ha *fb* bispyribac + carfentrazone 25 + 20 g/ha, which was at par with pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron 25 + 18 g/ha and it was significantly superior over others herbicidal treatments, thereby realizing an increase of 67.5% yield over weedy check and it was at par with weed-free plots. Application of pendimethalin *fb* tank mix of bispyribac with carfentrazone and ethoxysulfuron showed greater synergy in terms of increased weed control efficiency, yield attributes and yield of rice in comparison to other weed management treatments. These results can be attributed due to minimizing crop-weed competition, better nutrient uptake by crop which marked improvement in biomass, maximum number of effective tillers and ultimately improved the yield-attributing components and yield of crop. The minimum grain yield was recorded under weedy check which was attributed due to more weed growth, total weed dry weight and poor yield attributing characters. Results were in agreement with the findings of Veeraputhiran and Balasubramanian (2013), and Khaliq *et al.* (2012).

The pooled data of two years indicated that, interaction effect of nitrogen schedule and weed management practices were found significant for total weed density and dry weight at 60 days after sowing, number of effective tillers and grain yield of rice (Table 3, 4). Irrespective of nitrogen schedule, minimum weed density and weed dry weight was recorded under nitrogen schedule of ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WAS with all the herbicidal treatments. The minimum weed density and dry weight of weeds was recorded under application of pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone 25 + 20 g/ha in all the nitrogen schedules. Application of pendimethalin 1.0 kg/ha *fb* bispyribac + carfentra zone 25 + 20 g/ha under nitrogen

Table 2. Effect of nitrogen schedule and weed management on yield attributes and yield of crop in direct seeded rice (pooled over 2 year)

Treatment	No. of effective tillers/m	Panicle weight (g)	No. of spikelets/ panicle	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	HI (%)	Test weight (g)
Nitrogen Schedule								
$^{1}/_{4}$ basal + $^{3}/_{4}$ 4 weeks after sowing (WS)	53.61	2.41	97.14	3.42	5.07	8.49	39.16	23.16
$^{1}/_{3}$ 2 WS + $^{1}/_{3}$ 4 WS + $^{1}/_{3}$ 6 WS	65.00	2.67	105.86	4.05	5.77	9.82	40.07	23.67
$^{1}/_{4}$ 2 WS + $^{1}/_{4}$ 4 WS + $^{1}/_{4}$ 6 WS + $^{1}/_{4}$ 8 WS	69.72	2.88	111.19	4.09	5.82	9.91	40.33	23.85
$^{1}/_{4}$ basal + $^{1}/_{2}$ 4 WS + $^{1}/_{4}$ 6 WS	57.08	2.56	100.64	3.70	5.41	9.11	39.75	23.62
LSD (P=0.05)	5.81	0.31	8.70	0.25	0.48	0.71	1.17	0.74
Weed management								
Pendimethalin at 1.0 kg/ha	53.75	2.46	95.79	3.16	4.71	7.87	40.15	23.20
Pendimethalin1.0 kg/ha *fb* metsulfuron-methyl + chlorimuron (2 + 2 g/ha)	61.50	2.64	105.04	4.04	5.76	9.80	41.17	23.63
Pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone (25 + 20 g/ha)	70.13	2.87	114.13	4.62	6.26	10.88	42.43	24.19
Pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron (25 + 18.0 g/ha)	66.33	2.69	109.38	4.51	6.22	10.73	42.01	24.02
Weedy check	42.75	2.11	76.17	1.50	3.66	5.16	29.36	22.15
Weed free	73.67	3.00	121.75	5.06	6.49	11.55	43.84	24.27
LSD (P=0.05)	3.31	0.20	6.69	0.16	0.30	0.41	1.16	0.56
N x S	S		NS	NS	S	S	S	NS

Table 3. Interaction effect of nitrogen schedule and weed management on total weed density, total dry weight, number of effective tillers in one-meter row length and grain yield of crop in direct-seeded rice (pooled over 2 year)

Weed management	Total weed density at 60 DAS (m^2)				Total weed dry weight at 60 DAS (g/m^2)				Effective tillers one meter row length				Grain yield (t/ha)			
	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4
Pendimethalin at 1.0 kg/ha	16.2 (261)	13.7 (187)	13.2 (175)	15.6 (242)	14.5 (212)	12.6 (158)	11.4 (131)	14.4 (207)	49.0	55.7	58.2	52.2	2.66	3.68	3.21	3.10
Pendimethalin 1.0 kg/ha *fb* metsulfuron-methyl + chlorimuron (2 + 2 g/ha)	12.3 (150)	10.5 (110)	9.7 (94)	11.6 (135)	11.8 (139)	9.6 (92)	8.7 (76)	11.4 (131)	55.0	65.2	66.7	59.2	3.48	4.45	4.33	3.89
Pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone (25 + 20 g/ha)	9.8 (96)	8.7 (76)	8.3 (68)	9.3 (87)	8.2 (68)	5.0 (26)	5.2 (27)	7.7 (59)	58.2	75.7	84.3	62.3	4.10	4.74	5.09	4.54
Pendimethalin1.0 kg/ha *fb* bispyribac + ethoxysulfuron (25 + 18 g/ha)	10.3 (105)	9.2 (84)	9.1 (81)	10.1 (101)	9.5 (90)	6.1 (37)	5.5 (30)	8.7 (77)	57.3	71.2	75.0	61.8	4.08	4.74	4.92	4.40
Weedy check	19.7 (387)	16.8 (283)	16.0 (256)	18.5 (22)	18.0 (342)	15.5 (240)	15.0 (225)	17.7 (314)	39.3	44.5	47.2	40.0	1.25	1.56	1.77	1.41
Weed free	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	62.8	77.8	87.0	67.0	4.93	5.15	5.23	4.87
W at same N	0.26				0.36				2.32				0.11			
LSD (P=0.05)	0.74				1.02				6.63				0.31			
N at same W	0.27				0.37				270				0.12			
LSD (P=0.05)	0.78				1.06				7.72				0.35			

Figures in parentheses are the original values

N_1- $^1/_4$ basal + $^3/_4$ 4 weeks after sowing (WS), **N_2**- $^1/_3$ 2 WS +$^1/_3$ 4 WS +$^1/_3$ 6 WS, **N_3**- $^1/_4$ 2 WS + $^1/_4$ 4 WS + $^1/_4$ 6 WS +$^1/_4$ 8 WS, **N_4**- 4 basal + $^1/_2$ 4WS + $^1/_4$ 6 WS; *fb*- followed by

schedule at ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WAS was most effective in reducing the weed density and weed dry weight and found at par with pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron 25 + 18 g/ha significantly superior over other treatments.

Nitrogen schedule at ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WAS recorded more number of effective tillers of rice under all the weed management treatments (Table 3). The treatment combination of nitrogen schedule at ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WS and pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone 25 + 20 g/ha produced significantly more number of panicles over all the other treatment combinations, also recorded maximum grain yield and it was found at par with pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron 25 + 18 g/ha, and also with their counterparts under nitrogen schedule of $^1/_3$ 2 WS + $^1/_3$ 4 WS + $^1/_3$ 6 WS but these were significantly superior over remaining treatment combinations. While the maximum grain yield was recorded under weed free plots due no weed crop competition during whole period of crop growth, and minimum grain yield was recorded under weedy check in all the nitrogen schedules. This was owing to the fact that all the weed management treatments under different nitrogen schedule produced maximum crop growth, and thereby the increased accumulation of photosynthates in reproductive parts, which ultimately brought about marked improvement in yield.

Total nutrient uptake by crop

Significant effect of nitrogen schedule and weed management treatments on total nutrient uptake of nitrogen, phosphorus and potassium by crop was observed during both the years of experimentation (Table 4). The pooled data clearly indicated that maximum total nitrogen, phosphorus and potassium uptake were recorded under ¼ 2 WAS + ¼ 4 WAS + ¼ 6 WAS+ ¼ 8 WAS, which was found at par with $^1/_3$ 2 WAS + $^1/_3$ 4 WAS + $^1/_3$ 6 WAS and it was significantly superior to rest nitrogen schedules during both the years. This was mainly due to splitting of whole nitrogen in to four split in equal part of ¼ and also in three split in to $^1/_3$ part gave similar results, as it might have helped in minimized the nitrogen losses through uptake by weeds, leaching and denitrification *etc*. Ultimately, it led to more nutrients availability to the crop and resulted in vigorous crop growth and development. Split application of N has been reported as the best method to improve N fertilizer use efficiency (Ali *et al*. 2007) and improve nitrogen uptake.

Amongst weed management treatments, higher total nitrogen, phosphorus and potassium uptake was recorded under application of pendimethalin 1.0 kg/ha *fb* bispyribac + carfentrazone 20 + 20 g/ha, which was found at par with pendimethalin 1.0 kg/ha *fb* bispyribac + ethoxysulfuron 25 + 18 g/ha and it was significantly superior over rest of the herbicidal treatments during both the years. But, highest total

Table 4. Interaction effect of nitrogen schedule and weed management on nutrient depletion (kg/ha) by weeds at 60 DAS

Weed management	Nitrogen				Phosphorus				Potassium			
	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4
Pendimethalin 1.0 kg/ha (PE)	5.34 (28.1)	4.58 (20.4)	4.30 (18.1)	5.40 (28.8)	2.34 (5.0)	2.13 (4.0)	2.01 (3.5)	2.04 (5.1)	6.06 (36.3)	5.72 (32.2)	5.27 (27.3)	5.96 (35.0)
Pendimethalin 1.0 kg/ha (PE) *fb* metsulfuron-methyl + chlorimuron (2 + 2 g)/has (PO)	4.46 (19.4)	3.60 (12.5)	3.35 (10.8)	4.31 (18.1)	2.04 (3.7)	1.81 (2.8)	1.66 (2.3)	2.02 (3.6)	5.25 (27.1)	4.62 (20.9)	4.19 (17.1)	5.07 (25.2)
Pendimethalin at 1.0 kg/ha (PE) *fb* bispyribac + carfentrazone (25+20g)/ha (PO).	3.15 (9.5)	2.04 (3.7)	2.09 (3.9)	2.92 (8.0)	1.60 (2.1)	1.13 (0.8)	1.20 (0.9)	1.50 (1.8)	3.79 (13.9)	2.60 (6.3)	2.77 (7.2)	3.71 (13.3)
Pendimethalin 1.0 kg/ha (PE) *fb* bispyribac + ethoxysulfuron (25 + 18g)/ha (PO).	3.59 (12.4)	2.38 (5.2)	2.16 (4.2)	3.33 (10.6)	1.73 (2.5)	1.24 (1.0)	1.18 (0.9)	1.67 (2.3)	4.28 (17.8)	3.00 (8.5)	2.75 (7.1)	4.08 (16.2)
Weedy check	6.50 (41.8)	5.66 (31.6)	5.41 (28.9)	6.45 (41.2)	2.62 (6.4)	2.53 (5.9)	2.15 (4.1)	2.69 (6.7)	7.25 (52.1)	6.45 (41.0)	6.34 (39.7)	7.15 (50.6)
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)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)
	LSD (P=0.05)				LSD (P=0.05)				LSD (P=0.05)			
W at same level of N	0.12		0.35			0.005		0.015	0.01		0.05	
N at same level of W	0.13		0.38			0.005		0.015	0.01		0.05	

nitrogen, phosphorus and potassium uptake by crop was associated with weed free treatment, which was significantly superior to all herbicidal treatments. This was owing to lower nutrient depletion by weeds under these treatments due to less weed infestation and depletion of nutrient. Hence, it appears that under competition between crop and weed for nutrients, both could not utilize these to the maximum extent. These were in close proximity with findings of Sharma (2007) and Chaudhary *et al.* (2011).

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Weed management through tank mix and premix herbicides in wheat

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ABSTRACT

A field experiment was conducted during the *Rabi* (winter) season of 2014-15 and 2015-16 at Agricultural Research Station, Dharwad, Karnataka, India to evaluate the efficacy of tank mix herbicides and premix herbicides on weed control and its influence on productivity and profitability in irrigated wheat. Tank mix application of sulfosulfuron + metsulfuron 25 + 4 g/ha recorded significantly higher grain yield (4.31 t/ha) followed by clodinafop + metsulfuron 60 + 4 g/ha (4.15 t/ha) over weedy check. Biological yield was recorded significantly higher with clodinafop + metsulfuron 60 + 4 g/ha (12.21 t/ha) followed by sulfosulfuron + metsulfuron 25 + 4 g/ha (12.18 t/ha) over 2,4-D 2.5 kg/ha (10.68 t/ha) alone. The lower weed density, weed biomass and higher weed control efficiency was recorded with sulfosulfuron + metsulfuron 25 + 4 g/ha followed by clodinafop + metsulfuron 60 + 4 g/ha compared to weedy check. The more gross returns, net returns and benefit : cost ratio was obtained with sulfosulfuron + metsulfuron 25 + 4 g/ha over other weed management practices.

Key words: Crop growth, Herbicide mixture, Post-emergent, Tank mix, Weed management, Wheat

Weed infestation is one of the main biotic constraints in wheat production. Wheat is infested by diverse weed flora comprising of grasses and broad-leaved weeds. Nearly 50% of the wheat yield reduction is observed due to some dominant weed flora appearing at early stage and interfering the crop growth because of frequent irrigations. Manual weeding in wheat is cumbersome, laborious, time consuming and costly. Therefore, most of the wheat farmers depend on herbicides due to effective and easy application compared to manual weeding. Yaduraju and Das (2002) suggested that chemical herbicides play an important role for weed control in close spaced crops like wheat, barley where mechanical or manual weeding is difficult. Farmers use herbicides with similar mode of action. This leads to shift in weed flora and development of resistance against widely used herbicides. Pre-emergent herbicides are used for their effectiveness in initial stages, but their efficacy are lost within 15 DAS, which results in emergence of new flush of weeds. Post-emergent herbicides applied at 20-30 DAS may avoid this problem. Therefore, combination of herbicides in mixture will be an ideal means to increase the spectrum of weed control and also to prevent or delay the development of weed resistance in wheat. Hence, a study was undertaken to keep the weeds below threshold level and assess the effect of different herbicide mixtures on crop growth and yield performance of wheat.

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MATERIALS AND METHODS

A field experiment was conducted during *Rabi* (winter) season of 2014-15 and 2015-16 at Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka. The experiment was laid out in randomized complete block design with three replications on vertisols with pH of 8.1 and EC of 0.21 ds/m and available major nutrients of 325, 33.5 and 465 kg/ha NPK, respectively. Tank mix herbicides treatment consisted of sulfosulfuron + 2,4-D (25 g + 0.5 kg/ha); sulfosulfuron + metsulfuron (25 + 4 g/ha); clodinafop + 2,4-D (60 g + 0.5 kg/ha); clodinafop + metsulfuron (60 + 4 g/ha); metribuzin + 2,4-D (100 g + 0.5 kg/ha); metribuzin + metsulfuron (100 + 4 g/ha), while pre-mix herbicides were mesosulfuron + iodosulfuron (Atlantis) (12 + 2.4 g/ha) and fenoxaprop–p-ethyl + metribuzin (Accord plus) 100 + 175 g/ha, recommended 2,4-D 2.0 kg/ha, intercultivation + hand weeding and weedy check. Recommended doses of nitrogen, phosphorus, potassium were given in the form of urea, diammonium phosphate and murate of potash. Half of the recommended dose of N (100 kg/ha) and full dose of $P_2 0_5$ (75 kg/ha) and $K_2 0$ (50 kg/ha) were applied as basal and the remaining nitrogen was applied after 30 DAS. The variety '*UAS 304*' was sown with a spacing of 20 cm with seed rate of 150 kg/ha on 9 and 12 November 2014 and 2015 during the first and second year of experimentation. Irrigations were provided at fortnightly intervals. All the herbicides were applied at 20 - 25 days after sowing with the help of knapsack sprayer fitted with a flat–fan nozzle with a spray volume of 500 litres/ha. The weed free plot was maintained by repeated manual weeding. Inter-cultivation was done with hand operated wooden hoe at 20 - 25 DAS and weeding was done at 40 - 45 DAS. The crop was harvested on 22 and 25 March during 2015 and 2016, respectively. The weed density and weed biomass were recorded at 60 DAS with the help of 1 m^2 quadrate and data on weed parameters were subjected to square root transformation before statistical analysis. All the data obtained were statistically analyzed using the F-test procedure as given by Gomez and Gomez (1984). Least significant difference (LSD) values at P=0.05 were used to determine the significance of difference between means.

RESULTS AND DISCUSSION

Weed control

Weeds of experimental plots were *Chenopodium* sp., *Anagallis arvensis, Melilotus* sp., *Phyllanthus niruri, Ageratum conyzoides, Oxalis corniculata, Echinochloa colonum, Convolvulus arvensis, Amaranthus viridis, Portulaca oleraceae, Cynodon dactylon, Sida cordifolia* and *Digitaria sanguinalis.*

All weed control treatments recorded significantly lower weed density than weedy check (Table 1). Among the herbicide treatments, application of tank mix herbicide sulfosulfuron + metsulfuron 25 + 4 g/ha exerted the maximum herbicide effect and caused the highest reduction in total weed density and total biomass which however, was statistically at par with clodinafop + metsulfuron 60 + 4 g/ha and metribuzin + metsulfuron 100 + 4 g/ ha. This might be due to the fact that combined application of two herbicides known for controlling grassy and broad-leaf weeds provided effective control of all the weeds to achieve higher level of weed control. These results confirm the findings of Singh *et al.* (1998) and Pal *et al.* (2016). Higher weed control efficiency was noticed with sulfosulfuron + metsulfuron 25 + 4 g/ha (81.6%) followed by clodinafop + metsulfuron 60 + 4 g/ha (79.2%), metribuzin + metsulfuron 100 + 4 g/ha and mesosulfuron + iodosulfuron 12 + 2.4 g/ha (77.3%) over other weed control treatments.(Singh *et al.* 2003).

Crop growth

The higher plant height, more number of tillers and dry matter accumulation was observed with the treatment on sulfosulfuron + metsulfuron (25 + 4 g/ ha) and recorded significantly higher with 2,4-D alone (Table 1). This was in conformity with the findings by Singh *et al.* (1997).

Yield and yield parameters and economics

Application of tank mix herbicide sulfosulfuron + metsulfuron (25 + 4 g/ha) recorded significantly higher spike/m^2 (251.8) compared to 2,4-D alone and found at par with clodinafop + metsulfuron (60 + 4 g/ ha) and metribuzin + metsulfuron (100 + 4 g/ha). The corresponding increase was also observed in grains/ ear head and 1000-grain weight (Table 2). The improvement in yield characters through weed control could be ascribed to reduced density and dry weight of weeds and thus resulted in the least competition for moisture, space, nutrients, light *etc.* Significantly, higher 1000-seed weight was observed with tank mix herbicide sulfosulfuron + metsulfuron (25 +4 g/ha) as compared to mesosulfuron + iodosulfuron (12 + 2.4 g/ha), fenoxaprop–p-ethyl + metribuzin (100 + 175 g/ha) and 2,4-D alone (Bharat *et al.* 2012, Chaudry *et al.* 2013). Tank mix herbicide

Table 1. Density, biomass and weed control efficiency of various post-emergent herbicides at 60 DAS (pooled data of two years)

Treatment	Weed density/m^2			Weed biomass g / m^2			Weed control efficiency (%)
	Monocot	Dicot	Total	Monocot	Dicot	Total	
Sulfosulfuron + 2, 4- D (25 + 0.5 kg/ha)	2.75 (7.00)	3.38 (11.00)	4.25 (18.00)	2.44 (5.00)	2.93 (8.00)	3.70 (13.00)	65.43
Sulfosulfuron + metsulfuron (25 + 4 g/ha)	1.91 (3.00)	2.69 (6.00)	3.14 (9.00)	1.50 (1.00)	2.30 (4.00)	2.57 (5.00)	81.62
Clodinafop + 2, 4- D (60 g + 0.5 kg/ha)	3.07 (9.00)	3.73 (13.0)	4.74 (22.00)	2.83 (7.00)	2.86 (7.00)	4.05 (14.00)	79.72
Clodinafop + metsulfuron (60 + 4 g/ha)	2.02 (3.00)	2.81 (7.00)	3.32 (10.00)	1.70 (2.00)	2.32 (5.00)	2.70 (7.00)	79.72
Metribuzin + 2, 4- D (100 g + 0.5 kg/ha)	3.08 (9.00)	3.40 (11.00)	4.48 (20.00)	2.54 (6.00)	2.91 (8.00)	3.74 (14.00)	61.52
Metribuzin + metsulfuron (100 + 4 g/ha)	2.09 (4.00)	2.80 (7.00)	3.38 (11.00)	1.81 (2.00)	2.36 (5.00	2.82 (7. 00)	78.91
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha)	2.17 (4.00)	2.88 (8.00)	3.50 (12.00)	2.03 (3.00)	2.46 (5.00)	3.04 (8.00)	77.11
Fenoxaprop-p-ethyl + metribuzin (100 + 175 g/ha)	2.37 (5.00)	3.08 (9.00)	3.74 (14.00)	2.19 (4.00)	2.67 (6.00)	3.31 (10.00)	73.33
Recommended (2,4-D 2.0 kg/ha)	2.27 (4.00	3.00 (8.00)	3.62 (12.00)	2.06 (3.00)	2.55 (6.00)	3.13 (9.00	75.36
Intercultivation + hand weeding	2.44 (5.00)	3.31 (10.00)	3.99 (15.00)	2.29 (4.00	2.83 (7.00)	3.51 (11.00)	69.71
Weedy check	4.65 (10.00)	5.48 (21.00)	5.15 (31.00)	3.46 (8.00)	3.72 (10.00)	4.33 (18.00)	0.00
LSD (P=0.05)	0.29	0.39	0.24	0.22	0.52	0.35	5.13

Data subjected to ($\sqrt{x+0.5}$) transformation, and figures in parentheses are original values

Table 2. Crop growth, yield and yield attributes and economics of wheat as influenced by various post-emergent herbicides (pooled data of two years)

Treatment	Plant height (cm) at harvest	Tillers (no./m) at harvest	DMA (g/m) at harvest	Spikes/ m^2	Grains/ spike	Test weight (g)	Grain yield (t/ha)	Biomass yield (t/ha)	Gross returns (x 10^3 `/ha)	Net returns (x 10^3 `/ha)	Benefit: cost ratio
Sulfosulfuron + 2, 4- D (25 + 0.5 kg/ha)	88.80	90.50	123.80	243.82	42.32	41.43	3.99	12.03	87.7	44.4	2.03
Sulfosulfuron + metsulfuron (25 + 4 g/ha)	89.40	99.50	128.50	251.81	43.73	42.37	4.31	12.18	94.8	51.4	2.19
Clodinafop + 2, 4- D (60 g + 0.5 kg/ha)	81.90	77.93	112.50	228.64	36.64	37.04	3.41	9.74	74.9	31.6	1.73
Clodinafop + metsulfuron (60 + 4 g/ha)	89.30	93.20	127.40	249.18	42.72	41.25	4.15	12.21	91.2	47.8	2.11
Metribuzin + 2, 4- D (100 g + 0.5 kg/ha)	82.60	86.70	110.50	236.12	39.52	38.45	3.68	10.00	81.0	38.4	1.90
Metribuzin + metsulfuron (100 + 4 g/ha)	88.50	91.57	120.60	249.87	41.86	40.48	3.90	11.28	85.8	43.0	2.00
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha)	84.60	89.30	118.20	240.23	40.73	40.21	3.82	11.01	84.0	40.5	1.93
Fenoxaprop-p-ethyl + metribuzin (100 + 175 g/ha)	83.10	82.40	114.85	236.47	40.63	38.44	3.76	10.47	82.7	38.8	1.89
Recommended (2,4-D 2.0 kg/ha)	83.00	84.80	116.50	237.63	41	38.53	3.79	10.68	83.4	40.2	1.93
Intercultivation + hand weeding	80.00	80.40	114.50	230.61	38.3	38.27	3.51	9.96	77.1	31.6	1.70
Weedy check	73.20	74.50	95.50	227.07	36.09	36.09	2.70	8.09	59.4	17.2	1.41
LSD (P=0.05)	8.32	13.79	9.79	19.23	2.89	1.52	0.40	1.26	9.64	9.76	0.23

application provided weed free environment to crop and excellent yield characteristics as compared to 2,4-D alone. Application of tank mix herbicide sulfosulfuron + metsulfuron (25 + 4 g/ha) recorded significantly higher grain yield (4.31 t/ha) over 2,4-D alone and found at par with clodinafop + metsulfuron 60 + 4 g/ha (4.15 t/ha) and sulfosulfuron + 2,4-D 25 g + 0.5 kg/ha (3.99 t/ha). Clodinafop + metsulfuron 60 + 4 g/ha recorded significantly higher biomass yield (12.2 t/ha) followed by sulfosulfuron + metsulfuron 25 + 4 g/ha (12.2 t/ha) and sulfosulfuron + 2,4-D 25 g + 0.5 kg/ha (12.03 t/ha) over 2,4-D alone. Reduction in crop weed competition under weed control treatments led to enchanced crop growth and finally biomass yield. Our results support the findings of Pisal and Sagarka (2013) and Pandey *et al.* (2006). All the weed control treatments fetched significantly more gross returns, net returns and benefit : cost ratio over weedy check, which might be due to more grain yield registered in these treatments. Application of tank mix herbicide sulfosulfuron + metsulfuron 25 + 4 g/ha recorded significantly higher benefit : cost ratio (2.19) over 2,4-D alone and at par with clodinafop + metsulfuron 60 + 4 g/ha, metribuzin + metsulfuron 100 + 4 g/ha (2.00) and sulfosulfuron + 2,4-D 25 g + 0.5 kg/ha (2.03).

It was concluded that tank mix herbicide sulfosulfuron + metsulfuron 25 + 4 g/ha is advisable for reducing the weed pressure and obtaining the higher grain yield of wheat.

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Chemical weed management to increase productivity of wheat

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ABSTRACT

Pinoxaden 50 g/ha reduced *P. minor* weeds, significantly which was statistically at par with clodinafop 60 g/ha, sulfosulfuron 24.5 g/ha but significantly superior over pendimethalin 750 g/ha, isoproturon 937 g/ha. Numbers of effective tillers/m^2 were higher among pinoxaden, clodinafop and sulfosulfuron treatment from the isoproturon, pendimethalin and unweeded check. All other herbicide treatments failed to produce any significant effect on the plant height, ear length, number of grains/ear and 1000- grain weight of wheat crop. Pinoxaden 50 g/ha produced higher average grain yield (4.9 t/ha), which was statistically at par with clodinafop 60 g/ha (4.80 t/ha), sulfosulfuron 24.5 g/ha (4.76 t/ha) but significant superior from the isoproturon 937 g/ha (4.52 t/ha), pendimethalin 750 g/ha (4.18 t/ha) and unweeded check (3.98 t/ha). The increase in yield was due to less weed competition among these treatments. Benifit: cost ratio was higher in case of clodinafop (1.83:1) followed by pinoxaden (1.82:1), sulfosulfuron (1.82:1) and isoproturon (1.70:1) and pendimethalin (1.46:1) but lower B:C ratio was obtained with unweeded check (1.45:1).

Key words: B:C ratio, Chemical control, Herbicide, Weed density, Wheat, Yield

Wheat (*Triticum aestivum* L.) occupies about 17% of the total world's cropped land and contributes 35% of staple foods (Shamsi *et al.* 2006). In India wheat is grown on 29.64 mha area with total production of 92.46 mt and average productivity of 3.12 t/ha (Anon. 2013). In 2025, the estimated food requirement is around 300 million tonnes, which can be elevated from present 230.67 mt through proper management of weeds, insect-pests, diseases and nutrient (Gill and Singh 2009). Among the various factors responsible for low productivity, wheat is infested with several broad as well as narrow-leaved weeds resulting in the yield loses varying from 7 - 50% depending on their densities (Walia and Brar 2001) hence, better grain yield is not possible without proper weed control (Chhokar *et al*. 2012). Chemical method for controlling weeds is most effective, efficient, up-to-date and time saving. In view of above, the present experiment was undertaken to study the efficacy of different herbicides against narrow leaved weeds in wheat under irrigated condition and to study the economics.

MATERIALS AND METHODS

A field experiment was conducted at Krishi Vigyan Kendra, Sri Muktsar Sahib. (30°.26'56" N, 74°.30'28" E) during the *Rabi* 2013 and 2014 to find out the best herbicide for controlling *P. minor* in wheat crop. The annual rainfall of the area was 430.7 mm, most of which is received during July to September (Anonymous 2011). The soil was sandy loam, slightly alkaline in reaction (pH 7.79), high EC (0.980 dS/m), low in available organic carbon (0.24 %), medium in available phosphorus (17.5 kg/ha) and high in available potassium (736 kg/ha).The experimental field had been in a cotton-wheat rotation for the last two years. The experiment was laid out in randomized complete block design with three replications having 4 x 10 m plot sizes. Wheat variety '*HD 2967*' was sown in 20 cm apart lines with single row hand drill having a seeding rate of 100 kg per hectare during both the years. All P, K and half of N applied at sowing while remaining half of N was applied at first irrigation. Recommended fertilizer dose of 125- 62.5-30 kg NPK per hectare was applied and irrigations were applied according to the requirement of the crop. All other practices were kept normal and uniform for all experimental units.

The field experiment was done with six herbicides. Among different herbicide, five herbicide namely isoproturon 937 g/ha, clodinafop 60 g /ha, pinoxaden 50 g/ha, sulfosulfuron 24.5 g/ha and pendimethalin 750 g/ha and one check plot was left unweeded. Pendimethalin was applied 1day after sowing and all other herbicides were sprayed at 4-6 leaf stage of weeds (35 days after sowing) in moist field after first irrigation with hand operated knapsack sprayer. Weed count was recorded at 60 days. The crop was harvested in the last week of April during

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both the years. Observations on plant height, number of effective tiller/m², number of grains per ear, ear length, 1000-grains weight, grain yield and straw yield were recorded. Collected data were further analyzed by using appropriate statistical tools. Economic analysis was carried out on the basis of extra income obtained from the enhanced yield by extra cost incurred for each treatment and prevailing market prices.

RESULTS AND DISCUSSION

Weed density

All the weed controlling treatments significantly reduced the weed population over the control treatment during both the years (Table 1). During 2013 pinoxaden 50 g/ha reduced *P. minor* weeds (1.4/m²) significantly, which was statistically at par with clodinafop 60 g/ha (1.8/m²), sulfosulfuron 24.5 g/ha (2.6/m²), over pendimethalin 750 g/ha (3.4/m²), and isoproturon 937 g/ha (3.7/m²). Higher weed density was observed with the unweeded check (7.1/m²). However, during 2014, lesser weed population was recorded with pinoxaden 50 g/ha (2.6/m²), which was statistically at par with clodinafop 60 g/ha (2.7/m²), sulfosulfuron 24.5 g/ha (3.4/m²) and significant superior weed control over isoproturon 937 g/ha (4.1/m²), pendimethalin 750 g/ha (7.6/m²), (Table 1). Similar results were also obtained by Bahart and Kachroo (2010) in which application of pinoxaden produced reduction of weeds in wheat crop.

Yield attributes and yield

During 2013, pinoxaden 50 g/ha produced the higher (355.7/m²) number of effective tillers/m², which was statistically at par with clodinafop 60 g/ha (355.5/m²), sulfosulfuron 24.5 g/ha (354.5/m²) and isoproturon 937 g/ha (353.8/m²) but significantly superior from pendimethalin 750 g/ha (336.9/m²) and unweeded check (326.1/m²). Whereas, during 2014, higher number of effective tillers were produced from sulfosulfuron (356.6/m²), which was statistically at par with pinoxaden (354.6/m²), clodinafop (353.2/m²), and isoproturon (352.7/m²) but significantly superior over pendimethalin (334.9/m²) and unweeded check (325.6/m²). All the different herbicide treatments failed to produce any significant effect on plant height ear length, number of grains/ear and 1000- grain weight of wheat crop during both the years (Table 2).

During 2013, pinoxaden produced higher grain yield (5.11 t/ha), which was statistically at par with clodinafop (5.01 t/ha), sulfosulfuron (4.95 t/ha) but significantly superior from isoproturon (4.76 t/ha), pendimethalin (4.29 t/ha) and unweeded check (4.05 t/ha). Similar results were obtained during 2014. Pinoxaden produced higher grain yield (4.90 t/ha), which was statistically at par with clodinafop (4.80 t/ha), sulfosulfuron 75 WG (4.76 t/ha) but significant superior from the isoproturon (4.52 t/ha), pendimethalin (4.18 t/ha) and unweeded check treatment (3.98 t/ha). Punia *et al*. (2006), also reported the similar results.

Table 1. Effect of different herbicides on weed density, plant height and effective tillers of wheat

Treatment	No. of weeds/m²			Plant height (cm)			No. of Effective tillers/m²		
	2013-14	2014-15	Average	2013-14	2014-15	Average	2013-14	2014-15	Average
Isoproturon 937 g/ha	3.7	4.1	3.9	98	96	97	354	353	353
Clodinafop 60 g/ha	1.8	2.7	2.2	100	94	97	355	353	354
Pinoxaden 50 g/ha	1.4	2.6	2.0	99	95	97	356	355	355
Sulfosulfuron 24.5 g/ha	2.6	3.4	3.0	97	95	96	354	357	355
Pendimethalin 750 g/ha	3.4	7.6	5.5	99	95	97	337	335	336
Unweeded check	7.1	9.5	8.3	98	97	97	326	326	326
LSD (P=0.05)	1.3	1.6	1.8	NS	NS	NS	13	12	12

Table 2. Effect of different herbicides on ear length, grain/ear and 1000-grain weight of wheat crop

Treatment	Ear length (cm)			Grains/ear			1000 grain wt. (g)		
	2013-14	2014-15	Average	2013-14	2014-15	Average	2013-14	2014-15	Average
Isoproturon 937 g/ha	10.3	10.1	10.2	61.0	61.0	61.0	42.9	42.6	42.7
Clodinafop 60 g/ha	10.5	10.3	10.4	61.8	62.3	62.0	42.6	41.9	42.2
Pinoxaden 50 g/ha	10.6	10.8	10.7	61.7	64.8	63.2	43.5	43.2	43.3
Sulfosulfuron 24.5 g/ha	10.4	10.1	10.2	61.6	58.8	60.2	43.2	42.4	42.8
Pendimethalin 750 g/ha	10.5	10.9	10.7	60.3	61.8	61.0	43.7	43.0	43.3
Unweeded check	10.1	10.4	10.2	58.1	59.9	59	42.5	42.2	42.3
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of different herbicides on grain, straw and biological yield of wheat crop

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Biological yield (t/ha)		
	2013-14	2014-15	Average	2013-14	2014-15	Average	2013-14	2014-15	Average
Isoproturon 937 g/ha	4.76	4.28	4.52	6.96	7.03	6.99	11.7	11.3	11.5
Clodinafop 60 g/ha	5.01	4.60	4.80	7.39	7.58	7.48	12.4	12.2	12.3
Pinoxaden 50 g/ha	5.11	4.69	4.90	7.47	7.50	7.48	12.6	12.2	12.4
Sulfosulfuron 24.5 g/ha	4.95	4.58	4.76	7.34	7.45	7.39	12.3	12.0	12.2
Pendimethalin 750 g/ha	4.29	4.07	4.18	6.36	7.09	6.72	10.6	11.2	10.9
Unweeded check	4.05	3.92	3.98	5.99	6.74	6.36	10.0	10.7	10.3
LSD (P=0.05)	0.30	0.24	0.22	0.47	0.45	0.32	0.77	0.58	0.52

Table 4. Effect of different herbicides on economics and benefit cost ratio of wheat crop

Treatment	Gross returns (x10^3 `/ha)			Input cost (x10^3 ` /ha)			Net returns (x10^3 ` /ha)			Benefit: cost ratio		
	2013-14	2014-15	Average	2013-14	2014-15	Average	2013-14	2014-15	Average	2013-14	2014-15	Average
Isoproturon 937 g/ha	66.68	62.06	64.37	23.45	24.27	23.86	43.23	37.79	40.51	1.84:1	1.56:1	1.70:1
Clodinafop 60 g/ha	70.09	66.70	68.40	23.80	24.54	24.17	46.29	42.15	44.22	1.94:1	1.72:1	1.83:1
Pinoxaden 50 g/ha	71.47	68.00	69.74	24.33	25.15	24.74	47.14	42.86	45.00	1.94:1	1.70:1	1.82:1
Sulfosulfuron 24.5 g/ha	69.35	66.41	67.88	23.70	24.52	24.11	45.65	41.89	43.77	1.93:1	1.71:1	1.82:1
Pendimethalin 750 g/ha	60.11	59.01	59.56	23.86	24.67	24.27	36.25	34.34	35.29	1.52:1	1.39:1	1.46:1
Unweeded check	56.63	56.84	56.73	22.80	23.63	23.22	33.83	33.21	33.52	1.48:1	1.41:1	1.45:1

In both the years average straw yield was higher in pinoxaden (7.48 t/ha) and clodinafop (7.48 t/ha), which was statistically at par with sulfosulfuron (7.39 t/ha) but significant superior from the isoproturon (6.99 t/ha), pendimethalin (6.72 t/ha) and unweeded check (6.36 t/ha). Bharat and Kachroo (2010) also revealed the similar results that these treatments produced significantly higher grain and straw yield. Similarly biological yield was also higher in pinoxaden and statistically equal with clodinafop and sulfosulfuron but significant superior from the isoproturon, pendimethalin and unweeded check treatment. Higher biological yield among these treatments was due to higher grain yield among these treatments. Similar results were also obtained by Bahart and Kachroo (2010) in which application of pinoxaden produced the higher grain and straw yield.

Economics and benefit: cost ratio

Average gross return was higher in treatment pinoxaden (` 69738) followed by clodinafop (` 68397) followed by sulfosulfuron (` 67878) than isoproturon (` 64369) and pendimethalin (` 59561) but lower gross return was obtained with unweeded check (` 56735). Similarly, net return was also higher in these treatments. Benifit: cost ratio, was higher among the clodinafop (1.83:1) followed by pinoxaden (1.82:1) and sulfosulfuron (1.82:1) than isoproturon (1.70:1) and pendimethalin (1.46:1) but lower B: C ratio was obtained with unweeded check treatment (1.45:1). Higher B:C ratio among these treatments was only due to lower input cost in these treatments.

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Wheat residue incorporation and weed management effect on weed seedbank and groundnut yield

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ABSTRACT

The experiment was laid out in split plot design with three replications. The main plots comprised three residue management treatments and sub-plots comprised seven weed management treatments. Results revealed that significantly, highest pod yield (1.47 t/ha) with maximum net returns was recorded under the wheat residue incorporation (IC) *fb* soil solarization. Among the weed management, significantly highest pod yield (1.68 t/ha) and haulm yield (3.35 t/ha) was recorded under weed free and unweeded check registered significantly lowest pod yield (0.72 t/ha). Significantly lower number of total weeds at 30, 60 DAS and at harvest, dry weight of weeds and weed seedbank, lowest weed index and higher weed control index was recorded under the wheat residue incorporation *fb* soil solarization and weed free. Among the weed management, next superior treatments were pendimethalin *fb* imazamox + imazethapyr, pendimethalin *fb* IC and HW and suicidal germination *fb* tillage *fb* IC and HW in the both year of 2014 and 2015.

Key words: *Arachis hypogaea*, Economics, Residue management, Weed indices, Weed management, Weed seed-bank

Groundnut is highly susceptible to weed infestation because of its slow growth in the initial stages up to 40 days, short stature and underground pod bearing habit. Season long weed competition reduces the yield as high as 24 to 70% (Wani *et al*. 2010). The main limiting production factor of groundnut is poor cultural and weed management practices. Therefore, it is essential to keep groundnut fields weed free at the critical stages of crop-weed competition which was found to be the first four to eight weeks after sowing (Jat *et al*. 2011).

The weed seedbank is an important part of crop-weed ecology as it is the most important source of annual weeds in cropping systems and effects efficiency of weed management. This study aims to acquire the information on weed seedbank dynamics and its integrated management by incorporating cultural, physical and chemical methods. Wheat (*Rabi*)-fallow (summer)-groundnut (*Kharif*) is the pre-dominant crop sequence in the Saurashtra region of Gujarat. Owing to labour shortage and its high cost, harvesting of wheat is mostly carried out by combine harvester, which left large quantities of wheat residue. Now their usefulness has been considered as an important resource that can bring significant physical, chemical, biological changes into the soil and suppresses weeds and prevent weed seeds to recycle in soil (Sharma 2014).

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MATERIALS AND METHODS

An experiment was conducted at Weed Control Research Scheme, Department of Agronomy, Junagadh Agricultural University, Junagadh (Gujarat) during *Kharif* (rainy) seasons of 2014 and 2015. The soil of the experimental plot was clayey in texture and slightly alkaline in reaction (pH 8.1 and EC 0.43 dS/m), medium in organic carbon (0.57 and 0.60%), low in available N (249.30 and 241.00 kg/ha), medium in available P_2O_5 (39.48 and 35.89 kg/ha) and medium in available K_2O (274.60 and 279.00 kg/ha) in 2014 and 2015, respectively. The experiment was laid out in split plot design with three replications. The main plots comprised of residue management treatments, *viz*. (i) burning of wheat residues, (ii) wheat residue incorporation by rotavator *fb* soil solarization with 25 µm polythene sheet for 15 days and (iii) wheat residue incorporation by rotavator *fb* application of *Trichoderma viride* 5 kg/ha + 20 kg N/ha and sub-plots contained weed management treatments, *viz*. (i) stale seedbed (pre-sowing irrigation *fb* killing the weed flush by subsequent tillage) *fb* IC and HW at 45 DAS, (ii) suicidal germination (application of ethylene 2000 ppm + KNO_3 2000 ppm with pre-sowing irrigation) *fb* killing the weed flush by subsequent tillage) *fb* IC and HW at 45 DAS, (iii) pendimethalin 900 g/ha as Pre-emergence (PE) *fb* IC and HW at 45 DAS, (iv) HW and IC at 15 DAS *fb* pre-mix imazamox + imazethapyr 70 g/ha as POE at 25 DAS, (v) pendimethalin 900 g/ha as PRE *fb* pre-mix imazamox + imazethapyr 70 g/ha as POE at 25 DAS, (vi) weed free-three IC + five HW and (vii) unweeded check. The groundnut (cv. *Gujarat Groundnut-20*) was sown at 60 x 10 cm spacing using seed rate of 120 kg/ha by bullock drawn seed driller on 24th and 8th June during 2014 and 2015, respectively. The crop was fertilized with 12.5, 25 and 50 kg N P_2O_5 K_2O/ha, respectively. Herbicides were sprayed as per treatments using knapsack sprayer fitted with flat fan nozzle using spray volume of 500 l/ha water. Data on species wise weed count, dry weight of weeds and number of weed seeds in soil per core sample was recorded as per the FAO protocol. The experimental data recorded for growth parameters, yield attributes and yield parameters were statistically analyzed for level of significance.

RESULTS AND DISCUSSION

Weed flora and weed seedbank

The weed species observed during both the years of experiment and their % dominance have been given (Table 1). Significantly lowest numbers of total weeds at 30, 60 DAS and at harvest, dry weight of weeds and weed seedbank, lowest weed index and higher weed control index was recorded under wheat residue incorporation (IC) *fb* soil solarization and weed free-three IC + five HW (Table 2 and 3). Among the weed management next superior treatments were pendimethalin *fb* imazamox + imazethapyr, pendimethalin *fb* IC and HW and suicidal germination *fb* tillage *fb* IC and HW. Soil solarization might have destroyed weed seeds and propagules present in the upper soil, but not so effective against sedge propagules existed deeper in soil, hence there would be less population of weeds than other treatments, while *Trichoderma viride* might have decomposed weed seeds and propagules which reflected in less number of weeds and ultimately lower weed biomass under both these treatments. These findings were in conformity with those reported by Branko *et al.* (2011).

Table 1. Weed species and per cent dominance

Weed species		% dominance in experimental site 2014	2015
Monocots	*Echinochloa colona*	23.65	53.76
	Eluropus villosus	14.86	1.55
	Indigofera glandulosa	6.53	5.80
	Brachiaria ramosa	2.03	-
	Dactyloctenium aegyptium	-	3.68
Dicots	*Ammannia baccifera*	18.02	-
	Leucas aspera	5.40	1.47
	Digera arvensis	2.70	5.40
	Commelina benghalensis	2.03	2.61
	Eclipta alba	2.03	5.72
	Portulaca oleracea	1.58	0.98
	Commelina nudiflora	0.68	0.57
	Phyllanthus niruri	0.45	1.88
	Euphorbia hirta	-	1.14
	Parthenium hysterophorus	-	0.65
	Tridax procumbens	-	0.57
Sedge	*Cyperus rotundus*	20.04	14.22

Yield attributes, yields and economics

Significantly, highest pod yield (1.47 t/ha) with maximum net returns was recorded under the wheat residue incorporation *fb* soil solarization with increased magnitude of 14.2% over the burning of residues among the different residue management treatments (Table 2). Among the weed management, significantly highest pod yield (1.68 t/ha) and haulm yield (3.35 t/ha) was recorded under weed free, which was statistically at par with pendimethalin *fb* imazethapyr + imazamox and pendimethalin *fb* IC and HW with increased magnitude of 124.9 and 124.5%. Conversely, the unweeded check registered significantly lowest pod yield (0.72 t/ha). The higher yield under these treatments could be ascribed to lower dry weight of weeds. Burning of residues and unweeded check recorded lowest pod and haulm yields owing to severe crop-weed competition for resources. These findings were in agreement with earlier reports (Dubey *et al.* 2010, Kalhapure *et al.* 2014. Among the weed management, maximum net returns and B:C ratio were achieved with pendimethalin *fb* IC and HW closely followed by weed free, pendimethalin *fb* pre-mix imazethapyr + imazamox and suicidal germination *fb* tillage *fb* IC and HW (Table 2). This might be due to effective and efficient control of weeds by integration of hand weeding and pre-emergence and post-emergence herbicides. The higher benefits obtained under these treatments were also due to comparatively less cost of herbicides than manual weeding as well as higher pod and haulm yields of groundnut. These findings was in vicinity with those reported by Vaghasia and Nadiyadhara (2013).

It was concluded that effective management of wheat residues, weeds and weed seedbank along with profitable cultivation of groundnut in *Kharif* season can be achieved by incorporation of wheat residues in soil by rotavator followed by soil solarization with 25 µm polythene sheet for 15 days during hot summer or application *Trichoderma viride* 5 kg/ha + 20 kg N/ha and pre-emergence application of pendimethalin 900 g/ha supplemented with either IC and HW at 45 DAS or pre-mix imazamox + imazethapyr 70 g/ha as post-emergence at 25 DAS.

Table 2. Effect of residue and weed management on weed counts, weed dry weight and weed seedbank in groundnut

Treatment	Total weed count per m^2 at						Dry weight of weeds (kg/ha)		Number of weed seeds/core	
	2014			2015						
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	2014	2015	2014	2015
Residues management(Main Plot)									215 (Initial)	181 (Initial)
Burning of wheat residues	3.72(15.9)	3.42(14.1)	4.33(21.1)	5.72(41.7)	4.81(32.1)	5.78(43.2)	1142	1419	259	242
Wheat residue incorporation *fb* soil solarization with 25 µm polythene sheet for 15 days	2.82(9.4)	3.21(10.9)	3.42(12.9)	4.20(20.9)	3.92(18.3)	4.73(25.8)	687	951	161	171
Wheat residue incorporation *fb T. viride* + N	3.28(12.7)	3.33(13.1)	4.12(18.5)	5.32(37.5)	5.01(33.4)	5.70(40.5)	813	1229	234	245
LSD(P=0.05)	0.55	NS	0.36	0.49	0.47	0.58	151	200	45	51
Weed management(Sub plot)										
Stale seedbed *fb* IC and HW	4.43(19.4)	3.37(11.1)	4.15(16.9)	6.80(46.6)	3.22(10.1)	4.37(19.1)	979	1272	168	170
Suicidal germination *fb* tillage *fb* IC and HW (Before sowing the crop)	4.85(23.4)	3.34(10.9)	4.11(16.7)	6.73(45.8)	4.01(15.9)	4.78(22.7)	788	870	99	95
Pendimethalin *fb* IC and HW	2.34(5.2)	3.15(9.7)	3.63(13.0)	5.02(25.3)	3.61(12.8)	4.37(19.1)	521	553	86	78
HW and IC *fb* imazethapyr + imazamox	2.24(4.9)	2.88(7.9)	3.53(12.2)	2.23(4.8)	4.47(20.2)	5.34(28.2)	770	1188	191	180
Pendimethalin *fb* imazethapyr + imazamox	2.49(6.2)	3.09(9.6)	3.33(10.9)	4.48(20.2)	4.19(17.2)	4.93(24.2)	489	628	89	80
Weed free	1.35(1.6)	1.19(1.0)	1.95(3.6)	0.96(0.6)	1.96(3.7)	2.50(6.1)	40	58	68	58
Unweeded check	5.23(27.8)	6.23(39.0)	6.99(49.3)	9.33(90.4)	10.60(115)	11.52(136)	2577	3825	824	876
LSD(P=0.05)	0.50	0.33	0.40	0.53	0.41	0.58	128	159	50	56

$\sqrt{x+0.5}$ transformation (figures in parentheses are original values)

Table 3. Weed indices, yields and economics of groundnut under residue and weed management

Treatment	Weed index (%)		Weed control efficiency (%)		Pod yield (t/ha)	Haulm yield (t/ha)	Gross returns (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	Net returns (x10^3 `/ha)	BCR
	2014	2015	2014	2015						
Residues management (main plot)										
Burning of wheat residues	21.85	18.76	64.71	68.03	1.28	3.11	71.59	28.44	43.15	2.49
Wheat residue incorporation *fb* soil solarization with 25 µm polythene sheet for 15 days	17.71	17.15	67.36	69.26	1.47	2.86	78.77	34.38	44.39	2.27
Wheat residue incorporation *fb T. viride* + N	17.85	17.77	65.66	68.74	1.36	3.13	7506	31.51	43.55	2.36
LSD (P=0.05)	-	-	-	-	0.07	NS	-	-	-	-
Weed management (sub plot)										
Stale seedbed *fb* IC and HW	38.07	32.72	62.38	66.90	1.08	2.8	61.64	30.37	31.27	2.03
Suicidal germination *fb* tillage *fb* IC and HW (Before sowing the crop)	6.62	4.35	68.97	77.21	1.59	3.14	85.51	32.85	52.66	2.61
Pendimethalin *fb* IC and HW	4.65	1.91	79.94	85.49	1.62	3.22	87.50	31.15	56.35	2.82
HW and IC *fb* imazethapyr + imazamox	25.18	24.26	70.56	68.98	1.26	3.16	70.93	31.47	39.46	2.26
Pendimethalin *fb* imazethapyr + imazamox	4.35	2.70	81.04	83.67	1.62	3.27	87.60	32.09	55.50	2.74
Weed free	0.00	0.00	98.49	98.48	1.68	3.35	90.73	34.76	55.96	2.62
Unweeded check	55.10	59.32	0.00	0.00	0.72	2.21	42.09	27.42	14.67	1.54
LSD (P=0.05)	-	-	-	-	0.08	0.29	-	-	-	-

Groundnut yields and economics are pooled of two years

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Increase in yield of winter maize + potato intercropping system by weed management

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ABSTRACT

A field experiment consisted of four intercropping systems, *viz.* winter maize (sole), potato (sole), winter maize + potato (additive series) and winter maize + potato (replacement series) and six sub-plot treatments comprised of weedy check, weed free, alachlor as pre-emergence at1.5 kg/ha, atrazine as pre-emergence at 0.5 kg/ha, early post-emergence alachlor at 2.0 kg/ha and atrazine as post-emergence at 0.75 kg/ha was laid out in split plot design with three replications. Results revealed that *Medicago sativa, Anagallis arvensis* and *Cyperus rotundus* recorded highest relative weed density and dry weed weight. The values of weed smothering efficiency were numerically higher in additive as compared to replacement treatment. Maximum yield loss was in weedy check in comparison to weed-free plots. Pre-emergence application of atrazine 0.5 kg/ha resulted in significantly lower dry-matter accumulation of all the weed species and highest weed-control efficiency which lead to significantly higher crop productivity.

Key words: Intercropping, Potato, Winter maize, Weed management, Weed smothering efficiency

Winter maize is assuming the status of being one of the most important and well-adopted cereal crops to be grown after rice in irrigated areas, with high productivity. The average productivity of winter maize is double as compared to productivity of conventional *Kharif* maize. Intercropping has a great potential as a mean of weed control because it offers the possibility of a consortia of crops capturing a great share of available resources as compared to that in sole cropping. The use of herbicides offers a good scope for timely and adequate control of weeds. Efficiency of weed control can be further enhanced if herbicidal treatments coupled with intercropping, which plays a very significant role in suppression of weeds through their smothering effect. Keeping the above facts in view, the study was undertaken to determine the weed spectrum, frequency and density of weeds in winter maize + potato intercropping system under sub-tropical agro-climatic conditions of Jammu region.

MATERIALS AND METHODS

A field experiment was conducted on sandy loam soil during the *Rabi* 2009-10 and 2010-11 in split plot design with three replications. The experiment consisted of four main plot treatments; winter maize (sole), potato (sole), winter maize + potato (additive series) and winter maize+ potato (replacement series) and six sub-plot treatments comprised of weedy check, weed free, alachlor pre-emergence at 1.5 kg/ha, atrazine (pre) at 0.5 kg/ha, early post-emergence alachlor at 2.0 kg/ha and atrazine (post) at 0.75 kg/ha. Winter maize '*Bulland*' of 175 days duration and potato '*Kufri Sinduri*' of 120 days duration were sown at row to row spacing of 60 cm. Sole maize crop was fertilized with 175-60-30 kg N-P-K/ha, whereas in case of sole potato the crop was fertilized with 120-60-120 kg N-P-K/ha. Entire quantity of P and K along with one-third of N were applied basal at the time of sowing and remaining N was applied in 2 equal splits one-third in mid of January at knee high stage and the one-third at pre-tasseling stage, whereas in case of sole potato, it was 120–60–120 kg N-P-K/ha. Herbicides were sprayed by knapsack sprayer fitted with flat fan T-jet nozzle using a spray volume of 500 l/ha. Weedy check plots remained infested with native population of weeds till harvest. Observations on weeds were recorded with the help of quadrate 0.5 x 0.5 m placed randomly at 2 spots in each plot at harvest. Data on weeds were subjected to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution. Weed population and weeds dry weight was recorded at 90 days interval. The weed indices, *viz.* weeds smothering efficiency, weed index, weed control efficiency, relative weed density, relative dry weed weight and summed dominance ratio were calculated.

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RESULTS AND DISCUSSION

Weed

The experiment field was heavily infested with *Medicago sativa*, *Anagallis arvensis*, *Melilotus alba*, *Convolvulus arvensis*, *Chenopodium album*, *Trachysperum* sp, *Dacus carota*, *Phalaris minor*, *Poa annua*, *Cynodon dactylon* and *Cyperus rotundus* at harvest. Intercropping and herbicidal treatments significantly influenced the population and dry matter production of weeds. Among the intercropping system, sole winter maize resulted in higher weed density (8.4/m^2), which was significantly higher than sole potato and winter maize + potato (additive series), whereas the lowest total weed density (7.2/m^2) was recorded in winter maize + potato (additive series). Amongst weed management practices, lowest total weed density (6.6/m^2) and weed biomass (6.1 g/m^2) were recorded with application of atrazine as pre-emergence at 0.5 kg/ha, which was followed by post-emergence application of atrazine at 0.75 kg/ha (Table 1). Better efficacy and prolonged effectiveness of applied herbicides, did not allow weeds to germinate and even resulted in rapid depletion of carbohydrate reserves of weeds already germinated through rapid respiration, senescence of leaves, reduction in leaf area and diminution of photosynthesis process (Roy *et al.* 2008).

Yield of maize and potato

Intercropping of winter maize + potato (additive series) significantly enhanced grain yield (3.6 t/ha) of winter maize. Amongst the weed control practices, pre-emergence application of atrazine at 0.5 kg/ha recorded significantly higher grain yield, which was statistically at par- with post-emergence application of atrazine at 0.75 kg/ha and pre-emergence application of alachlor at 1.5 kg/ha. Winter maize + potato (additive series) resulted numerically highest production efficiency (88.87 kg/ha/day) followed by winter maize + potato (replacement series) (Table 1). These results were in conformity with the findings of Pandey *et al.* (2003) and Tripathi *et al.* (2010).

Weed indices

The experimental field was infested mainly with broad-leaved weeds (*Medicago sativa*, *Anagallis arvensis* and *Trachyspermum* spp.) followed by grasses (*Phalaris minor, Poa annua* and *Cynodon dactylon*) and one sedge (*Cyperus rotundus*). Broad-leaved weeds were predominant followed by sedges and grassy weeds. *Medicago sativa* among the broad-leaved weeds, *Phalaris minor* among the grassy weeds and *Cyperus rotundus* among the sedge were most dominant. *Medicago sativa* accumulated higher dry matter, followed by *Anagallis arvensis* and *Tracyspermum* spp. at harvest (Table 2). Among the grassy weeds, *Cynodon dactylon* was followed by *Poa annua* in accumulating more dry matter at harvest, whereas *Cyperus rotundus* recorded relatively highest weed dry matter among all the weed species under weedy check. The most dominant weed species were ranked on the basis of their summed dominance ratio, and followed the order: *Medicago sativa* > *Anagallis arvensis* > *Cyperus rotundus* > *Trachyspermum* spp. > *Cynodon dacylon*. *Medicago sativa* was the most dominant weed, followed by *Anagallis arvensis.*

Highest weed-control efficiency at harvest for winter maize was recorded with pre-emergence application of atrazine at 0.5 kg/ha (85.47%),

Table 1. Weed density, weed dry weight, production efficiency and yield of maize and potato as influenced by different weed control treatments in winter maize-potato intercropping system (pooled data of two years)

Treatment	Weed density/m^2 90 DAS	Weed dry weight (g/m^2) 90 DAS	Maize (t/ha)	Potato (t/ha)	Production efficiency (kg/ha/day)
Intercropping					
Sole maize	8.4(90.6)	8.0(73.6)	4.8	-	26.43
Sole potato	7.7(75.8)	7.4(67.7)	-	23.7	84.94
Winter maize + potato (additive series)	7.2(66.8)	6.9(60.0)	3.6	19.2	88.87
Winter maize + potato (replacement series)	8.2(88.0)	8.2(80.3)	2.3	14.5	65.04
LSD (P=0.05)	0.14	0.13	o.14	0.9	-
Weed management					
Alachlor as pre-emergence at 1.5 kg/ha	7.5(57.3)	7.3(50.5)	3.8	20.9	72.24
Alachlor early-post at 2.0 kg/ha	9.2(84.0)	9.2(80.5)	3.4	20.1	68.34
Atrazine as pre-emergence at 0.5 kg/ha	6.6(42.4)	6.1(33.9)	4.0	20.5	72.03
Atrazine as post-emergence at 0.75 kg/ha	7.5(57.0)	7.3(50.4)	3.9	19.4	68.50
Weedy check	15.5(241.0)	14.8(208.5)	1.75	12.3	40.34
Weed free	1.0(0.00)	1.0(0.00)	4.4	21.5	76.46
LSD (P=0.05)	0.08	0.09	0.13	0.7	-

Table 2. Relative weed density, relative dry weed weight and summed dominance ratio of individual 6 weed species as per cent of total weed dynamics at harvest in sole winter maize and potato (pooled data of two years)

Weed species	Winter maize			Potato		
	Relative weed density (%)	Relative dry weed weight (%)	Summed dominance ratio	Relative weed density (%)	Relative dry weed weight (%)	Summed dominance ratio
Broad-leaved weed						
Medicago sativa	19.22	10.85	15.04	21.12	12.46	16.79
Anagallis arvensis	8.79	8.06	8.43	10.76	11.95	11,35
Trachyspermum spp.	7.49	2.90	5.20	8.76	3.22	5.99
Grasses						
Cynodon dactylon	8.14	5.30	6.72	3.98	5.56	4.77
Phalaris minor	4.89	3.11	4.0	7.17	2.59	4.88
Sedges						
Cyperus rotundus	29.32	27.78	28.53	31.08	29.46	30.27
Others	22.15	42.00	32.08	17.13	34.76	25.95

Table 3. Effect of different herbicidal treatments on weed-control efficiency and weed index in winter maize + potato intercropping system (pooled data of two years)

Treatment	Weed control efficiency		Weed index	
	Maize	Potato	Maize	Potato
Alachlor PRE at 1.5 kg/ha	67.7	70.8	3.0	13.5
Alachlor E-POST at 2.0 kg/ha	50.1	53.0	6.5	23.4
Atrazine PRE at 0.5 kg/ha	79.2	85.5	4.7	9.1
Atrazine POST at 0.75 kg/ha	70.8	77.3	10.2	11.1
Weedy check	0.0	0.0	43.0	60.4
Weed free	100.0	100.0	0.0	0.0

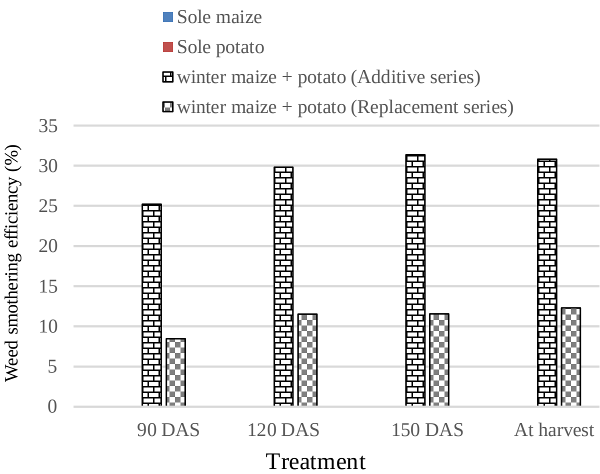

Fig. 1. Effect of intercropping treatments on weed-smothering efficiency in winter maize + potato intercropping system at harvest. (pooled data of two years)

followed by post-emergence application of atrazine at 0.75 kg/ha (Table 3). However, lowest weed index was recorded with pre-emergence application of atrazine at 0.5 kg/ha. Application of lower optimum dose of herbicides reduced the cost of weed management assisted weed shifts, prevented herbicides resistance in weeds (Singh *et al.* 2005). Among the intercropping treatments, winter maize + potato (additive treatments) registered numerically higher weed-smothering efficiency (WSE) than maize with potato in replacement treatments, which might be due to the fact that additive series ensured better coverage of soil surface from the beginning and diminished light penetration to the soil reducing the weed growth and ensuring better WSE (Fig. 1). Tripathi *et al.* (2008) also reported similar findings.

Based on the investigation, it was concluded that among intercropping systems, winter maize + potato in additive treatment along with the application of atrazine as pre-emergence at 0.50 kg/ha and alachlor as pre-emergence at 1.5 kg/ha may be recommended under the sub-tropical irrigated conditions of Jammu.

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Management of complex weed flora in maize with post-emergence herbicides

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ABSTRACT

Some weed species are not controlled by atrazine where the farmers are using this herbicide year after year and different flushes of weeds in rainy season are among the major problems in maize growing areas of India. A field experiment was conducted during the crop growing seasons of 2012 and 2013 at Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana to evaluate the efficacy of glyphosate 41% SL against complex weed flora in maize. The treatments included glyphosate 41% SL 900, 1800 and 3600 g/ha applied as post-emergence at 2-4 leaf stage of weeds, atrazine 750 g/ha as pre-emergence, paraquat 24 SL 500 g/ha as post-emergence at 2-4 leaf stage of weeds, 2,4-D sodium salt 1000 g/ha as post-emergence at 2-4 leaf stage of weeds, weed free and unweeded control. The results revealed that non-selective herbicides paraquat at 500 g/ha and glyphosate at 900 and 1800 g/ha as a directed spray in maize as post-emergence at 2-4 leaf stage of weeds recorded effective control of grass and broad-leaf weeds during both the years and recorded grain yield at par with atrazine.

Key words: Glyphosate, Grain yield, Herbicides, Maize, Post-emergence, Weed flora, Weeds

Maize (*Zea mays* L.) is an important cereal crop of *Kharif* season in Punjab and it ranks third on the basis of area and production amongst cereals after wheat and rice. In Punjab, maize was grown on an area of 130 thousand hectares with average productivity of 3898 kg/ha during 2013-14 (Anonymous 2015). Some hardy weeds like *Bracharia reptans, Acrachne racemosa, Commelina benghalensis etc*. posing serious problems and are not controlled by atrazine. Worldwide maize production is reduced to about 40% due to competition from weeds, which are the most important pest groups (Oerke and Dehn 2004). Use of atrazine as pre-emergence is the biggest tool in the hands of farmers as it provides good control of weeds during initial stages of crop-weed competition. But some weeds start emerging afterwards and attain good growth due to frequent incessant rains. Some post-emergence herbicide is therefore, required to check the complex weed flora and late emerging weeds.

Directed post-emergence herbicide sprays are a possible alternative for mid- to late-season weeds and have been used in various crops (Borland 1973, Richards 1977). This practice usually involves relatively non-selective herbicides sprayed at the base of the crop and is aimed at controlling existing weeds and often provides residual control of further weed flushes. These herbicides should be used with care to avoid drift losses to main crop.

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Glyphosate and paraquat are the most commonly and widely used herbicides on the wastelands, uncropped situations *etc*. Gylphosate is mainly used by the farmers in non–agricultural or wastelands in India. It is mostly used before sowing of the crop or with specialized application equipment (hood) to avoid contact with the crop or other desirable vegetation. Glyphosate provides a viable, flexible and profitable alternative to conventional weed control programmes. The widespread use of glyphosate is due to its very broad weed spectrum and high efficacy. It is a nonselective, systemic (or translocated) post-emergence herbicide. Being nonselective, it is a broad-spectrum herbicide capable of killing grasses, sedges and broad-leaved weeds. Although paraquat is also a non-selective, broad spectrum herbicide, it does not move through plants systemically like glyphosate. So, non-selective herbicides can be used in maize for inter-row weed control to remove weeds growing between the crop rows. Shield/hood sprayers are commonly used for precision, directed-spray applications of non selective herbicides. Keeping in view the above points, the experiment was planned to evaluate the bio-efficacy of glyphosate 41% SL against mixed weed flora in maize, to find out effect of different doses of herbicide on growth and grain yield of maize.

MATERIALS AND METHODS

A field experiment was conducted during *Kharif* 2012 and 2013 at Research Farm, Department of

Agronomy, Punjab Agricultural University, Ludhiana, India. The experimental site was situated at 30° 542 N latitude and 75° 482 E longitude with an altitude of 247 metre above mean sea level in the central plain region of Punjab state under Trans-Gangetic agro-climatic zone of India. The climate of this region is sub-tropical and semi-arid with very hot and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February and March. The soil of the experimental area was sandy loam with available N, P and K of 191.2, 14.6 and 159.1 kg/ha, respectively. The seedbed was prepared by one ploughing with disc harrow followed by two ploughings with cultivator and each ploughing was followed by planking. The experiment was laid out with a plot size 7.0 x 4.0 m and row to row distance of 60 cm and plant to plant distance of 20 cm. Maize was sown on 13.7.2012 and 2.7.2013. Variety '*PMH 1*' was sown during both years using 20 kg seed/ha in a randomized complete block design replicated four times. The seed was treated with a fungicide agrozim 50 WP carbendazim at 3 g/kg seed. The crop was fertilized with 125 kg N, 60 kg P_2O_5 and 30 kg K_2O/ha. The nitrogen was applied in the form of urea (46% N), P_2O_5 in form of single super phosphate (16% P_2O_5) and K_2O in form of muriate of potash (60% K_2O). One-third of nitrogen and the entire quantity of phosphorus and potassium was drilled at the time of sowing. Remaining one-third of nitrogen was top-dressed at the knee-high stage and the remaining one-third at the pre-tasseling stage. The treatments included glyphosate 41% SL at 900, 1800 and 3600 g/ha applied as post-emergence at 2-4 leaf stage of weeds, atrazine at 750 g/ha as pre-emergence, paraquat 24 SL at 500 g/ha as post-emergence at 2-4 leaf stage of weeds, 2,4-D sodium salt at 1000 g/ha as post-emergence at 2-4 leaf stage of weeds, weed free and unweeded control. Glyphosate and paraquat were applied as directed spray by hood.

The crop was harvested on 23.10.2012 and 19.10.2013. The data on maize grain yield was recorded at the time of crop harvest from the centre rows of each plot. The cobs were shelled, dried and weighed. At each harvest, weeds were clipped at the soil surface, sorted by species, counted, and dried at 70°C to constant moisture content to obtain a measure of aboveground dry matter accumulation. The weed density and dry matter was taken with a quadrate measuring 0.5 x 0.5 m randomly from two spots per plot at 30 days after treatment. The data on weed count and weed dry matter were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. All data were analyzed statistically using CPCS1 software.

RESULTS AND DISCUSSION

The experimental field had enough population of *Acrachne racemosa, Dactyloctenium aegyptiacum, Commelina benghalensis, Eragrostis tenella, Digitaria sanguinalis, Echinochloa colona, Trianthema portulacastrum, Phyllanthus niruri, Euphorbia hirta, Euphorbia microphylla, Digera arvensis, Amaranthus viridis, Cyperus rotundus, Cyperus compressus etc*.

Phytotoxicity on the crop was recorded on 0-10 scale which indicated that glyphosate was safe to maize crop when applied at 3600 g/ha during both the years (data not shown).

During 2012, weed density was at par with atrazine when glyphosate was applied at 900 g/ha. *D. aegyptiacum* was effectively controlled by glyphosate at 900 and 1800 g/ha at par with atrazine and paraquat. Glyphosate at 1800 g/ha were at par with paraquat for the control of *C. benghalensis*. 2,4-D sodium salt, being broad-leaf weed killer did not show its phytotoxic effect on any of the grass weed species. Dry matter of grass weeds was significantly less in glyphosate 900 g/ha as compared to atrazine. The dry matter of weeds was significantly decreased as the dose of glyphosate increased (Table 1). With the increase in dose of glyphosate, density of *T. portulacastrum* also decreased considerably. 2, 4-D sodium salt also effectively controlled this weed. Similar trend in weed dry matter was recorded during both the years.

During *Kharif* 2013, all doses of glyphosate recorded similar control of *D. aegyptiacum* and at par with atrazine and paraquat. Similar was the trend for *A. racemosa* except paraquat where the population was significantly more. *C. benghalensis* was effectively controlled by atrazine, glyphosate and paraquat. Significantly less dry matter of grasses was recorded at higher doses of glyphosate than at 900 g/ha, atrazine and paraquat. Similarly in case of broad-leaf weeds, higher dose of glyphosate recorded significantly less dry matter than its lower dose. 2,4-D sodium salt recorded significantly more dry matter of grass weeds than all herbicides (Table 2).

The maize grain yield was at par where glyphosate was applied at 900 and 1800 g/ha. Paraquat also recorded significantly more grain yield than 2,4-D. As 2,4-D only killed the broad-leaf weeds and the grass weeds pose full competition to the crop which ultimately resulted into reduction in grain yield. During 2013, all the herbicide treatments yielded at par with each other and attained significantly more grain yield than 2,4-D due to kill of only broad-leaf weeds. Weeds significantly reduced grain yield in unsprayed control. The weed free treatment recorded significantly higher maize grain yield than all the herbicidal treatments during both the years. Glyphosate at all the doses recorded significantly lower grain yield than atrazine during 2012 while during 2013, the grain yield with glyphosate at all the levels was at par to atrazine.

Paraquat 500 g/ha recorded grain yield similar to atrazine during 2013 but lower than atrazine during 2012 (Table 3). Paraquat and glyphosate both being non-selective in nature, kill weed flora and provided weed free environment for good time and by then the maize crop attained so much growth, that it is not affecting its yield. Atrazine provided good control of weeds during earlier stages and contributed towards attaining good yield. The only advantage of using non-selective herbicides was that the farmers have the option to use some post-emergence herbicide in maize as a directed spray. So farmers have the option to use non-selective herbicide, *viz*. paraquat at 500 g/ ha and glyphosate at 900 and 1800 g/ha as a directed spray in maize in case the need for weed control arises in maize.

These results corroborate with the findings of Larbi *et al.* (2013) where maize showed differential response in terms of yield to the application of the herbicides while better yields were observed on glyphosate and gramoxone treated plots. Maize which was sprayed at later stages lost some lower leaves but this did not affect grain production or did not consistently affect other maize attributes (Thomas 1986)

Regression analysis indicated that there was significant negative linear relationship between grain yield and weed biomass at 60 DAS. In regression analysis, the equations Y = -0.0036x + 4.4482 (Fig. 1) and Y= -0.0027x + 4.7356 (Fig. 2) were found to be fit for the maize grain yield and dry matter of weeds where Y is grain yield and X is weed dry matter. Correlation between grain yield and weed dry matter at 60 DAS was $R^2 = 0.8302$ (Fig. 1) and $R^2 = 0.8218$ (Fig. 2). It indicated a high degree of negative correlation between weed dry matter and grain yield during both the years. Results indicated that that as the weed dry matter increased, the grain yield of maize was decreased.

Table 1. Effect of different herbicide treatments on weed density and dry matter at 60 days after sowing on maize during *Kharif* 2012

Treatment	Dose (g/ha)	Weed density (no./m^2)				Weed dry matter (g/m^2)			WCE (%)
		A. racemosa	*D. aegyptiacum*	*C. benghalensis*	*T. portulacastrum*	Grasses	BLW	Total	
Atrazine	750	3.0 (8)	2.1 (4)	4.1 (16)	1.3 (0.7)	8.0 (64)	6.3 (39)	10.4 (107)	75.7
Glyphosate	900	2.8 (7)	2.2 (4)	2.9 (7)	1.9 (3)	7.6 (57)	6.2 (37)	10.7 (114)	74.1
Glyphosate	1800	2.4 (5)	2.0 (3)	2.5(5)	1.5 (1)	7.4 (53)	5.9(34)	10.7 (114)	74.1
Paraquat	500	2.4 (5)	2.0 (3)	2.3 (4)	1.8 (2)	7.4(54)	5.9 (34)	10.8 (116)	73.7
2,4-D sodium salt	1000	3.8 (13)	3.2 (9)	4.3 (18)	1.5 (1)	12.5(155)	5.6(30)	13.2 (173)	60.8
Weed free	-	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	100
Unweeded control	-	4.0 (15)	3.4 (11)	4.4 (19)	3.7 (13)	12.3 (150)	11.4 (128)	21.0 (441)	-
LSD (P=0.05)	-	0.3	0.3	0.4	0.3	0.2	0.3	0.3	-

* Figures within brackets are original means, subjected to square root; transformation; BLW - Broad-leaf weeds

Table 2. Effect of different herbicide treatments on weed density and dry matter at 60 days after sowing in maize during *Kharif* 2013

Treatment	Dose (g/ha)	Weed density (no./m^2)					Weed dry matter (g/m^2)			WCE (%)
		A. racemosa	*D. egyptiacum*	*C. benghalensis*	*D. sanguinalis*	*T. Portulacastrum*	Grasses	BLW	Total	
Atrazine	750	1.9 (3)	2.4 (5)	1.7 (2)	1.7 (2)	2.6 (6)	9.7 (93)	9.1 (82)	10.4 (107)	79.3
Glyphosate	900	1.9 (3)	2.6 (6)	2.4 (5)	1.8 (2)	2.6 (6)	10.1(101)	7.5 (55)	10.5 (108)	79.2
Glyphosate	1800	1.9 (3)	2.3 (4)	2.1 (3)	1.6 (2)	2.4 (5)	9.4 (87)	6.7 (44)	10.4 (107)	79.3
Paraquat	500	3.0 (8)	2.8 (7)	2.1 (3)	2.2 (4)	2.2 (4)	10.4 (107)	7.0 (48)	10. 9 (118)	77.2
2,4-D sodium salt	1000	6.1 (36)	3.3 (11)	3.4 (11)	3.5 (11)	2.0 (3)	15.3 (233)	7.3 (53)	15.4 (235)	54.6
Weed free	-	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	100
Unweeded control	-	6.0 (35)	4.0 (15)	3.5 (11)	3.5 (11)	5.1 (25)	16.6 (275)	9.9 (97)	22.8 (518)	-
LSD (P=0.05)	-	0.7	0.3	0.4	0.5	0.4	0.3	0.3	0.3	-

*Figures within brackets are original means, subjected to square root transformation; BLW - Broadleaf weeds

Table 3. Effect of different herbicide treatments on growth and yield of maize during *Kharif* 2012 and 2013

Treatment	Dose (g/ha)	Plant height (cm)		Cob length (cm)		Cob weight (g)		Grain yield (t/ha)	
		2012	2013	2012	2013	2012	2013	2012	2013
Atrazine	750	230.5	242.6	21.3	22.1	19.6	21.3	4.39	4.40
Glyphosate	900	229.5	240.7	20.7	22.3	20.3	20.3	4.01	4.36
Glyphosate	1800	215.7	242.6	20.7	22.1	20.4	20.5	4.04	4.36
Paraquat	500	222.3	238.6	20.4	21.7	18.4	18.3	3.99	4.23
2,4-D sodium salt	1000	235.7	236.9	19.4	19.8	17.2	17.9	3.61	3.92
Weed free	-	238.5	245.1	21.9	22.9	22.4	24.8	4.56	5.14
Unweeded control	-	217.9	222.4	17.6	18.8	11.4	14.9	2.91	3.49
LSD (P=0.05)	-	10.0	5.8	0.4	0.5	0.9	1.0	0.2	0.31

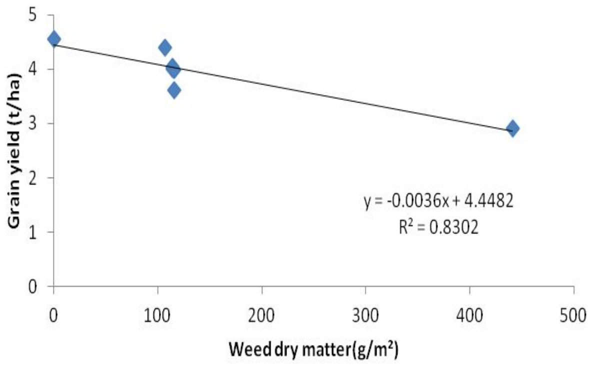

Fig. 1. Correlation and regression analysis of weed dry matter and grain yield of maize (*Kharif* 2012)

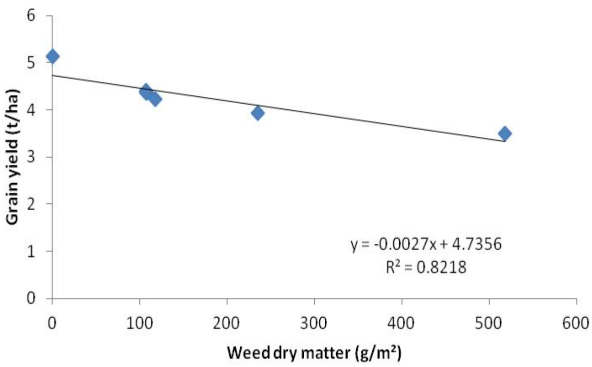

Fig. 2. Correlation and regression analysis of weed dry matter and grain yield of maize (*Kharif* 2013)

Under heavy weed infestation, post-emergence application of paraquat if field is infested with annual weeds can also be done as protected spray using hood. Glyphosate at 900 and 1800 g/ha recorded effective control of grass and broad-leaf weeds during both the years and recorded grain yield at par with atrazine. Thus, the glyphosate at the above doses was safe for use as directed spray maize along with the hood.

Non-selective herbicides paraquat at 500 g/ha and glyphosate at 900 and 1800 g/ha as a directed spray in maize can be used as post-emergence at 2-4 leaf stage of weeds for the control of complex weed flora in maize.

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Energy budgeting of weed management in soybean

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ABSTRACT

An experiment was conducted at ICAR-Directorate of Weed Research, Jabalpur during *Kharif* season of 2015 and 2016 in order to assess the energy budgeting of weed management in soybean cultivation. Ten treatments comprising of pendimethalin (750 g/ha PE), pendimethalin (750 g/ha PE) *fb* imazethapyr (100 g/ha at 20 DAS), pendimethalin (750 g/ha PE) *fb* 1 HW (at 20 DAS), metribuzin (500 g/ha), metribuzin (500 g/ha) *fb* imazethapyr (100 g/ha at 20 DAS), metribuzin (500 g/ha PE) *fb* 1 HW (at 20 DAS), imazethapyr (100 g/ha at 20 DAS), imazethapyr (100 g/ha at 20 DAS) *fb* 1 HW (at 40 DAS), 2 HW (at 20 and 40 DAS) and unweeded check were laid-out in randomized block design with three replications. Sequential application of pendimethalin 750 g/ha PE *fb* imazethapyr 100 g/ha at 20 DAS was found to be the most energy efficient weed management strategy and had maximum value of total output energy (71.90 x 10^3 MJ/ha) and net energy returns (62.32 x 10^3 MJ/ha). Other parameters like energy ratio (7.50), energy profitability (6.50) and human energy profitability (164.27) were also higher under the same treatment whereas, it recorded less specific energy (11.53 10^3 MJ/ha) and energy intensity (0.48).

Key words: Energy budget, Herbicide, Indices, Soybean, Weed management

Soybean (*Glycine max*) is one of the most important oilseed crops in India. The crop is called "Golden bean" or "Miracle crop" of the 21st century because of its multiple uses (Jadhav 2014). Weed infestation is one of the major constraints in the cultivation of soybean. If weeds are not controlled during critical periods of crop-weed competition, reduction in the yield of soybean to the tune of 26 to 71 % has been recorded depending upon the type and intensity of weeds (Rathore *et al,* 2006). Hand weeding is a traditional and effective method of weed control, but unavailability of labour during peak period of demand and hinderance for manual weeding due to continuous rains in the growing period is the main limitations of hand weeding. Thus, the herbicidal weed control either alone or in integrated manner remains the only choice under such situations to minimize the weed menace effectively and economically. Sole application of herbicide as pre-emergence fails to control subsequent flushes of weeds. So, there is need to apply pre- and post-emergence herbicides in a sequential manner to reduce weed menace and keep the crop free from weed competition during entire critical period of crop growth (Tuti and Das 2011). Energy budgeting of weed management is also important because energy and economics are mutually dependent. There is a close relationship between agriculture, economics and energy. Very scanty information is available on this aspect. Therefore, the present study was undertaken to assess the energy budgeting of weed management in soybean.

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MATERIALS AND METHODS

An experiment was conducted at ICAR-Directorate of Weed Research, Jabalpur during *Kharif* season of 2015 and 2016. The total rainfall received during *Kharif* season (June to October) for the year 2015 and 2016 was 971.0 mm and 2114.8 mm, respectively. Minimum and maximum temperature ranged from 21.1 ^{0}C to 33.8 ^{0}C during 2015 and 22.1 ^{0}C to 35.8 ^{0}C during 2016. The relative humidity ranged from 78 to 91% in morning and 35 to 70% in evening during 2015 and 87 to 94% in morning and 55 to 91% in evening hours during 2016. Ten treatments consisted of pendimethalin (750 g/ha PE), pendimethalin (750 g/ha PE) *fb* imazethapyr (100 g/ha at 20 DAS), pendimethalin (750 g/ha PE) *fb* 1 HW (at 20 DAS), metribuzin (500 g/ha), metribuzin (500 g/ha) *fb* imazethapyr (100 g/ha at 20 DAS), metribuzin (500 g/ha PE) *fb* 1 HW (at 20 DAS), imazethapyr (100 g/ha at 20 DAS), imazethapyr (100 g/ha at 20 DAS) *fb* 1 HW (at 40 DAS), 2 HW (at 20 and 40 DAS) and unweeded check were laid-out in randomized block design (RBD) with three replications. Soybean '*JS 97-52*' was grown with row spacing of 45 cm and a plant to plant spacing of nearly 5 cm during both years. The recommended dose of fertilizers was 20 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha, respectively. The whole quantity of N, P_2O_5 and K_2O were applied through di-ammonium phosphate and muriate of potash, respectively at the time of sowing as a basal application.

Methods of energy budgeting

The inputs and the energy requirements of each input for soybean production including weed management were collected, determined and presented. General inputs in soybean production were machinery, human labor, chemical fertilizers, irrigation water, fuel, pesticide and seed. Output was soybean seed and haulm as a product. The energy equivalent of different inputs and output were used to determine the energy values (Table 1). The human energy as an energy input was calculated by multiplying the number of man-hours (hr/ha) by estimated power rating of human labor (MJ/ha) from (Table 1). Energy used by woman labor was converted into human energy with suitable factors. Energy used by farm machinery was calculated by methodology given by Kitani (1999).

$$ME = M \times G \times T$$

Where, ME is the machinery energy (MJ), E the production energy of machine, G the mass of machine (kg), and T is the economic life of machine (year). Other inputs like fuel, seed, pesticide and chemical fertilizers used in soybean production were converted into energy value (MJ/ha) by multiplying the quantity of the material used in the production process by the energy equivalent of each material. For example, energy consumption of chemical fertilizer (nitrogen) was calculated by multiplying the amount of nitrogen used (kg/ha) by energy coefficient of nitrogen fertilizer (60.60 MJ/kg from Table 1); hence the result is the energy consumption of nitrogen fertilizer (MJ/ha) in soybean production. Also, energy used by other inputs can be determined by applying same methods as suggested for nitrogen. The amount of output energy (MJ/ha) was estimated by multiplying the soybean seed and haulm yield (kg/ha) by soybean energy equivalent (MJ/kg).

Energy indices

On the basis of energy input and output; energy ratio, net energy returns, specific energy, energy intensiveness, energy profitability and human energy profitability were calculated by using the following formulae as suggested by Mittal and Dhawan (1988) and Burnett (1982).

Table 1. Energy equivalents of inputs and outputs in soybean production

S. No	Particulars	Unit	Equivalent energy (MJ/unit)	Reference
A. Inputs				
1. Labour				
1a	Adult man	hr	1.96	Mittal and Dhawan (1988)
1b	Woman	hr	1.57	Mittal and Dhawan (1988)
2	Fuel (diesel)	l	56.31	Mittal and Dhawan (1988)
3	Seed	kg	18.14	Mittal and Dhawan (1988)
4	Electricity	kWh	11.93	Mittal and Dhawan (1988)
5	Pump	hr	2.40	Dagistan *et al.* (2009)
6. Chemical fertilizers				
6a	Nitrogen	kg	60.60	Kitani (1999)
6b	P_2O_5	kg	11.10	Kitani (1999)
6c	K_2O	kg	6.70	Kitani (1999)
7. Pesticide				
7a	Herbicide	kg *a.i*	288	West and Marland (2002)
7b	Insecticide	kg *a.i*	237	West and Marland (2002)
7c	Fungicide	kg *a.i*	196	West and Marland (2002)
8	Bio-fertilizer	kg	10.0	West and Marland (2002)
9	Irrigation	m^3	1.02	Singh *et al.* (2008)
10	Knapsack sprayer	hr	0.17	Dagistan *et al.* (2009)
11. Farm machinery				
11.a	Power thresher	hr	200	Kitani (1999)
11.b	Rotavator	hr	6.69	Kitani (1999)
11.c	Cultivator	hr	22.80	Dagistan *et al.* (2009)
11.d	Harrow	hr	37.62	Dagistan *et al.* (2009)
11.e	Tractor	hr	303.6	Dagistan *et al.* (2009)
11.f	Seed drill	hr	12.54	Dagistan *et al.* (2009)
B	Outputs			
12	Seed	kg	18.14	Kitani (1999)
13	Haulm	kg	12.50	Kitani (1999)

Energy ratio (ER)

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

Net energy returns

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

Specific energy

$$\text{Specific energy} = \frac{\text{Input energy (MJ/ha)}}{\text{Yield (t/ha)}}$$

Energy intensiveness

$$\text{Energy intensiveness} = \frac{\text{Input energy (MJ/ha)}}{\text{Cost of cultivation (Rs/ha)}}$$

Energy profitability

$$\text{Human energy profitability} = \frac{\text{Output energy (MJ/ha)}}{\text{Labor energy (MJ/ha)}}$$

Human energy profitability

$$\text{Energy profitability} = \frac{\text{Net energy returns (MJ/ha)}}{\text{Input energy (MJ/ha)}}$$

RESULTS AND DISCUSSION

Major weed flora

The experimental field was infested with monocot weeds like *Echinochloa colona* (29.67%), *Dinebra retroflexa* (35.15%) and *Cyperus iria* (1.67%), and dicot weeds like *Euphorbia geniculata* (24.20%), *Phyllanthus niruri* (5.80), *Commelina benghalensis* (2.67%) and *Alternanthera sessilis* (1.93%).

Productivity

The seed yield (223.33 kg/ha) and haulm yield (2008.17 kg/ha) were minimum in unweeded control. It may be due to severe competitional stress during entire critical period of crop growth, leading to poor growth parameters and yield attributing traits and finally the minimum seed yield. But, the yields increased marginally when weeds were controlled with pre-emergence application of either pendimethalin (750 g/ha) (386.67 kg/ha) or metribuzin (500 g/ha) (460 kg/ha) being higher under plots treated with pendimethalin (750 g/ha) *fb* imazethapyr (100 g/ha) and metribuzin (500 g/ha) *fb* imazethapyr (100 g/ha) (831.67 and 806.67 kg/ha, respectively). However, none of the herbicidal treatments surpassed hand-weeding twice (20 and 40 DAS), which proved significantly superior over other treatments (Table 4). The crop under two hand weeded plots resulted highest yield (1061.67 kg/ha). Since the weather conditions during crop growing season were not favorable for its growth and development. The crop yield was less than the potential yields. However, it was nearer to average productivity of the country.

Energetics

Energy input requirement of crops: Common input energy required for the production of soybean is presented in Table 2. Total common input energy required for the cultivation of soybean was 9267.3 MJ/ha (100%). Of the inputs for different operations, field preparation consumed the bulk of energy for crops which was 21.10% of the total common input energy required for the crop production (Table 2). Energy for sowing of crop contributes 6.82%. Energy consumed by diesel for field preparation was 14.58% of the total common input energy consumption. Seed is an important input for the cultivation of any crop. For the cultivation of soybean, only seed contributes 11.74% of the total common input energy required. In the production systems, fertilizer accounted for the largest share of total energy input (23.15%). Among the fertilizers, energy embedded in N fertilizer was particularly high (13.07%), although it was applied at lower rate (20 kg N/ha). Seed treatment through bio-fertilizer and fungicide is also a very important practice which shared very negligible input energy (0.17%). Energy required for spraying of insecticide which includes insecticide, water, labor and sprayer constituted only 0.96%. Energy required by labor for seed treatment and application of fertilizer was 0.25%. Energy requirement for harvesting and post harvest process was 18.18%.

Energy used in different treatments of soybean cultivation is presented in Table 3. Unweeded check required almost zero energy because neither hand weeding nor herbicide application was done in this treatment. Among the herbicidal treatment, maximum energy (313.98 MJ/ha) was required in plots treated with pendimethalin (750 g/ha) PE *fb* imazethapyr (100 g/ha) at 20 DAS while minimum energy (63.39 MJ/ha) was required in plot treated with imazethapyr (100 g/ha) alone. Two hand weeded treatments required maximum energy (690.8 MJ/ha). It was due to maximum labor required (55 man days of 8 hours each) for two hand weeding operation.

Total input energy used in different treatments of soybean is presented in Table 4. Unweeded check required minimum total input energy (9.27×10^3 MJ/ha). Among the herbicidal treatments, maximum total input energy (9.58×10^3 MJ/ha) was required in plot treated with pendimethalin (750 g/ha) *fb* imazethapyr (100 g/ha), while minimum total input energy (9.33×10^3 MJ/ha) was required in plot treated with imazethapyr (100 g/ha) alone. Two hand weeded treatment required maximum total input energy (9.96×10^3 MJ/ha).

Energy input-output relationship: The total input energy (MJ/ha) consumed and total output energy produced (MJ/ha) in each treatment has been presented in Table 4. Based on the seed and haulm yield, treatment wise energy production was calculated. Minimum total output energy (29.15×10^3 MJ/ha) was recorded in unweeded check where weeds were allowed to grow throughout the crop season. However, its total input energy requirement was also minimum but in comparison to its total energy requirement, energy production was very less due to poor yield. Among the herbicidal treatment, lowest total output energy (45.61×10^3 MJ/ha) was produced in the plot treated with pendimethalin (750 g/ha) alone while its total input energy requirement was higher (9.52×10^3 MJ/ha) than alone application of imazethapyr (100 g/ha). It may be due to better control of weeds by alone application of imazethapyr

Table 2. Common input energy in soybean cultivation (mean of two years)

Particulars	Unit	Quantity/ha	Equivalent energy (MJ/unit)	Energy (MJ/ha)
Ploughing with cultivator including tractor	hr	2	22.8 + 303.6	652.80
Harrowing with disc harrow including tractor	hr	2	37.62 + 303.6	682.44
Pulverization with rotavator including tractor	hr	2	6.69 + 303.6	620.58
Sowing with seed-drill including tractor	hr	2	12.54 + 303.6	632.22
Fuel (Diesel)	l	24	56.31	1351.44
Driver	hr	8	1.96	15.68
Seed	kg	60	18.14	1088.4
Nitrogen	kg	20	60.60	1212
P_2O_5	kg	60	11.10	666
K_2O	kg	40	6.70	268
Bio-fertilizer	kg	0.5	10.0	5
Insecticide	kg *a.i*	0.089	237	21.09
Fungicide	kg *a.i*	0.06	196	11.76
Irrigation	m^3	100	1.02	204
Pump	h	4	2.4	9.6
Electricity	kWh	4	11.93	47.72
Water used for spraying insecticide	m^3	1	1.02	1.02
Sprayer	hrs	32	0.17	5.44
Labour: Fertilizer application-1 man days	hrs	8	1.96	15.68
Labour: Insecticide spray-4 man days	hrs	32	1.96	62.72
Labour: Seed treatment-0.5 man days	hrs	4	1.96	7.84
Labour: Harvesting, bundling and transportation-20 women + 5 man	hrs	160+40	1.57+1.96	329.6
Threshing and winnowing-3 man+3 women	hrs	24 + 24	1.57 + 1.96	84.72
Power thresher	hrs	6	200	1200
Electricity for threshing	kWh	6	11.93	71.58
Total	-	-	-	9267.33

Table 3. Energy used in different weed management treatments in soybean (mean of two years)

Treatment	Dose (g/ha)	Total energy used in the herbicide (MJ)	Labor used in hand weeding/ spraying	Energy used in the hand weeding/ spraying (MJ)	Knapsack sprayer used (hrs)	Energy used by knapsack sprayer in the spraying of herbicides (MJ)	Water used in the application of herbicides (m^3)	Energy used by water (MJ/ha)	Total energy (MJ/ha)
Pendimethalin 750 g/ha PE	750	216.0	16 man hours	31.36	16	2.72	0.50	0.51	250.59
Pendimethalin 750 g/ha PE *fb* imazethapyr 100 g/ha at 20 DAS	750 + 100	244.8	32 man hours	62.72	32	5.44	1.00	1.02	313.98
Pendimethalin 750 g/ha PE *fb* 1 HW at 20 DAS	750	216.0	16 man hrs+200 woman hours	345.36	16	2.72	0.50	0.51	564.59
Metribuzin 500 g/ha	500	144.0	16 man hours	31.36	16	2.72	0.50	0.51	178.59
Metribuzin 500 g/ha *fb* imazethapyr 100 g/ha at 20 DAS	500 + 100	172.8	32 man hours	62.76	32	5.44	1.00	1.02	242.02
Metribuzin 500 g/ha PE *fb* 1 HW at 20 DAS	500	144.0	16 man hrs+200 woman hours	345.36	16	2.72	0.50	0.51	492.59
Imazethapyr 100 g/ha at 20 DAS	100	28.8	16 man hours	31.36	16	2.72	0.50	0.51	63.39
Imazethapyr 100 g/ha at 20 DAS *fb* 1 HW at 40 DAS	100	28.8	16 man hrs+200 woman hours	345.36	16	2.72	0.50	0.51	377.39
2 HW at 20 and 40 DAS	-	-	440 woman hours	690.8	-	-	-	-	690.8
Unweeded control	-	-	-	-	-	-	-	-	0

fb- Followed by, PE- Pre-emergence, HW-Hand weeding, DAS-Days after sowing

(100 g/ha) than pendimethalin (750 g/ha) which resulted in better growth and development of crop plants thereby higher seed and haulm yield and ultimately higher total output energy. Among the herbicidal treatments, maximum total output energy (71.90×10^3 MJ/ha) was recorded with sequential application of pendimethalin 750 g/ha *fb* imazethapyr 100 g/ha. None of the herbicidal treatments surpassed hand weeding twice which produced highest total output energy (80.86×10^3 MJ/ha).

Energy indices: Energy ratio, specific energy, energy intensiveness / intensity (total energy used to produce 1 kg of grain (MJ/kg), energy profitability, net energy return (production), specific energy, and human energy profitability were calculated for each treatment separately (Table 5). This enabled comparing different management options in terms of energy use with reference to seed and haulm yield, in order to identify the most energy efficient weed management system.

Energy ratio: Energy ratio indicates the energy output under particular treatment with each unit of energy used. Energy output-input ratio varied across management scenarios depending upon the biomass production (Table 5). Energy ratio was minimum (3.15) with unweeded check because of lower output energy produced. However, this ratio was increased significantly when weed control measures were adopted. Among the different herbicidal treatments, minimum energy ratio (4.79) was in plot treated with pendimethalin (750 g/ha) alone. Maximum energy ratio was obtained with sequential application of pendimethalin (750 g/ha) *fb* imazethapyr (100 g/ha) at 20 DAS. Among all the treatments, maximum energy ratio (8.12) was gained by hand weeding twice (at 20 and 40 DAS).

Energy intensiveness/intensity: Energy intensity increased with the improvement in management practices which was significantly affected by seed and haulm productivity (Table 5). Energy intensity required to produce 1 kg soybean seed was highest (0.59) under unweeded check. Among the herbicidal treatments, energy intensity (0.54) was maximum under alone application of pendimethalin (750 g/ha) and metribuzin (500 g/ha) while it was minimum (0.48) under sequential application of pendimethalin (750 g/ha) *fb* imazethapyr (100 g/ha) and metribuzin (500 g/ha) *fb* imazethapyr (100 g/ha). Among all the treatments, energy intensity (0.40) was minimum under two hand weeding (20 and 40 DAS).

Energy profitability: Energy profitability increased with the decrease in management intensity and was highly correlated with total biomass productivity. Weed management practices had significant effect on this index (Table 5). Unweeded check gave lowest energy profitability (2.14). Among the herbicidal treatments, energy profitability was highest (6.50) with pendimethalin (750) PE *fb* imazethapyr (100 g/ha) closely followed by metribuzin (500 g/ha) *fb* imazethapyr (100 g/ha) (6.25). However, none of the herbicidal treatments surpassed hand weeding twice (20 and 40 DAS) which gave highest energy profitability *i.e.* 7.11.

Net energy return: There was marginal profit of 19.89 x 10^3 MJ/ha when the crop was not weeded throughout the growing season. However, it increased identically (62.32 x 10^3 MJ/ha) when weeds were controlled with the pre-emergence application of pendimethalin (750 g/ha) *fb* imazethapyr (100 g/ha). Among all the treatments, highest net energy (70.90 x 10^3 MJ/ha) was recorded with two hand weeding (20 and 40 DAS).

Specific energy: Specific energy requirement was minimum (9.38 x 10^3 MJ/ha) with two hand weedings done at 20 and 40 DAS while maximum (41.50 x 10^3 MJ/ha) in unweeded check where no weed control measures were adopted (Table 5). Among the herbicidal treatments, maximum specific energy (24.62 x 10^3 MJ/ha) was required by alone

Table 4. Total input and output energy of weed management in soybean (mean of two years)

Treatment	Seed yield (kg/ha)	Output energy by seed (x10^3 MJ/ha)	Haulm yield (t/ha)	Output energy by haulm (x10^3 MJ/ha)	Total output energy (x10^3 MJ/ha)	Total input energy used (x10^3 MJ/ha)
Pendimethalin 750 g/ha PE	387	07.01	3.09	38.60	45.61	9.52
Pendimethalin 750 g/ha PE *fb* imazethapyr 100 g/ha at 20 DAS	831	15.09	4.54	56.81	71.90	9.58
Pendimethalin 750 g/ha PE *fb* 1 HW at 20 DAS	773	14.03	4.47	55.95	69.98	9.84
Metribuzin 500 g /ha	460	08.34	3.25	40.69	49.03	9.45
Metribuzin 500 g/ha *fb* imazethapyr 100 g/ha at 20 DAS	807	14.64	4.35	54.38	69.01	9.51
Metribuzin 500 g/ha PE *fb* 1 HW at 20 DAS	810	14.70	4.30	53.76	68.45	9.76
Imazethapyr 100 g/ha at 20 DAS	750	13.61	3.68	46.02	59.62	9.33
Imazethapyr 100 g/ha at 20 DAS *fb* 1 HW at 40 DAS	870	15.79	4.58	57.23	73.01	9.64
2 HW at 20 and 40 DAS	1062	19.26	4.93	61.59	80.86	9.96
Unweeded control	223	04.05	2.01	25.10	29.15	9.27
LSD (P = 0.05)	117	2.13	0.40	5.02	5.88	-

Table 5. Effect of weed management on energy ratio, energy intensiveness, energy profitability, net energy return, specific energy and human energy profitability of soybean (mean of two years)

Treatment	Energy ratio	Energy intensiveness (MJ/` ha)	Energy profitability (MJ/ha)	Net energy return (x 10^3 MJ/ha)	Specific Energy (x 10^3 MJ/ha)	Human energy profitability
Pendimethalin 750 g/ha PE	4.79	0.54	3.79	36.09	24.62	112.08
Pendimethalin 750 g/ha PE *fb* imazethapyr 100 g/ha at 20 DAS	7.50	0.48	6.50	62.32	11.53	164.27
Pendimethalin 750 g/ha PE *fb* 1 HW at 20 DAS	7.12	0.45	6.11	60.15	12.72	123.52
Metribuzin 500 g /ha	5.19	0.54	4.19	39.58	20.54	120.48
Metribuzin 500 g/ha *fb* imazethapyr 100 g/ha at 20 DAS	7.26	0.48	6.25	59.50	11.79	157.67
Metribuzin 500 g/ha PE fb 1 HW at 20 DAS	7.01	0.45	6.01	58.69	12.05	120.83
Imazethapyr 100 g/ha at 20 DAS	6.39	0.52	5.38	50.29	12.45	146.50
Imazethapyr 100 g/ha at 20 DAS fb 1 HW at 40 DAS	7.57	0.44	6.56	63.36	11.09	128.87
2 HW at 20 and 40 DAS	8.12	0.40	7.11	70.90	9.38	109.65
Unweeded control	3.15	0.59	2.14	19.89	41.50	77.75

fb- Followed by, PE- Pre-emergence, HW-Hand weeding, DAS-Days after sowing

application of pendimethalin (750 g/ha). This index was minimum (11.53 x 10^3 MJ/ha) under sequential application of pendimethalin (750 g/ha) *fb* imazethapyr (100 g/ha).

Human energy profitability: Human energy profitability was calculated based on man power and its energy equivalent used to produce the output (Table 5). This index was lowest (77.75) under unweeded check. However, it increased appreciably when various weed control measures were adopted. Among the herbicidal treatments, this index was lowest (112.08) with pendimethalin (750 g/ha) alone. Human energy profitability was highest (164.27) with pendimethalin (750 g/ha) *fb* imazethapyr (100 g/ha) closely followed by metribuzin (500 g/ha) *fb* imazethapyr (100 g/ha) (157.67). Among all the weed management treatments, human energy profitability was lowest (109.65) under two hand weeding. It was due to maximum labor required for two hand weeding which resulted in increase in labor energy and finally human energy profitability was lowest.

Results indicated that among the herbicidal treatments, sequential application of pendimethalin 750 g/ha PE *fb* imazethapyr 100 g/ha at 20 DAS was the most energy efficient weed management practice in soybean and had maximum value of total output energy (71.90 x 10^3 MJ/ha) and net energy return (62.32 x 10^3 MJ/ha). Other parameters like energy ratio (7.50), energy profitability (6.50) and human energy profitability (164.27) were also higher under the same treatment whereas less specific energy (11.53 10^3 MJ/ha) and energy intensity (0.48) were recorded.

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Productivity and economics of rainy season groundnut as influenced by weed management practices

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ABSTRACT

Field experiment was conducted on medium black calcareous clayey soil at Junagadh Agricultural University, Junagadh during two consecutive seasons of 2013 and 2014 to study the influence of different weed management practices on productivity and economics of *Kharif* groundnut (cv. *GG-20*). Higher weed control efficiency (82.6%), herbicide efficiency index (74.1%), lower weed index (5.1%) and lesser monocot weed density were recorded with pendimethalin 0.9 kg/ha pre-emergence application (PE) followed by (*fb*) intercultivation (IC) and hand weeding (HW) at 40-45 days after seeding (DAS). Weed density of most dominated sedge weed species at 30 DAS, 60 DAS and at harvest were significantly lowered with application of pendimethalin 0.9 kg/ha PE *fb* imazethapyr 75 g/ha as post-emergence application (POE) at 25-30 DAS compared to other herbicides, which were 92.7, 93.5 and 93.0% less over the unweeded control, respectively. The same treatment also recorded the lowest weed dry biomass at harvest. Besides weed free, significantly the higher pod yield (1.75 t/ha) and net return (` 40,657/ha) and B: C ratio (2.38) were recorded with application of pendimethalin 0.9 kg/ha PE *fb* IC and HW at 40-45 DAS. No phytotoxicity symptoms has been observed with any of the herbicides applied to *Kharif* groundnut.

Key words: Economics, Groundnut, Pod yield, Weed control efficiency, Weed index, Weed management

Groundnut (*Arachis hypogaea* L.) is an important third largest oilseed crop species in the legume family (Fabaceae) cultivated in the world. In India, it occupies about 6.0 million hectare area, scattered over 260 districts of 12 states. Peanut oil is extensively used as a cooking medium, especially in central and western India and the raw peanut consumption has recently increased due to attention as a functional food for good health. India has a diverse climate, as such groundnut is grown throughout the year in *Kharif* (rainy season), *Rabi* (winter season) and summer seasons in one or other parts of the country. Area wise, about 85% groundnut is grown during the *Kharif* season under rainfed situations where the vagaries of monsoon and seasonal biotic and abiotic stresses attenuating to low productivity (Dayal 2004). In rainfed areas of Gujarat, Rajasthan and Maharashtra, semi-bunch type varieties are recommended due to their lower incidence of diseases and higher yield potential, particularly longer dormancy period.

Among the different constraints that limit the productivity of peanut in India, weed menace is one of the serious bottlenecks as peanut is confronted with repeated flushes of diverse grassy, broad-leaved and sedge weeds throughout its growing season which cause substantial 15 to 75% yield losses (Jat *et al.* 2011). Uncontrolled weed reduce the yield of *Kharif* groundnut by 54 to 71% especially during early period of crop growth (Agasimani *et al.* 2010). Therefore, weeding has to be completed before pegging. As per national web portal of Agriculture Information, when the groundnut fields are kept weed free for a period of at least first 6 weeks, there is no significant reduction in pod yield but when groundnut competes with weeds at 4 to 8 weeks the reduction in pod yield is substantial. The average loss in groundnut crop yield owing to crop-weed competition (3-6 weeks after planting) under ordinary management condition turns out to be 34%, whereas under poor management the loss may be as high as 60% in the major groundnut producing states like Tamil Nadu, Andhra Pradesh and Uttar Pradesh (Ikisan 2016).

Since cost of seed is very high in groundnut and investment on manual weeding further reduces the profit margin, a viable and economic weed control strategy is required. Pre-emergence (PE) herbicides, *viz.* pendimethalin (Patel *et al.* 2013) and oxyfluorfen (Ramalingam *et al.* 2013) and post-emergence (POE) herbicides, *viz.* imazethapyr (Kalhapure 2013) and

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quizalofop-ethyl (Samant *et al.* 2014) were found very effective in controlling weeds, higher crop yield and increased income in different parts of the country. This field experiment was conducted to evaluate suitable weed management practices for increasing groundnut productivity through weed control efficiency while reducing labour usage in groundnut production.

MATERIALS AND METHODS

Field experiment was carried out at the Junagadh Agricultural University, Junagadh (Gujarat) on medium black calcareous soil during two consecutive *Kharif* seasons of 2013 and 2014. The soil was clayey in texture and slightly alkaline in reaction (pH 8.0 and EC 0.34 dS/m), low in available nitrogen (236.5 kg N/ha), while medium in available phosphorus (22.9 kg P_2O_5/ha) and potash (241.7 kg K_2O/ha). Ten treatments comprising of weed management practices, *viz.* pendimethalin 0.9 kg/ha PE followed by (*fb*) intercultivation (IC) and hand weeding (HW) at 40-45 days after seeding (DAS), oxyfluorfen 0.18 kg/ha Pre-emergence (PE) *fb* IC and HW at 40-45 DAS, quizalofop-ethyl 40 g/ha Post-emergence (POE) at 25-30 DAS *fb* IC and HW at 40-45 DAS, imazethapyr 75 g/ha POE at 20-25 DAS *fb* IC and HW at 40-45 DAS, pendimethalin 0.9 kg/ha PE *fb* quizalofop-ethyl 40 g/ha POE at 20-25 DAS, pendimethalin 0.9 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS, oxyfluorfen 0.18 kg/ha PE *fb* quizalofop-ethyl 40 g/ha POE at 25-30 DAS, oxyfluorfen 0.18 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS, weed free and unweeded control were evaluated in randomized block design replicated thrice. The gross and net plot sizes were 6.0 x 4.8 m and 5.0 x 2.4 m, respectively. The groundnut (cv. *Gujarat Groundnut-20*) was grown with standard package of practices. The crop was fertilized with 12.5-25-0 kg N-P_2O_5-K_2O/ha. Herbicides were applied as per treatments using manually operated knapsack sprayer fitted with flat fan nozzle using spray volume of 500 l/ha. Species wise weed density (number/m² area) were recorded at 30 DAS, 60 DAS and at harvest of the crop. Economics was worked out as per the prevailing market price.

RESULTS AND DISCUSSION

Effect on weeds growth

Predominant weed species identified in the experimental field were *Cynodon dactylon* (9.6%), *Asphodelus tenuifolius* (7.65%), *Commelina benghalensis* (5.95%), *Echinochloa colona* (5.3%) among the monocot species; *Eclipta alba* (8.3%), *Phyllanthus niruri* (8.1%), *Euphorbia hirta* (7.1%), *Boerhavia diffusa* (5.95%), *Portulaca oleracea* (5.1%) and *Parthenium hysterophorus* (0.6%) among the dicot weeds. *Cyperus rotundus* was noted as a major dominated sedge weed (23.7%) throughout the growing season.

Monocot weeds density were significantly lowered down at 30 DAS, 60 DAS and at harvest (5.66, 8.50 and 9.33/m^2, respectively) with application of pendimethalin 0.9 kg/ha PE *fb* IC and HW at 40-45 DAS, which were 82.3, 89.9 89.4% less over the unweeded control, respectively. The application of pendimethalin followed by manual weeding resulted in lower monocot weeds density (Table 1). Further, pendimethalin prevented the weeds from emerging, particularly during the initial crucial development phases of the crop as reported by Jat *et al.* (2011) and Sathyapriya *et al.* (2013) and also caused high herbicide efficiency index (74.1%).

The lowest dicot weeds density at 30 DAS (9.33/m^2) was recorded with application of pendimethalin 0.9 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS, which was 90.1% less over the unweeded control. At 60 DAS and at harvest, submission of oxyfluorfen 0.18 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS and oxyfluorfen 0.18 kg/ha PE *fb* quizalofop-ethyl 40 g/ha POE at 25-30 DAS was found superior and counted minimum dicot weed (13.67 and 8.33 /m^2, respectively), although reported at par with all the other herbicides. Pre-emergence application of oxyfluorfen at 0.18 kg/ha followed by post-emergence application of imazethapyr at 75 g/ha or quizalofop-ethyl 40 g/ha at 25-30 days crop growth was found more effective in controlling of dicot weeds population.

The application of pendimethalin 0.9 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS resulted in 92.7, 93.5 and 93.0% lesser density of sedge weeds than the unweeded control at 30 DAS, 60 DAS and at harvest, respectively. Pre-emergence application of oxyfluorfen (0.18 kg/ha) followed by post-emergence application of imazethapyr (75 g/ha) at 25-30 DAS of the crop was found more effective in control of most dominated sedge weed (*Cyperus rotundus*) under the rainfed groundnut fields of Gujarat.

Higher weed control efficiency and herbicide efficiency index were recorded with pre-emergence application of pendimethalin 0.9 kg/ha PE *fb* IC and HW at 40-45 DAS. The same treatment also recorded the lowest weed index (5.1%). Administration of

Table 1. Effect of different weed management treatments on weed density (no./m^2) in *Kharif* groundnut (mean of two years)

Treatment	Monocot weed density at			Dicot weed density at			Sedge weed density at		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Pendimethalin 0.9 kg/ha PE *fb* IC and HW at 40-45 DAS	2.47 (5.66)	3.02 (8.67)	3.12 (9.33)	3.34 (12.68)	3.81 (14.98)	3.96 (16.34)	2.40 (5.28)	2.97 (8.45)	2.58 (6.27)
Oxyfluorfen 0.18 kg/ha PE *fb* IC and HW at 40-45 DAS	3.15 (9.67)	3.99 (15.60)	3.88 (15.00)	3.62 (13.16)	3.74 (13.69)	4.61 (20.83)	3.57 (12.30)	3.92 (14.93)	4.03 (15.90)
Quizalofop-ethyl 40 g/ha POE at 25-30 DAS *fb* IC and HW at 40-45 DAS	3.61 (12.61)	3.87 (14.62)	3.76 (13.75)	3.38 (10.99)	4.17 (16.98)	3.95 (15.16)	3.43 (11.40)	4.16 (16.90)	3.24 (10.26)
Imazethapyr 75 g/ha POE at 20-25 DAS *fb* IC and HW at 40-45 DAS	3.37 (11.00)	4.45 (19.50)	4.46 (19.46)	3.28 (10.50)	4.03 (16.00)	3.65 (13.00)	4.05 (16.03)	3.74 (13.57)	3.50 (11.87)
Pendimethalin 0.9 kg/ha PE *fb* Quizalofop-ethyl 40 g/ha POE at 20-25 DAS	2.94 (8.66)	2.97 (8.50)	3.26 (10.50)	3.21 (9.85)	3.89 (14.80)	4.02 (15.97)	2.26 (4.66)	2.46 (5.62)	2.79 (7.40)
Pendimethalin 0.9 kg/ha PE *fb* Imazethapyr 75 g/ha POE at 25-30 DAS	3.10 (9.16)	3.21 (9.83)	3.32 (11.17)	3.04 (9.33)	4.42 (19.14)	3.08 (9.34)	2.18 (4.38)	2.10 (4.00)	2.09 (4.10)
Oxyfluorfen 0.18 kg/ha PE *fb* Quizalofop-ethyl 40 g/ha POE at 25-30 DAS	2.49 (5.83)	3.33 (10.67)	3.86 (14.50)	3.32 (10.57)	4.15 (17.00)	2.97 (8.33)	3.07 (8.94)	2.89 (7.95)	3.28 (10.46)
Oxyfluorfen 0.18 kg/ha PE *fb* Imazethapyr 75 g/ha POE at 25-30 DAS	3.42 (11.33)	3.88 (15.00)	4.54 (20.57)	3.51 (12.19)	3.73 (13.67)	3.68 (13.34)	2.35 (5.10)	2.21 (4.55)	2.86 (7.93)
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)	0.71 (0.0)
Unweeded control	5.55 (32.06)	9.20 (84.86)	9.42 (88.35)	9.76 (95.20)	9.56 (93.97)	10.07 (101.20)	7.78 (60.30)	7.90 (62.04)	7.63 (57.90)
LSD (P=0.05)	0.44	0.52	0.53	0.40	0.46	0.56	0.38	0.38	0.49

Transformation data (figure in parentheses are original values) $\sqrt{x + 0.5}$; *fb* = followed by

Table 2. Effect of different weed management treatments on weed parameters in *Kharif* groundnut (mean of two years)

Treatment	Total weed biomass (kg/ha)	Weed index (%)	Weed control efficiency (%)	Herbicide efficiency index (%)
Pendimethalin 0.9 kg/ha PE *fb* IC and HW at 40-45 DAS	23.20 (547)	5.1	82.6	74.1
Oxyfluorfen 0.18 kg/ha PE *fb* IC and HW at 40-45 DAS	35.07 (1286)	13.6	60.9	58.5
Quizalofop-ethyl 40 g/ha POE at 25-30 DAS *fb* IC and HW at 40-45 DAS	31.53 (994)	12.9	66.8	59.9
Imazethapyr 75 g/ha POE at 20-25 DAS *fb* IC and HW at 40-45 DAS	25.03 (635)	14.4	78.1	57.1
Pendimethalin 0.9 kg/ha PE *fb* quizalofop-ethyl 40 g/ha POE at 20-25 DAS	28.63 (825)	13.7	71.8	58.3
Pendimethalin 0.9 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS	23.00 (531)	12.0	82.6	61.5
Oxyfluorfen 0.18 kg/ha PE *fb* quizalofop-ethyl 40 g/ha POE at 25-30 DAS	27.36 (750)	14.0	75.2	57.7
Oxyfluorfen 0.18 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS	24.18 (648)	15.8	81.1	54.5
Weed free	0.71 (0)	0.0	100	-
Unweeded control	55.79 (3148)	45.5	0.0	-
LSD (P=0.05)	2.01	-	-	-

Transformation data (figure in parentheses are original values) $\sqrt{x + 0.5}$; *fb* = followed by

pendimethalin 0.9 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS, reduced 83.1% weed biomass over the unweeded control (Table 2) and statistically comparable with pre-emergence application of pendimethalin 0.9 kg/ha *fb* IC & HW at 40-45 DAS and oxyfluorfen 0.18 kg/ha PE *fb* imazethapyr 75 g/ ha POE at 25-30 DAS. This might be attributed due to the effective control of weeds under these treatments, which reflected in less density of weeds, higher weed control efficiency (82.6%), least weed index (5.1%), maximum herbicide efficiency index (74.1%) and ultimately production of low weed biomass.

The unweeded control witnessed significantly highest weed species count, weed index and weed dry biomass they were controlled, which favored luxurious weed growth and results in 45.5% less pod yield over the weed free situation.

Effect on crop yield and economics

Different weed management practices influenced the pod and haulm yield significantly and the highest pod and haulm yield (1.85 and 3.01 t/ha, respectively) were recorded with the weed free condition, which was statistically remained on the same bar with pre-emergence application of

Table 3. Effect of different weed management treatments on yield and economics of *Kharif* groundnut (pooled of two years)

Treatment	Yield (t/ha)		Cost of cultivation (x10^3 `/ha)	Net return (x10^3 `/ha)	B: C ratio
	Pod	Haulm			
Pendimethalin 0.9 kg/ha PE *fb* IC and HW at 40-45 DAS	1.75	2.90	29.48	40.66	2.38
Oxyfluorfen 0.18 kg/ha PE *fb* IC and HW at 40-45 DAS	1.60	2.75	29.74	34.47	2.16
Quizalofop-ethyl 40 g/ha POE at 25-30 DAS *fb* IC and HW at 40-45 DAS	1.61	2.80	29.36	35.39	2.21
Imazethapyr 75 g/ha POE at 20-25 DAS *fb* IC and HW at 40-45 DAS	1.58	2.77	29.66	33.96	2.14
Pendimethalin 0.9 kg/ha PE *fb* quizalofop-ethyl 40 g/ha POE at 20-25 DAS	1.59	2.81	29.61	34.64	2.17
Pendimethalin 0.9 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS	1.63	2.78	29.91	35.24	2.18
Oxyfluorfen 0.18 kg/ha PE *fb* quizalofop-ethyl 40 g/ha POE at 25-30 DAS	1.59	2.74	29.87	33.93	2.14
Oxyfluorfen 0.18 kg/ha PE *fb* imazethapyr 75 g/ha POE at 25-30 DAS	1.56	2.68	29.49	33.12	2.12
Weed free	1.85	3.01	35.38	38.33	2.08
Unweeded control	1.01	1.80	26.50	14.18	1.54
LSD (P=0.05)	0.17	0.25	-	-	-

pendimethalin 0.9 kg/ha *fb* IC and HW at 40-45 DAS (Table 3). The higher yields under this treatment could be ascribed to lower density and biomass of weeds, which reduced the crop-weed competition and crop had not faced stress for available nutrients, moisture, light and space as compared to under heavy weed infestation throughout the growing season. Significantly, lowest pod and haulm yield (45.5 and 40.1% less over weed free, respectively) were recorded under the unweeded control due to deprived growth and development of yield attributing characters of the crop (Dutta *et al.* 2005, Kalhapure *et al.* 2013 and Jadhav *et al.* 2015).

The economics of different weed management practices revealed that next to weed free, the maximum net returns (` 40,657/ha) was accrued under pre-emergence submission of pendimethalin 0.9 kg/ha PE *fb* IC and HW at 40-45 DAS (Table 3). Benefit cost ratio was higher (2.38) with PE of pendimethalin 0.9 kg/ha *fb* IC and HW at 40-45 DAS. However, weed free practice of weed management recorded lowest B: C ratio (2.14) due to higher cost of cultivation owing to higher wages of manual weeding. Unweeded control also recorded the lowest net returns (` 14,179 /ha) and B: C ratio (1.54).

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Use of herbicides against *Orobanche* in tomato and their residual effect on succeeding crop

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ABSTRACT

Egyptian broomrape (*Orobanche aegyptiaca*) is the most troublesome root holoparasitic weed cause severe damage to tomatoes grown in Mewat and Bhiwani areas of Haryana. In the present study, efficacy and selectivity of two sulfonylurea herbicides, *viz.* sulfosulfuron and ethoxysulfuron, neem cake, pendimethalin/metribuzin in conjunction with metalaxyl were tested in controlling on tomatoes grown under field conditions. Sulfosulfuron and ethoxysulfuron applied as post-emergence at 30, 60 and 90 DAT were more selective to tomato and controlled the parasite more effectively. Neem cake or metalaxyl were not found to inhibit growth of *Orobanche aegyptiaca*. No herbicide residues were observed in tomato fruits and soil at harvest. No residual carry over effect of these herbicides was observed on succeeding sorghum crop planted 2 months after harvest of tomato crop. It was concluded that post-emergence application of ethoxysulfuron at 25 g/ha at 30 DAT followed by at 50 g/ha or sulfosulfuron at 50 g/ha at 30 and 60 DAT, provided 85-90% control of *Orobanche* in tomato without any adverse effect on crop with yield increase of 46-58% as compared to untreated check.

Key words: Egyptian broomrape, *Orobanche aegyptiaca,* Sulfosulfuron, Ethoxysulfuron, Tomato

Egyptian broomrape (*Orobanche aegyptiaca* Pers.) locally known as "Margoja/Rukhri/Khumbhi/ Gulli" is an achlorophyllous, phanerogamic troublesome root parasite that depend completely on host to complete its life cycle. This parasitic plant caused economic damage in field crops and vegetable production worldwide (Parker and riches 1993, Eizenberg *et al.* 2004). Tomato is highly vulnerable to three broomrape species, *viz. O. aegyptiaca, O. ramosa and O. cernua* that are known to cause damage and reduce yields of tomato (Joel *et al.* 2007). Egyptian broomrape is the main limiting factor in tomato production in Israel, Egypt, Sudan, Syria, Tunisia, Turkey and Lebanon.

During survey of weed flora in tomato fields in Haryana, in Nuh, Ferozepur Jhirka, Nagina, Taoru areas of Mewat, Charkhi Dadri and Loharu of district Bhiwani was found badly infested with *Orobanche aegyptiaca* threatening the cultivation of this crop in the regions. Farmers reported 40-75% loss in fruit yield due to its infestation in tomato crop depending on intensity of infestation (Anonymous 2014). A continuous increase in *Orobanche* infestation in these ares has forced farmers to abandon tomato cultivation and switch over to other profitable crops cultivation.

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Orobanche exert their greatest damage prior to emergence of flowering shoot. Therefore, most of the field losses may occur before diagnosis of infection. In such situation, chemical control measures and host resistance appear to be the most appropriate measures when available and affordable. Potiental herbicides must be selective for the host plant but phytotoxic to the parasite. The most effective chemical method is soil fumigation with highly volatile compounds such as methyl bromide, metham sodium and dazomet (Foy *et al.* 1989), but cost of treatment is very high and moreover due to environmental concerns, methyl bromide has been phased out. Soil fumigation with metham-sodium provides only partial and inadequate control of Egyptian broom rape in tomato (Goldwasser *et al.* 1995)

Studies conducted earlier by Eizenberg *et al.* (2003a, 2004), Hershenhorn *et al.* (2009) in Israel demonstrated effectiveness and selectivity of sulfosulfuron and other ALS inhibiting herbicides to control broomrape in tomato by killing preconditioned seeds or young attachments. Mode of resistance of specific solancaeous species to sulfosulfuron has not been studied but it probably involves alteration of acetolactate synthatase (ALS) binding site or metabolism of the herbicide to non phytotoxic products. Sulfosulfuron applied in wheat caused residual toxicity to sorghum and maize crops grown in quick succession after wheat harvest (Chhokar *et al.* 2006).

Information on chemical control of *Orobanche* in tomato under Indian conditions is meager or not available and results reported above are mostly from green house studies in Israel. So, to validate these results under field conditions and generate data under Indian context, present investigation was planned to assess the efficacy of various sulfonylurea herbicides against *Orobanche aegyptiaca* in tomato under Indian conditions.

MATERIALS AND METHODS

Tomato hybrid '*Himsona*' was planted for two consecutive years on November 15, 2013 and December 5, 2016 at Farm of Arsad s/o Nurdin, tehsil Nuh Distt. Mewat (Haryana). Crop was grown as per university recommended package of practices for tomato except herbicide treatments. All pre-emergence herbicides were sprayed by knapsack sprayer fitted with flat fan nozzle using 750 litres of water/ha. Quantity of water applied in post-emergence treatments was 375 litres/ha. Post-emergence herbicides were applied at various stages as per treatment using 375 litres of water/ha. Observations on number of broomrape spikes/m^2 and broomrape visual control (0-100 scale) by different treatments was recorded at 60, 90, 120 DAT and at harvest. Data on plant height, length of broom rape spike were recorded at 120 DAT. Number of fruits/ plant was recorded from five tagged plants at 90,120 DAT and harvest which were averaged to compute values/plant. Tomato fruits picked in four flushes were weighed and thus total yield/plot was computed. WCE was recorded on the basis of fresh biomass of broomrape spikes. These observations were subjected to ANOVA and means were compared with appropriate Fisher's protected LSD test at 5% level of probability. Crop phyto-toxicity due to different treatments was assessed at 80, 120 DAP and harvest on a scale of 0-100, where 0 means no injury and 100 means complete mortality of tomato plant. Foliar necrosis, yellowing, stunting, necrosis and wilting were the main symptoms considered while making visual estimate of visual injury on tomato plants. Injury data were arc sin transformed prior to ANOVA.

To study residual carryover effect on succeeding sorghum crop, variety '*Hara chara*' of sorghum was planted during June, 2015 and 2016 on the same plots without disturbing the original layout.

For herbicides residues estimation, tomato and soil samples from the experimental field were collected in triplicate at crop maturity. A standard stock solution of sulfosulfuron and ethoxysulfuron were prepared in acetonitrile (HPLC grade) and that of pendimethalin and metribuzin was prepared in n-hexane. The standard solutions required for constructing a calibration curve (1.00, 0.5, 0.25, 0.1, 0.05, 0.01, 0.005 and 0.001 µg/ml) were prepared from stock solution by serial dilutions in respective solvents as mentioned above. All standard solutions were stored at -4°C before use. Sulfosulfuron and ethoxysulfuron were extracted by methods developed by Anjana *et al.* (2006) with slight modifications. For extraction of these herbicides fifty gram of the finely grinded, sieved soil and 25 gm crushed tomato samples were taken in separate conical flasks and about 50 ml of acetonitrile and ammonium carbonate mixture in ration 9:1v/v was added to the flask. The flask was shacked for half hour on shaker and the content was poured in another flask by filtering it. The residues were again extracted with another 50 ml of acetonitrile and ammonium carbonate with same procedure. The content was again filtered in the same flask containing the first fraction. The combined content was concentrated on Heidolph rotavapour to 20 ml at 40 °C and was partitioned thrice with dichloromethane (50, 30 and 20 ml) after dissolving 20 ml of saturated brine solution. The combined dichloromethane extract was collected and passed through anhydrous sodium sulphate packed in a funnel so as to remove the moisture. Filtrate was collected, pooled and dried at 40 °C on flash evaporator to near dryness. The residues were finally dissolved in 2 ml of HPLC grade acetonitrile and filtered through 0.45µm syringe filter before injection into HPLC. For extraction and clean-up of pendimethalin and metribuzin 20 g of air dried, finely grounded and sieved (through a 2 mm sieve) soil samples and 25 g finely crushed tomato fruit was taken in separate 250 ml conical flasks and added with 50 ml of acetone. The samples were shaked over rotary shaker for one hour. The contents were decanted in separate conical flask by passing over a bed of anhydrous Na_2SO_4. The contents were concentrated to about 10 ml over rotary evaporator at 35 °C. The samples were partitioned with hexane-ethyl acetate (9:1) thrice by taking 50, 30 and 20 ml after adding 50 ml saturated brine solution. The organic phases were collected by passing over Na_2SO_4 in separate bottles and concentrated over rotary evaporator to 10 ml at 35 °C. No further clean-up was required for soil samples as the samples were clear and containing no color.

High pressure liquid chromatography Waters e2695 (e-alliance) was used for the analysis of sulfosulfuron and ethoxysulfuron residues in tomato fruits and soil samples using a reverse phase C-18 column (Sunfire) having dimension 250 x 4.6 (mm) with particle size of 5 µ. Photo dioade array detector (PDA) (model Waters 2998) was used for analysis at wavelength of 245 nm. Solvents used were acetonitril: water (7:3) in isocratic mode at flow rate of 1 ml/min. Injection volume was 10 µl. Under these conditions the retention time for sulfosulfuron and ethoxysulfuron was 1.8 and 1.6 minutes respectively.

Analysis of the pendimethalin and metribuzin was carried out using GCMS tandem mass spectrometry (Agilent 7890 A series with 7000 GCMS/MS detector). The instrument was tuned properly before injecting standards of herbicides. The operating parameters were: injection port temperature: 280 °C. Column: HP-5 (30 m x 0.32 mm i.d. x 0.25 µm film thickness). Oven temperature ramping was: 70 °C (2 min. hold), then increased at 25°C/min to 150 °C (0 min. hold), then increased at 15°C/min to 200 °C (0 min. hold), then increased at 8°C/min to 280 °C (2 min hold). Detector parameters were: source temperature, 230°C; emission current, 35 µA; energy, – 70 eV; repeller voltage, 11 V; ion body, 12 V; extractor, –7.2 V; ion focus, –7.4 V; quadrupole one (MS1) temperature, 150 °C; quadrupole two (MS2) temperature, 150 °C. Gas flow rates: helium (carrier gas), 1 ml/min though column and 2.25 ml/min as collision flow/quench flow, nitrogen (collision cell), 1.15 ml/min. Other parameters: split: pulsed splitless; vacuum (high pressure), 2.23 x 10–5 torr; rough vacuum, 1.51 x 102 torr; injection volume, 2 µl. Under these instrumental conditions, the retention time of pendimethalin and metribuzin was 19.6 and 12.9 minutes, respectively. A calibration curve was plotted for concentration of the standard injected versus area by injecting known concentration of working solutions of different herbicides in HPLC and GCMS/MS and the curve was found linear up to the lowest concentration range 0.01 µg/ml for sulfosulfuron, ethoxysulfuron and 0.001 µg/ml for pendimethalin and metribuzin, respectively.

RESULTS AND DISCUSSION

Weed studies

Broomrape panicles did not appear in any of the treatment up to 90 DAT during both the years of study (data not shown). Application of neem cake at sowing in combination with pendimethalin or metribuzin followed by soil drenching of metalaxyl MZ 0.2% at 20 DAT did not cause any inhibition in broomrape (*Orobanche*) emergence as evident from density of broomrape at 120 DAT and harvest (Table 1). *Orobanche* appeared only in weedy check and neem cake treatments up to 120 DAT. Excellent control of *Orobanche* was obtained with post- or pre-plus post-treatments of sulfosulfuron and ethoxysulfuron when compared with non treated controls. During 2014-15, ethoxysulfuron and sulfosulfuron treated plots remained free from *Orobanche* up to 120 DAT and gave 96.7 to 98.3% control of *Orobanche* up to harvest without any crop suppression. Only 1.7 spikes/m^2 of *Orobanche* were recorded with use of ethoxysuluron 25 g/ha at 60 and 90 DAT but during 2015-16, *Orobanche* stalks to the tune of 0.67-4.0 panicles/m^2 appeared in various herbicide treatments, which was significantly less than untreated control. Sulfosulfuron is registered for broomrape control in Israel in tomato, so was no damage reduction was expected in tomato yields. Weed control efficiency (WCE) in various herbicide treatments calculated on the basis of fresh weight of bromrape spikes varied from 96.2 - 97.7% in 2014-15 where as it was 85.2 - 89.2% during 2015-16. These results were in accordance with findings of Plakhine *et al.* (2001), Eizenberg *et al.* (2003) and Eizenberg *et al.* (2007) who reported effective control of broom rape in tomato with post-emergence use of sulfosulfuron at 37.5 and 75.0 g/ha. Length of broom rape spikes emerged at 120 DAT and harvest varied significantly among different treatments. Maximum spike length (13.9 - 15.2 cms) was recorded with use of neem cake 200 kg/ha either alone or in combination with pendimethalin 1.0 kg/ha at 3 DAP and soil drenching of metalaxyl MZ 0.2% at 20 DAT, which was significantly higher than ethoxysulfuron and sulfosulfuron treatments. Broom rape spikes which emerged at harvest or 120 DAT in ethoxysulfuron and sulfosulfuron treatments were very weak and small sized.

Crop studies

Treatments of ethoxysulfuron 25 g/ha (pre-emergence) were more phytotoxic than post-emergence and tomato exhibited severe growth reduction. Minor developmental delay in tomato was observed with ethoxysulfuron applied pre-emergence or 30 DAT at 25 g/ha. This delay was attributed to the herbicides and not to Egyptian broomrape (visual observation) but plants recovered upon maturity. No damage was observed to tomato plant with use of post-emergence application of either sulfosulfuron or ethoxysulfuron (Table 2). Ethoxysulfuron 25 g/ha (pre-emergence) and 50 g/ha at 45 DAT and ethoxysulfuron 25 g/ha (pre-emergence) *fb* 50 g/ha as 30 and 60 DAT treatments although proved very effective against *Orobanche* but caused 13.3-28.3% suppression in crop growth, which had reflection on plant height, number of fruits/plant and total fruit yield of tomato. During both the years, maximum fruit yield (18.7 and 20.6 t/ha) was recorded from use of sulfosulfuron 50 g/ha at 60 and 90 DAT, respectively, which was at par with ethoxysulfuron 25 g/ha at 60 and 90 DAT, ethoxysulfuron 25 g/ha at 30 and 60 DAT, ethoxysulfuron 25 g/ha at 45 DAT *fb* 50 g/ha 90 DAT and sulfosulfuron 25 g/ha at 60 and 90 DAT, which was 46 - 58% higher than untreated check (Table 2). Panicles which emerged with ethoxysulfuron and sulfosulfuron treatments were weak and length of these panicles was significantly less than neem cake, metalaxyl, pendimethalin and metribuzin treatments. Maximum B:C ratio (7.89 and 8.81) was obtained with post-emergence use of sulfosulfuron 25 g/ha at 60 and 90 DAT and minimum (4.15 and 3.82) with use of neem cake 200 kg/ha at sowing *fb* metribuzin *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT. These findings were in accordance with those of Dinesha *et al.* (2012) who reported excellent efficacy of sulfosulfuron 75 g/ha at 30 DAT in preventing the development of broomrape and reducing the seed inoculum potential in the soil by registering significantly lowest broomrape number, spike height, spike dry weight with higher broomrape control efficiency, which also accounted for higher tomato plant height, number of branches, leaf area/plant at harvest, higher fruit weight/plant and fruit yield of tomato in Karnataka state of India.

Residue studies

Table 1. Effect of different weed control measures on *Orobanche* population, WCE, visual control and spike length (2014-15 and 2015-16)

Treatment	Number of broomrape spikes/m²				WCE (broomrape) (%) 120 DAP		Broom rape control (%)				Broomrape spike length (cms)	
	120 DAP		Harvest				120 DAP		Harvest			
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAT*fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	5.1 (25)	5.7 (32)	6.2 (38)	6.0 (36)	7.9	9.9	18 (10)	18 .4 (10)	12.9 (5.0)	12.9 (5.0)	15.2	14.7
Neem cake 200 kg/ha at sowing *fb* metribuzin 0.5 kg/ha pre-em, 3 DAT*fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	5.8 (32.7)	6.2 (38)	6.4 (40)	6.8 (46)	4.7	2.5	0 (0)	15.9 (8)	0 (0)	0 (0)	13.9	15.2
Neem cake 200 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	5.2 (26.3)	6.5 (41.2)	6.2 (37.3)	6.5 (41.9)	6.2	-4.9	0(0)	0(0)	15.6 (7.3)	0 (0)	14.8	14.8
Ethoxysulfuron 25 g/ha (PRE) and 50 g/ha at 45 DAT	1 (0)	2.6 (5.7)	2.2 (3.7)	2.9 (7.8)	95.2	88.5	90 (100)	63.5 (80)	79.5 (95)	53.7 (65)	5.8	6.3
Ethoxysulfuron 25 g/ha (PRE) *fb* 50 g/ha as 30 and 60 DAT	1 (0)	3.0 (8)	1.7 (2.3)	2.0 (3.2)	96.3	89.9	90 (100)	67.4 (85)	82.3 (97.3)	65.2 (82.3)	8.1	8.3
Ethoxysulfuron 25 g/ha at 30 and 60 DAT	1 (0)	2.3 (4.3)	2.2 (4)	3.0 (8.3)	96.0	85.2	90 (100)	59.6 (75)	81.4 (96.7)	56.8 (70)	7.0	7.6
Ethoxysulfuron 25 g/ha at 45 DAT *fb* 50 g/ha 90 DAT	1 (0)	1(0)	1.8 (2.7)	2.0 (3.0)	96.6	88.9	90 (100)	69.5 (88)	85.7 (98.3)	67.4 (85)	7.7	8.2
Ethoxysulfuron 25 g/ha at 60 and 90 DAT	1.6 (1.7)	2.2 (3.8)	1.9 (2.7)	2.4 (4.8)	97.0	89.2	81.4 (96.7)	74.8 (90)	83.8 (96.7)	59.8 (75)	7.4	8.0
Sulfosulfuron 50 g/ha at 60 and 90 DAT	1 (0)	1.5 (1.3)	1.3 (0.67)	1.8 (2.1)	97.7	88.3	90 (100)	75 (90)	85.7 (98.3)	71.9 (90)	7.2	7.8
Sulfosulfuron 25 g/ha at 60 and 90 DAT	1 (0)	1.6 (1.7)	1.7 (2.3)	1.5 (2.3)	96.8	87.6	90 (100)	65.4 (82.7)	82.3 (97.3)	60.1 (75)	8.5	6.8
Weedy check	6 (35)	6.1 (36.3)	6.4 (40)	6.8 (46)	0	0	0 (0)	0(0)	0(0)	0	14.1	15.9
LSD (P=0.05)	0.4	0.4	0.79	0.84			4.9	10.7	9.6	3.6	0.4	1.
CV(%)	8.9	8.9	12.7	11.3			5.1	13.4	10.7	5.1	2.3	

*Original figures in parentheses related to *Orobanche* density were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. Values on *Orobanche* control were subjected to arc sine transformation before statistical analysis. Broom rape did not emerge above ground up to 90 DAP so no data was generated; PRE-Pre-emergence

Residues of sulfosulfuron, ethoxysulfuron or any of the herbicide at any dose and time of application did not cause any adverse on succeeding sorghum crop as is evident from number of plants/ meter row length, plant height and sorghum yield at 45 DAT (Table 3). Deep ploughing of field after harvest of tomato and 2 months interval between tomato harvest and sorghum sowing might be responsible for dissipation of sulfosulfuron from soil. These observations are in accordance with findings of Sondhia (2008) where even sulfosulfuron residues were not observed after wheat harvest.

Table 2. Effect of different weed control measures on plant height, crop toxicity and fruit yield of tomato (2014-15 and 2015-16)

Treatment	Plant height (cm)		Crop phytotoxicity (%) 20 DAT		Crop phytotoxicity (%) 80 DAT		Crop phytotoxicity (%) Harvest		No. of fruits/ plant		Fruit yield (t/ha)		B:C	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAT *fb* soil drenching of metalaxyl MZ 0.2 % at 20 DAT	37.2	40.5	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	18.0	16.7	10.49	11.20	4.43	4.66
Neem cake 200 kg/ha at sowing *fb* metribuzin 0.5 kg/ha pre-em, 3 DAT *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	36.6	39.8	28.8 (23.3)	31.5 (27.7)	0 (0)	0(0)	0(0)	0(0)	15.3	16.0	9.73	9.10	4.15	3.82
Neem cake 200 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	35.3	38.0	0(0)	0(0)	0 (0)	0(0)	0(0)	0(0)	15.7	16.3	9.51	10.31	4.17	4.46
Ethoxysulfuron 25 g/ha (PRE) and 50 g/ha at 45 DAT	34.7	35.9	32.1 (28.3)	29.9 (25)	27.7 (21.7)	25.6 (18.7)	21.3 (13.3)	23.6 (15.7)	19.7	20.6	13.13	13.50	5.35	5.43
Ethoxysulfuron 25 g/ha (PRE) *fb* 50 g/ha as 30 and 60 DAT	36.6	36.2	34.2 (31.7)	36.2 (35.3)	32.1 (28.3)	33.1 (30.3)	32.1 (28.3)	30.6 (25.7)	17.7	19.0	12.52	13.85	4.76	5.20
Ethoxysulfuron 25 g/ha at 30 and 60 DAT	41.0	42.8	10.4 (5)	12.9 (5)	0 (0)	0(0)	0(0)	0(0)	24.0	26.4	17.13	16.84	7.22	7.00
Ethoxysulfuron 25 g/ha at 45 DAT *fb* 50 g/ha 90 DAT	40.8	41.9	10.4 (5)	12.9 (5)	0 (0)	0(0)	0(0)	0(0)	25.0	27.9	17.77	19.20	7.49	7.98
Ethoxysulfuron 25 g/ha at 60 and 90 DAT	39.7	41.7	0(0)	0(0)	12.9 (5.0)	0(0)	0(0)	0(0)	26.3	29.2	18.19	19.95	7.67	8.29
Sulfosulfuron 50 g/ha at 60 and 90 DAT	40.5	42.9	0 (0)	0(0)	0 (0)	0(0)	0(0)	0(0)	27.0	28.7	18.74	20.56	7.89	8.81
Sulfosulfuron 25 g/ha at 60 and 90 DAT	40.7	42.5	0 (0)	0(0)	0 (0)	0(0)	0(0)	0(0)	25.7	27.0	18.12	19.7	7.75	8.25
Weedy check	37.0	37.5	0 (0)	0(0)	0 (0)	0(0)	0(0)	0(0)	14.0	13.3	9.68	8.64	4.40	3.87
LSD(P=0.05)	0.8	1.2	6.7	2.6	1.6	1.7	1.8	2.0	2.7	2.1	0.77	2.1	-	-
CV(%)	3.5	2.6	30.2	13.3	12.4	18.7	18.9	23.9	7.7	10.2	3.32	5.6	-	-

Values on crop phytotoxicity were subjected to arc sine transformation before statistical analysis; PRE-Pre-emergence

Table 3. Residual effect of different herbicides applied in tomato on succeeding sorghum crop at 45 DAT

Treatment	No. of plants/m.r.l.		Plant height (cm)		Green fodder yield (t/ha)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAT *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	20	24	144	134	38.9	36.8
Neem cake 200 kg/ha at sowing *fb* metribuzin 0.5 kg/ha pre-em, 3 DAT *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	18	24	142	132	38.4	36.5
Neem cake 200 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	19	26	144	134	38.0	36.8
Ethoxysulfuron 25 g/ha (PRE) and 50 g/ha at 45 DAT	18	28	145	135	37.4	37.8
Ethoxysulfuron 25 g/ha (PRE) *fb* 50 g/ha as 30 and 60 DAT	20	26	144	136	37.4	36.8
Ethoxysulfuron 25 g/ha at 30 and 60 DAT	19	24	142	132	38.0	37.0
Ethoxysulfuron 25 g/ha at 45 DAT *fb* 50 g/ha 90 DAT	18	27	145	134	37.8	36.2
Ethoxysulfuron 25 g/ha at 60 and 90 DAT	20	28	142	130	37.8	36.4
Sulfosulfuron 50 g/ha at 60 and 90 DAT	18	26	144	132	38.2	36.8
Sulfosulfuron 25 g/ha at 60 and 90 DAT	19	25	144	135	37.8	36.6
Weedy check	18	26	146	134	37.4	36.4
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

m.r.l. - Meter row length

Table 4. Percent recovery of different herbicides in tomato and soil

Herbicides	Average* recovery (%)±SD			
	Tomato		Soil	
	Fortification level (0.01 mg/kg)	Fortification level (0.05 mg/kg)	Fortification level (0.01 mg/kg)	Fortification level (0.05 mg/kg)
Sulfosulfuron	81.92±2.65	88.95±1.15	91.30±2.95	92.27±1.25
Ethoxysulfuron	84.66±2.40	86.31±1.32	83.42±1.27	89.62±3.70
Pendimethalin	84.22±3.11	86.60±2.45	88.41±3.60	90.23±2.56
Metribuzin	81.16±2.41	85.40±2.01	85.70±2.45	87.62±2.10

*Average of three replicates

Herbicides residues in soil and tomato fruit: Recovery experiments were carried out to check the validity of the method in soil and tomato fruit samples by fortifying the control samples of each matrix at 0.01 mg/kg and 0.05 mg/kg level in triplicate. Per cent recoveries in all the samples of soil, and tomato fruit were greater than 80 (Table 4), therefore, no correction factor was needed for calculation of residues. It was observed that none of the samples of soil and tomato were having residues of any of the applied herbicides above detection limit of 0.01 μg/ml (in case of sulfosulfuron, ethoxysulufron) and 0.001 μg/ml (in case of pendimethalin and metribuzin). These results also corroborate with the finding of Singh and Kulshresthatha (2007) who studied the dissipation of sulfosulfuron and observed that the dissipation followed first-order rate kinetics and dissipated with a half-life of 5.4–6.3 days. After harvest, field soil was used for conducting a pot experiment with bottle gourd (*Lagenaria siceraria*) as test plants to study the carry over effect of sulfosulfuron. No phytotoxicity was observed to bottle gourd in pot experiment with harvest soil. This shows that the persistence of sulfonylurea residues at harvest is almost negligible. Sondhia (2008) also observed that sulfosulfuron degraded rapidly in soil and was not detected in soil, wheat grains and straw at harvest.

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Assessment of ecological parameters of crofton weed along the road-side forests of Kumaun Himalaya

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ABSTRACT

Present study deals with certain ecological attributes of crofton weed (*Eupatorium adenophorum* Spreng), an abnoxius invasive weed invading the road-side forests mixed with oaks and conifer. The average density of *E. adenophorum* shared 22.4 - 65.8% of total herb density which was almost higher in forest below the roadside. The biomass of *E. adenophorum* accounted for 84.0 - 99.8% of total herbaceous biomass in different forest sites. Study reveals the dominated impact of this species, which altered the composition, diversity and growth of herbs in forests, and also can change the habitat and disturb the ecology of native plants in the region. Therefore, needs of was felt to sustain the habitat of native species.

Key words: Forest, Roadside, Herbs, *Eupatorium adenophorum*, Species diversity, Biomass.

Forests are essential for the survival of people as they provide various benefits to society and environment. Recent degradation of forest ecosystems showed that biological diversity, species compostion and regeneration pattern have changed significantly influencing the productivity and sustainability of the forest ecosystem. The invasive species has been considered as one the severe threat to biological diversity and other natural resources after habitat destruction (Heywood 1995).

Invasive species like *Lantana camara,* has replaced natural forest of sal, pine and oak by forming pure stands or mixing up with understory forest vegetation. (Bhatt *et al.* 1994) and have had a deleterious impact on biological diversity and ecosystem processes (Mack *et al.* 2000). Invasion potential of species enables it to be successful invader and colonizer of the novel environments, whether introduced deliberately or accidentally (Dogra *et al.* 2009). Biological invasions by non-indigenous plants have become major global threats that alter landscapes, reduce biodiversity, and endanger national economies.

Eupatorium adenophorum Spreng. also called as Crofton weed and locally called as *'banmara'* (killer of forest) commonly growing as herb (occasionally as subshrub) has been considered a serious threat to biodiversity and agricultural productivity due to its rapid growth (Ma and Bai 2004). Once invades an area, it develops into a single pre-dominant plant community in a short period. Roadsides and wastelands were found most sensitive to *E. adenophorum* invasion as seed is carried by the wind or water, via sand and gravel used in road construction, and colonises disturbed areas readily. Once it is established, it further alter the soil community, inhibit native plants, which promote further invasion (Hao *et al.* 2010).

The objectives of the study were: to analysis of oak-conifer forests along the road sides, and to find out the extent of *E. adenophorum* invasion along the road side oak- conifer forest upto 0-50 m distance on both (above and below) the sides of road.

MATERIALS AND METHODS

The study sites were situated at Nainital (29°23 N - 79°27E, 29.38°N- 79.45°E), Uttarakhand of the outer Himalaya. Climate of Nainital is temperate and monsoon type. An average annual rainfall was 1247 mm in 2013-2014. Maximum rainfall was during June (763.0 mm). The mean minimum temperature ranged from 0.2 ^{0}C (February) to 16.3 ^{0}C (July) and the mean maximum day temperature varied from 15.2 ^{0}C (January) to 26.8 ^{0}C (May).

Herb species were analysed by placing 1 x 1 m quadrats in different forests along both the sides of road. Quadrats were placed in each forest at distance of 0-10 m, 10.1-20, 20.1-30, 30.1-40, and 40.1-50 m, above and below the road side towards inner side of forest. The vegetational data were quantitatively analyzed for density according to the formula given by Curtis and Mc Intosh (1950).

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$$\text{Density} = \frac{\text{Total number of individuals in all quadrats}}{\text{Total number of quadrats studied}}$$

For herbs, provenence value (PV) index was calculated by summing up the values of relative frequency and relative density (Phillips 1959, Curtis 1959).

Provenence value (PV) = RF + RD

Species diversity was calculated using Shannon-wiener information index (Shannon and Wienner, 1949) as:

$$H' = -\sum_{i=1}^{s}\left(\frac{Ni}{N}\right)\log_2\left(\frac{Ni}{N}\right)$$

Where, Ni is density of individual species and N the total density of all species in that forest.

For biomass estimation of herbaceous species, plants from 25 quadrats (1 x 1 m) were harvested and dry weight (after oven drying at 80 ^{0}C till constant weight) was determined.

RESULTS AND DISCUSSION

Forest site-1 (Khurpatal)

Cypress forest (above the road side): Total 10-14 herb species were present in 0-50 m distance from the road. The density of herbs ranged 41.2 - 63.7 ind./m^2 of which *E. adenophorum* showed maximum density 30.2 - 39.2 ind./m^2 and PV 69.8 - 104.2 (Table 1 and 2). Total herb species diversity (H') was 1.33 - 2.10 (Table 1). Total biomass of herb species was 726.0 g/m^2 of which total above ground biomass was 482.1 g/m^2 and total below ground biomass was 244.0 g/m^2. The biomass of *E. adenophorum* was 725.4 g/m^2, which shared around 99.8% of total herbaceous biomass. Biomass of other herb species was 0.7 g/m^2 which shared around only 0.2% of total herbaceous biomass above road side (Table 7).

Mixed-pine forest (below the road side): Total 7-13 herb species were present in 0-40 m distance from the road. *E. adenophorum* was not present from 40.1-50 m distance. Total density of herbs ranged 47.9 - 86.7 ind/m^2 of which *E. adenophorum* showed maximum density 30.3 - 45.8ind/m^2 and PV 71.01 - 92.67 (Table 1 and 2). Total herb species diversity (H') was 1.63-2.45 (Table 1). Total biomass of herb species was 704.33 g/m^2. The biomass of *E. adenophorum* was 701 g/m^2 which shared around 99.5% of total herbaceous biomass. Biomass of other herb species was 3.33 g/m^2 which shared around only 0.5% of total herbaceous biomass below road side (Table 7).

Forest site-2 (Hanumangarh)

***Cypress* forest (above the road side):** Total 18 herb species were present in 0 - 40 m distance from the road. Crofton weed was not present from 40.1 - 50 m distance. Total density of herbs ranged 57 - 112.9 ind./m^2 of which it showed maximum density 12.1 - 53.9 ind./m^2 and PV 35.51 - 61.25 (Table 3 and 4). Total herb species diversity (H') was 2.68-3.01 (Table 3). Total biomass of study site was 730.43 g/m^2. The biomass of *E. adenophorum* was 727.84 g/m^2 and which shared around 99.6% of total herbaceous biomass. Biomass of other herb species was 2.59 g/m^2 which shared around only 0.4% of total herbaceous biomass above road side (Table 7).

***Cypress* forest (below the road side):** Total 11-26 herbs were present in 0-50 m distance from the road. Total density of herbs ranged 89.8 - 234.7 ind./m^2 of which *E. adenophorum* showed maximum density 17.3 - 60.1 ind./m^2 and PV 30.64 - 61.25 (Table 3 and 4). Total herb species diversity (H') was 2.79 - 3.49 (Table 3). Total biomass of study site was 640.96 g/m^2. The biomass of *E. adenophorum* 630.04 g/m^2, which shared around 98.3% of total herbaceous biomass. Biomass of other herb species was 10.92 g/m^2, which shared around only 1.7% of total herbaceous biomass below road side (Table 7).

Forest site-3 (Bhowali)

Oak forest (above the road side): Total 12- 14 herb species were present in 0-50 m distance from the road. The density of herbs ranged 17.8 - 41.9 ind./m^2 of which *E. adenophorum* showed 2.5 - 19.3 density ind/m^2 and PV was 17.6 -78.14 (Table 5 and 6). Total herb species diversity (H') was 2.27 - 3.27 (Table 5). Total biomass of study site was 176.6 g/m^2. The biomass of *E. adenophorum* was 160.8 g/m^2 and which shared around 91% of total herbaceous biomass. Biomass of other herb species was 15.8 g/m^2 which shared around 9% only of total herbaceous biomass above road side (Table 7).

Oak forest (below the road side): Total 6-10 herb species were present in in 0-40 m distance from the road. *E. adenophorum* was not present in 40.1 - 50 m distance. The density of herbs ranged 39.8 - 86.4 ind/m^2 of which *E. adenophorum* showed density 10.9-17.4 ind./m^2 and PV 36.09 - 48.77 (Table 5 and 6). Total herb species diversity (H') was 0.0 - 2.98 (Table 5). Total biomass of study site was 135.68 g/m^2. The biomass of *E. adenophorum* was 113.68 g/m^2, which shared around 84% of total herbaceous biomass. Biomass of other herb species was 21.73 g/m^2, which shared around only 16% of total herbaceous biomass below road side (Table 7).

Table 1. Density and species diversity of herbaceous vegetation in Khurpatal forest site- 1

Species name/ distance (m)	Density (ind./m^2)					Species diversity				
	0-10	10.1-20	20.1-30	30.1-40	40.1-50	0-10	10.1-20	20.1-30	30.1-40	40.1-50
Cypress forest (above the road side)										
Anthraxon sp.	0.9	1.5	2.2	-	1.6	0.09	0.17	0.23	-	0.17
Agrimonia pilosa	-	1.5	0.5	1.5	-	-	0.17	0.08	0.13	-
Conyza canadensis	-	-	-	2.4	-	-	-	-	0.18	-
Cynodon dactylon	1.1	0.2	0.1	0.9	-	0.11	0.04	0.02	0.09	-
Eupatorium adenophorum	30.2	27.9	32.1	39.2	33.9	0.49	0.40	0.28	0.43	0.30
Erigeron annua	15.4	0.6	0.7	8.2	0.7	0.51	0.09	0.10	0.38	0.09
Gallium aparina	-	-	-	4.2	-	-	-	-	0.26	-
Gerenium wallichianum	0.7	0.2	2.8	0.3	4.9	0.08	0.04	0.26	0.04	0.35
Lindenbergia indica	2.8	2.0	1.4	2.1	0.3	0.21	0.21	0.17	0.16	0.05
Lytharus sp.	0.1	0.1			0.2	0.01	0.02			0.03
Oxalis latifolia	2.1	3.3	0.8	1.8	0.2	0.17	0.28	0.11	0.14	0.03
Prunella vulgaris	1.1	0.5	-	-	-	0.11	0.07	-	-	-
Rubia cordifolia	-	0.7	0.4	-	0.2		0.10	0.06	-	0.03
Rumex hastatus	0.8	0.1	0.1	0.4	-	0.08	0.02	0.02	0.06	-
Strobillanthus atropurpurem	1.8	3.4	-	2.7	1.1	0.16	0.29	-	0.19	0.13
Senecio nudicaulis	0.1	-	-	-	-	0.01	-	-	-	-
Thalictrum foliolosum	0.6	0.8	0.1	-	1.3	0.07	0.11	0.02	-	0.15
Total	57.7	42.8	41.2	63.7	44.4	2.10	2.01	1.35	2.06	1.33
Mixed pine forest (below the road side)										
Anthraxon sp.	-	0.3	-	2.6	0.3	-	0.03	-	0.23	0.03
Agrimonia pilosa	4.3	-	9.3	1.7	-	0.21	-	0.36	0.17	-
Conyza canadensis	9.7	-	1.7	-	-	0.35	-	0.12	-	-
Cynodon dactylon	3.4	4.3	2.3	-	1.3	0.18	0.26	0.15	-	0.11
Eupatorium adenophorum	45.8	39.2	44.9	30.3	38.6	0.49	0.42	0.47	0.42	0.47
Erigeron annua	-	-	1.8	-	1.2	-	-	0.12	-	0.10
Gallium aparina	1.8	7.7	3.4	-	0.2	0.12	0.37	0.19	-	0.02
Gerenium wallichianum	6.5	-	0.9	10.5	0.3	0.28	-	0.07	0.48	0.03
Lindenbergia indica	2.2	1.9	8.5	1.0	1.3	0.13	0.15	0.34	0.12	0.11
Oxalis latifolia	3.1	1.9	3.2	-	7.2	0.17	0.15	0.18	-	0.34
Rubia cordifolia	-	0.2	0.6	-	-	-	0.02	0.05	-	-
Rumex hastatus	0.3	0.2	-	-	1.5	0.03	0.02	-	-	0.12
Strobillanthus atropurpurem	0.2	7.2	2.7	1.4	15.0	0.02	0.35	0.16	0.15	0.48
Senecio nudicaulis	0.5	-	-	-	-	0.04	-	-	-	-
Stellaria media	4.6	0.3			2.3	0.22	0.03	-	-	0.16
Thalictrum foliolosum	-	-	0.1	0.4	-	-	-	0.01	0.06	-
Viola odorta	4.3	-	1.3	-	0.3	0.21	-	0.10	-	0.03
Total	86.7	63.2	80.7	47.9	69.5	2.45	1.80	2.32	1.63	2.00

Table 2. PV (provenence value) of herbaceous vegetation in pine *Cypress* forest site- 1

Species name/ distance (m)	PV(above the road side)					PV(below the road side)				
	0-10	10.1-20	20.1-30	30.1-40	40.1-50	0-10	10.1-20	20.1-30	30.1-40	40.1-50
Anthraxon sp.	5.07	10.48	21.13	-	11.71	-	3.04	-	20.13	2.93
Agrimonia pilosa	-	12.81	3.85	9.17	-	14.05	-	22.64	15.31	-
Conyza canadensis	-	-	-	10.59	-	20.28	-	6.87	-	-
Cynodon dactylon	8.92	2.79	2.87	5.96	-	11.19	22.19	10.79	-	6.87
Eupatorium adenophorum	69.88	88.44	104.23	84.27	103.38	71.01	87.67	71.51	92.67	80.54
Erigeron annua	44.23	6.05	4.33	24.24	4.28	-	-	8.58	-	4.23
Gallium aparina	-	-	-	20.23	-	5.71	22.44	12.15	-	2.79
Gerenium wallichianum	8.23	5.12	22.59	2.74	35.36	22.04	-	7.46	51.33	2.93
Lindenbergia indica	18.89	18.63	19.19	14.66	6.08	11.63	10.70	20.06	5.03	9.37
Lytharus sp.	1.93	2.56			5.86	14.48	15.83	13.49	-	25.36
Oxalis latifolia	12.41	17.01	9.84	7.37	5.86	-	-	-	-	-
Prunella vulgaris	5.42	3.49	-	-	-	-	-	-	-	-
Rubia cordifolia		6.29	6.23	-	3.15	-	2.88	3.92	-	-
Rumex hastatus	4.90	2.56	2.87	2.90	-	3.98	2.88	-	-	9.66
Strobillanthus atropurpurem	11.89	19.57	17.87	17.87	7.88	2.05	29.34	12.87	11.75	41.58
Senecio nudicaulis	1.93	-	-	-	-	2.39	-	-	-	-
Stellaria media	6.30	4.19	2.87	-	16.44	8.94	3.04			10.81
Thalictrum foliolosum	-	-	-	-	-	-	-	1.71	3.78	-
Viola odorta	6.30	4.19	2.87	-	16.44	12.23	-	7.96	-	2.93
Total	200	200	200	200	200	200	200	200	200	200

Table 3. Density and species diversity of herbaceous vegetation in pine-*Cypress* forest in Hanumangarh forest site- 2

Species name/distance (m)	Density (ind/m^2)					Species diversity				
	0-10	10.1-20	20.1-30	30.1-40	40.1-50	0-10	10.1-20	20.1-30	30.1-40	40.1-50
Pine-*Cypress* forest (above the road side)										
Acorus calamus	3.4	8.6	6.0	22.3	-	0.15	0.30	0.34	0.51	-
Agrimonia pilosa	0.7	1.1	-	1.1	-	0.04	0.07	-	0.08	-
Ajuga parvifolra	7.1	-	-	-	-	0.25		-	-	-
Anthraxon sp.	1.1	2.2	-	11.8	-	0.06	0.12	-	0.40	-
Bidens biternata	1.0	1.6	1.7	-	-	0.06	0.09	0.15	-	-
Climantis pitcheri	-	0.2	-	-	-	-	0.18	-	-	-
Cyperus rotundus	2.8	-	-	3.3	-	0.13	-	-	0.19	-
Erigeron bonariensis	5.0	-	-	0.4	-	0.20	-	-	0.04	-
Eupatorium adenophorum	53.9	45.2	12.1	24.7	-	0.51	0.52	0.47	0.52	-
Gallium aparina	2.2	-	-	-	-	0.11	-	-	-	-
Gerenium wallichianum	1.5	1.4	1.7	1.7	-	0.08	0.08	0.15	0.12	-
Justicia smilex	2.9	2.0	7.6	-	-	0.14	0.11	0.39	-	-
Lapidagathis sp.	0.4	4.7	1.1	-	-	0.03	0.20	0.11	-	-
Lytharus sp.	1.4	2.3	2.0	0.8	-	0.08	0.12	0.17	0.07	-
Micromeria sp.	2.9	-	-	-	-	0.14	-	-	-	-
Oxalis latifolia	2.4	6.9	1.9	5.4	-	0.12	0.26	0.16	0.26	-
Prunella vulgaris	-	4.6	4.9	0.2	-	-	0.20	0.30	0.02	-
Rubia cordifolia	-	0.5	2.4	2.2	-	-	0.04	0.19	0.14	-
Senecio nudicaulis	-	1.7	2.3	-	-	-	0.10	0.19	-	-
Siegesbecki orientalis	-	-	0.2	-	-	-	-	0.03	-	-
Stellaria media	15.2	12.7	6.2	-	-	0.39	0.37	0.35	-	-
Strobillanthus atropurpurem	8.5	6.6	6.9	6.5	-	0.28	0.25	0.37	0.29	-
Thalictrum foliolosum	0.5	-	-	0.5	-	0.03	-	-	0.04	-
Total	112.9	102.3	57.0	80	-	2.80	3.01	3.37	2.68	-
Pine-*Cypress* forest (below the road side)										
Acorus calamus	6.5	3.4	14.8	22.3	6.9	0.14	0.15	0.37	0.50	0.28
Acyrenthes bidentata	0.2	-	-	-	1.5	0.01	-	-	-	0.10
Agrimonia pilosa	1.8	0.7	2.5	-	0.9	0.05	0.04	0.12	-	0.07
Ajuga parviflora	8.1	7.1	-	1.3	0.4	0.17	0.25	-	0.09	0.03
Anthraxon sp.	5.5	1.1	2.4	13.8	11.4	0.13	0.06	0.11	0.41	0.37
Bidens biternata	2.2	1.0	3.2		7.8	0.06	0.06	0.14		0.30
Cynodon dactylon	38.3	-	-		3.5	0.43	-	-		0.18
Cypreus rotundus	1.2	2.8	-	3.9		0.04	0.13	-	0.20	
Erigeron bonariensis	8.3	5.0	9.4	2.7	-	0.17	0.20	0.29	0.15	-
Eupatorium adenophorum	60.1	53.9	39.3	24.7	17.3	0.50	0.51	0.53	0.51	0.45
Gallium aparine		2.2	1.1	2.4	-	-	0.11	0.06	0.14	-
Gerenium wallichianum	1.5	1.5	0.4	1.7	7.4	0.05	0.08	0.03	0.11	0.29
Hetropogon contontus	0.6	-	-	-	-	0.02	-	-	-	-
Justica simplex	16.4	2.9	3.2	-	4.2	0.27	0.14	0.14	-	0.20
Lapidagathis cristata	0.3	0.4	0.7	-	-	0.01	0.03	0.01	-	-
Lindenbengia indica	0.1	-	0.1	-	-	0.01	-	0.04	-	-
Lytharus sp.	0.6	1.4	2.2	0.8	0.2	0.02	0.08	0.11	0.06	0.02
Micromeria sp.	5.5	2.9	0.9	-	-	0.13	0.14	0.05		
Oxalis latifolia	13.7	2.4	10.7	9.7	8.7	0.24	0.12	0.31	0.35	0.32
Prunella vulgaris	3	-	1.9	-	3.1	0.08	-	0.11	-	0.17
Rubia cordifolia	0.3	-	1.5	-	1.9	0.01	-	0.08	-	0.12
Senecio nudicaulis	0.4	-	0.9	-	-	0.02	-	0.05	-	-
Siegesbecki orientalis	1.2	-	0.5	-	13.5	0.04	-	0.03	-	0.41
Stellaria media	26.6	15.2	13.9	-	-	0.36	0.39	0.36	-	-
Strobillanthus atropurpurem	31.2	8.5	9.0	6.5	0.8	0.39	0.28	0.28	0.27	0.06
Thalictrum foliolosum	0.5	0.5	-	-	1.6	0.02	0.03	-	-	0.10
Vitis himalayana	0.6		-	-	0.2	0.02	-	-	-	0.02
Total	234.7	112.9	118.6	89.8	91.3	3.39	2.80	3.22	2.79	3.49

Forests in Himalaya are playing a significant role in socio-economic and environmental development. But recently they are degrading by various distrubences such as biotic, infrastructural expansion and also by many invasive plant species in natural forest habitats. *Lantana camara*, *Eupatorium adenophorum* and *Parthenium hysterophorus* are most troublesome plants commonly occupied every possible habitat (Singh and Vashistha 2014). This rapid and increasing rate of invasive potential and its establishment have very little prospect of reversing (Muniappan *et al.* 2009, Sharma and Raghubanshi 2011).

Table 4. PV (provenence value) of herbaceous vegetation in pine-*Cypress* forest in Hanumangarh forest site- 2

Species name/ distance (m)	PV(above the road side)					PV(below the road side)				
	0-10	10.1-20	20.1-30	30.1-40	40.1-50	0-10	10.1-20	20.1-30	30.1-40	40.1-50
Acorus calamus	8.42	17.38	19.10	39.10	-	6.77	8.42	21.65	35.55	14.05
Acyrenthes bidentata						1.09	-	-	-	2.94
Agrimonia pilosa	6.03	3.64	-	5.21	-	5.77	6.03	8.53	-	4.88
Ajuga parvifolra	8.99	-	-	-	-	7.45	8.99	-	6.80	1.74
Anthraxon sp.	2.33	3.43	-	26.12	-	7.34	2.33	7.53	27.87	22.88
Bidens biternata	4.94	7.97	10.13	-	-	6.94	4.94	10.04	-	16.34
Climantis pitcheri	-	1.48	-	-	-	-	-	-	-	-
Cynodon dactylon	-	-	-	-	-	23.32	-	-	-	12.92
Cyperus rotundus	10.59	-	-	13.69	-	1.51	10.59	-	15.06	-
Erigeron bonariensis	9.83	-	-	2.42	-	7.54	9.83	12.51	4.79	-
Eupatorium adenophorum	61.25	57.00	35.51	49.76	-	35.61	61.25	42.31	45.36	30.64
Gallium aparina	7.35	-	-	-	-	-	7.35	3.68	8.03	-
Gerenium wallichianum	5.38	9.06	12.98	9.79	-	4.64	5.38	3.09	9.04	15.90
Hetropogon contontus	-	-	-	-	-	1.26	-	-	-	-
Justicia smilex	6.62	5.80	23.33	-	-	13.99	6.62	8.20	-	9.80
Lapidagathis sp.	1.71	12.29	4.79	-	-	2.13	1.71	1.00	-	-
Lindenbengia indica						1.04	-	3.34	-	-
Lytharus sp.	5.29	11.22	13.51	8.68	-	3.26	5.29	8.28	8.03	1.52
Micromeria sp.	5.27	-	-	-	-	4.34	5.27	3.51	-	-
Oxalis latifolia	14.29	15.72	6.19	14.37	-	13.84	14.29	17.28	19.73	18.62
Prunella vulgaris	-	10.91	14.31	2.17	-	4.28	-	5.27	-	7.29
Rubia cordifolia	-	1.77	7.07	4.64	-	2.13	-	4.02	-	5.98
Senecio nudicaulis	-	6.79	11.18	-	-	1.17	-	2.59	-	-
Siegesbecki orientalis	-	1.78	1.78	-	-	3.51	-	4.09	-	21.28
Stellaria media	21.57	20.11	15.16	-	-	14.33	21.57	18.14	-	-
Strobillanthus atropurpurem	18.34	15.43	24.96	21.50	-	23.29	18.34	14.93	19.74	4.77
Thalictrum foliolosum	1.79	-	-	2.54	-	1.21	1.79	-	-	5.65
Vitis himalayana	-	-	-	-	-	2.26	-	-	-	2.82
Total	200	200	200	200	200	200	200	200	200	200

In present study, density of herbaceaous layer ranged the from 41.2 ind./m^2 to 234.7 ind./m^2 for conifer forest and 17.8 - 86.4 ind./m^2 in oak forest. The values were higher than 67.2 ind./m^2 during summer season for oak - pine mixed forest in Kumaun Himalaya by Joshi *et al.* (2012) and 20.3 - 34 ind./m^2 for banj oak forest by Kharkwal *et al.* (2010).

The species diversity of herb layer in present study ranged 1.33 - 3.49, which was on lower side than 2.11 - 3.56 reported for oak-pine mixed forest in Kumaun Himalaya by Joshi *et al.* (2012), and 3.3 -5.1 for Uttaranchal forests by Kumar and Ram (2005), and supporting the study that once *E. adenophorum* weed invaded barren land, it was able to restrain tree seedling growth as well as the regeneration of other species of grass (Sun *et al.* 2004).

Density of *E. adenophorum* ranged from 2.5 ind./m^2 to 60.1 ind./m^2 in present study. Average density of *E. adenophorum* in forest below the road side ranged 11.24 to 39.76 ind./m^2, which was higher almost in all sites than forest above road site that ranged 7.84 to 32.66 ind./m^2.

Density of *E. adenophorum* was higher in *Cypress* forest *i.e.* 30.1 - 65.4% followed by mixed pine forest 57.1% and lowest in mixed oak forest 23.2 - 26.8%. On the basis of density and PV, *E. adenophorum* was the dominant species of herbaceous layer in mixed conifer forest and shared 30 - 65.4% of total herbaceous density, when we moved upto 50 m above and below the road side. While in oak forest, it was not the dominant herb species and shared only 23.2 - 26.8%. Habitats with high diversity and complexity possessed strong resistance to the *E. adenophorum* invasion, while disturbed habitats favoured invasion (Hao *et al.* 2010).

Total herbaceous biomass ranged from 135.68 - 730.43 g/m^2, which was higher than 8.8-227 g/m^2 for banj oak forest (Kharkwal *et al.* 2010). Biomass of *E. adenophorum* shared 84 - 99.8% of total herbaceous biomass.

The values of density, PV, diversity and biomass of *E. adenophorum* indicated that it has highly reduced available habitat for the growth of other herbaceous species and dominated the ground layer

Table 5. Density and species diversity of herbaceous vegetation in oak forest in Bhowali forest site- 3

Species name/distance (m)	Density (ind/m^2)					Species diversity				
	0-10	10.1-20	20.1-30	30.1-40	40.1-50	0-10	10.1-20	20.1-30	30.1-40	40.1-50
Oak forest (above the road side)										
Acorus calamus	-	-	4.4	7.5	2.2	-	-	0.35	0.47	0.31
Agrimonia pilosa	0.2	0.3	0.9	0.2	0.7	0.04	0.1	0.12	0.04	0.15
Ajuga parvifolra	-	2.1	-	0.6	-	-	0.36	-	0.1	-
Anthraxon sp.	0.8	0.9	7.5	9.5	3.1	0.11	0.22	0.45	0.5	0.38
Clematis pitcher			1.2	2.1	1	-	-	0.15	0.24	0.19
Conyza canadensis	5.3	-	-	-	-	0.38	-	-	-	-
Cyperus rotundus	-	-	0.7	-	0.2	-	-	0.1	-	0.06
Erigeron annua	10	2.5	5.4	-	5.7	0.49	0.4	0.39	-	0.49
Eupatorium adenophorum	19.3	9.1	4.8	2.5	3.5	0.51	0.49	0.36	0.26	0.4
Gallium aparina	0.3	0.2	2.6	1.2	0.2	0.05	0.07	0.25	0.16	0.06
Gentian sp.	-	-	-	0.1	-	-	-	-	0.02	-
Gerenium wallichianum	2	0.5	0.9	-	0.5	0.21	0.14	0.12	-	0.11
Lindenbergia indica	2.7	1.6	7.1	8.3	2.4	0.25	0.31	0.44	0.48	0.33
Lytharus sp.	0.1	-	0.7	0.4	0.6	0.02	-	0.1	0.07	0.13
Micromeria sp.	-	-	-	0.9	-	-	-	-	0.13	-
Prunella vulgaris	0.3	0.2	-	0.3	-	0.05	0.07	-	0.06	-
Rubia cordifolia	0.2	-	-	-	-	0.04	-	-	-	-
Rumex hastatus	-	-	-	-	-	-	-	-	-	-
Senecio nudicaulis	0.4	0.1	-	-	0.6	0.06	0.04	-	-	0.13
Stellaria media	0.2	0.2	-	-	0.2	0.04	0.07	-	-	0.06
Strobillanthus atropurpurem	0.1	0.1	3.8	3	3.6	0.02	0.04	0.32	0.3	0.41
Thalictrum foliolosum	-	-	0.9	-	-	-	-	0.12	-	-
Total	41.9	17.8	40.9	36.6	24.5	2.27	2.31	3.27	2.83	3.21
Oak forest (below the road side)										
Acorus calamus	1.2	0.3	1.6	2.8	-	0.09	0.33	0.18	0.26	-
Agrimonia pilosa	0.1	3.1	3.6	8.4	-	0.01	0.19	0.3	0.47	-
Anthraxon sp.	31.2	4.3	2.4	1.4	-	0.41	0.24	0.23	0.17	-
Cyperus rotundus	1.3	7	4.8	4.7	-	0.09	0.32	0.35	0.36	-
Erigeron annua	10.9	1.9	2.6	3.6	-	0.37	0.14	0.25	0.31	-
Eupatorium adenophorum	17.4	14.7	13.2	10.9	-	0.47	0.47	0.52	0.51	-
Gallium aparina	4.6	-	-	-	-	0.22	-	-	-	-
Gerenium wallichianum	0.8	6.5	2.3	0.7	-	0.06	0.31	0.23	0.1	-
Lindenbergia indica	21.8	15.4	8.2	4.5	-	0.5	0.47	0.46	0.36	-
Oxalis letifolia	13.6	19.8	0.6	1.1	-	0.42	0.51	0.09	0.14	-
Strobillanthus atropurpurem	1.5	-	-	-	-	0.1	-	-	-	-
Thalictrum foliolosum	-	-	3.4	1.7	-	-	-	0.29	0.19	-
Total	104.4	73	42.7	39.8	0	2.74	2.98	2.9	2.87	0

Table 6. PV (provenence value) of herbaceous vegetation in oak forest in Bhowali forest site- 3

Species name/distance (m)	PV (above the road side)					PV(below the road side)				
	0-10	10.1-20	20.1-30	30.1-40	40.1-50	0-10	10.1-20	20.1-30	30.1-40	40.1-50
Acorus calamus	-	-	20.09	34.34	20.09	6.65	2	9.1	14.05	-
Agrimonia pilosa	2.98	7.09	10.2	3.62	6.56	1.87	16.94	19.15	36.9	-
Ajuga parvifolra	-	19.91	-	6.25	-	-	-	-	-	-
Anthraxon sp.	9.41	15.87	30.34	41.34	21.91	25.8	17	16.33	7.03	-
Clematis pitcher	-	-	12.27	13.43	9.64	-	-	-	-	-
Conyza canadensis	32.65	-	-	-	-	-	-	-	-	-
Cyperus rotundus	-	-	4.38	-	4.52	5.01	20.7	25.53	29.35	-
Erigeron annua	33.87	27.56	19.86	-	30.67	30.16	7.36	11.43	16.06	-
Eupatorium adenophorum	71.05	78.14	21.07	17.6	29.1	37.68	36.01	48.77	43.18	-
Gallium aparina	3.22	3.83	14.36	9.43	2.67	12.34	-	-	-	-
Gentian sp.	-	-	-	1.81	-	-	-	-	-	-
Gerenium wallichianum	12.27	10.92	6.2	-	5.74	2.68	23.19	14.31	7.02	-
Lindenbergia indica	11.44	19.8	28.03	36.52	20.91	39.27	36.97	37.06	20.08	-
Lytharus sp.	2.74	-	3.04	5.71	8	-	-	-	-	-
Micromeria sp.	-	-	-	5.54	-	-	-	-	-	-
Prunella vulgaris	3.22	3.83	-	3.9	-	-	-	-	-	-
Rubia cordifolia	5.48	-	-	-	-	-	-	-	-	-
Rumex hastatus	-	-	-	-	-	-	-	-	-	-
Oxalis letifolia	-	-	-	-	-	29.78	39.82	3.19	9.78	-
Senecio nudicaulis	5.95	3.26	-	-	6.15	-	-	-	-	-
Stellaria media	2.98	6.53	-	-	2.67	-	-	-	-	-
Strobillanthus atropurpurem	2.74	3.26	21.29	20.5	31.36	8.75	-	-	-	-
Thalictrum foliolosum	-	-	8.87	-	-	-	-	15.11	16.55	-
Total	200	200	200	199.99	199.99	199.99	199.99	199.9	200	

Table 7. Biomass of herb species

Component	Forest site-1		Forest site-2		Forest site-3	
	Above	Below	Above	Below	Above	Below
TAG biomass(g/m^2)	482.1 (481.4)	465.8 (463.6)	499.8 (498.0)	407.0 (400.4)	119.5 (115.2)	89.4 (75.4)
TBG biomass (g/m^2)	244.0 (244.0)	238.6 (237.4)	230.6 (229.8)	234.0 (234.0)	57.1 (45.6)	46.3 (38.5)
Total (g/m^2)	726.1 (725.4)	704.3 (704.0)	730.4 (727.8)	641.0 (641.0)	176.6 (160.8)	135.7 (113.9)

Values in parentheses are indicating biomass shared by *Crofton* weed

of forest. It was concluded that prevention and early detection of *E. adenophorum* is vital in protecting forest environments from non-indigenous and possibly invasive species as these species would have effective reproduction and dispersal mechanism, superior competitive ability and are capable of displacing native species.

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Assessment of genetic diversity among different biotypes of *Physalis minima*

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ABSTARCT

Physalis minima is abundant weed species in India commonly found in non-cropped and crop areas during *Kharif* season. Fruits of this weed species has been reported for high nutritional and medicinal values. Despite, no study has been made, so far, for their molecular diversity analysis. In the present study, genetic diversity was assessed among a total of 17 biotypes of *P. minima* and 1 intermediate biotype (which exhibits floral characteristics of both *P. minima* and *P. peruviana*). Using 42 random amplified polymorphic DNA (RAPD) markers, a total of 224 bands were amplified among all studied biotypes. The band size of amplified fragments ranged from 100 - 2200 base pairs (bp). Out of 224 bands amplified, 52 were found to be monomorphic (23.2%) and remaining 172 were polymorphic (78.8%). Average number of bands per primer were 5.33 while average number of polymorphic bands per primer were 4.09. Cluster analysis grouped all biotypes into two groups. This is the first report on molecular diversity analysis among *Physalis minima* biotypes.

Key words: Genetic diversity, Biotype, *Physalis minima*, RAPD, Similarity, Weed

Physalis minima is a diploid (2n=24) plant and is one of the important weed species in Solanaceae family. It is locally known as *'Ban Tipariya'*, *'Panchkota'* or *'Chirpati'* in India. *Physalis* is a genus of 80 to 100 species of mostly neotropical herbs. The plant is an annual grow well in most soil types particularly sandy soil and commonly found as weed in *Kharif* crops in India. Almost all parts of this plant have been reported to be useful as treatment for ulcer, cancer and the decoction. The green-yellowish edible berry is encapsulated by the calyx and it is a popular seasonal fruit among tribal areas. Fruits of *P. minima* have been reported as rich source of flavonoids, terpenoids, vitamins, alkaloids and antibacterial substance which make it valuable as a medicinal plant (Nathiya and Dorcus 2012). It also has been reported for treating diseases like cancer, leukemia, malaria, asthma, hepatitis, dermatitis and rheumatism (Joshi and Joshi 2015). Utilization of the nutritional potential of *Physalis* may be helpful to alleviate malnutrition problems in India and elsewhere (Pagare *et al.* 2015). Recently, the demand for fruit of its cultivated species (*P. peruviana*) has increased due to its potential as antioxidant and anticancer (Pietro *et al.* 2000, Shariff *et al.* 2006).

Characterization of genetic diversity is required for further improvement. Morphological markers tend to fluctuate with environmental conditions. Molecular markers have been employed in characterization of genetic diversity among biotypes/ species. Random amplified polymorphic DNA (RAPD) is increasingly being employed in diversity analysis owing to its easy protocol and simplicity. To date, no report on molecular marker study is available regarding the genetic diversity of *P. minima* in India. Therefore, this study was conducted to investigate the genetic diversity among different biotypes of *P. minima* using RAPD markers.

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MATERIALS AND METHODS

A total of 18 biotypes of *P. minima* were collected from different locations in the year 2013-14 (Table 1). Out of these, 17 biotypes exhibited typical floral pattern of *P. minima* (designated as PM1, PM2,.....PM17), while one biotype exhibited mixed floral characteristics of *P. minima* and *P. peruviana* (designated as intermediate and abbreviated as PI). Plants were grown in the containment facility at ICAR-Directorate of Weed Research in *Kharif* season of 2015 using pot culture. Second leaf from top of 20 days old plants were used for DNA extraction.

Genomic DNA was extracted using DNeasy Plant Mini Kit (Qiagen) following supplier's instruction. Twenty days young leaves were sampled from a single plant of each population. After thorough washing in distilled water, samples were stored in liquid N_2 till further used. For DNA extraction, samples were crushed in liquid N_2 using pestle and mortar. Quality and quantity of extracted genomic

Table 1. Collection sites of different biotypes of *Physalis minima*

Biotypes	Collection sites	Latitude	Longitude
PM1	Jabalpur-random collection	23.1812° N	79.9866° E
PM2	Raipur (G.G.)	21.1797° N	81.7787° E
PM3	Anand (Gujarat)	22.5645° N	72.9289° E
PM4	Bengaluru (Karnataka)	12.9716° N	77.5946° E
PM5	Jorhat (Assam)	26.2006° N	92.9376° E
PM6	Jorhat (Assam)	26.2004° N	92.9378° E
PM7	DWR, Jabalpur (MP)	23.1815° N	79.9864° E
PM8	Jabalpur-random collection	23.1814° N	79.9865° E
PM9	Jabalpur-random collection	23.1818° N	79.9862° E
PM10	Jabalpur-random collection)	23.1816° N	79.9863° E
PM11	Jabalpur-random collection	23.1811° N	79.9860° E
PM12	Jabalpur-random collection	23.1812° N	79.9866° E
PM13	Jagdalpur (C.G.)	19.0741° N	82.0080° E
PM14	Jabalpur-random collection	23.1814° N	79.9868° E
PM15	Jabalpur-random collection	23.1810° N	79.9867° E
PM16	Jabalpur-random collection)	23.1811° N	79.9865° E
PM17	Jabalpur-random collection	23.1813° N	79.9868° E
PI	DWR, Jabalpur	23.1815° N	79.9864° E

DNA was assessed by UV-spectrophotometer (DS 11+, DeNovix) and submerged horizontal electrophoresis using agarose gel (0.8%).

PCR amplifications were performed in a programmable thermocycler (Takara). Each sample was amplified in a reaction mixture containing 50 ng genomic DNA, 1 unit of *Taq* polymerase (New England Biolabs), 10x PCR buffer with 2.5 mM $MgCl_2$ and 200 µM of each dNTP (New England Biolabs), 10 pmol of 10-mer RAPD primers (Operon Technologies, USA; Table 2). Cycling parameters for RAPD were adjusted to 5 min at 94 °C for pre-denaturation, 45 cycles each of 1 min at 94 °C for denaturation, 1 min for annealing at 37 °C, 2 min at 72 °C for extension and a final extension at 72 °C for 5 min. After cooling to 4 °C, amplified PCR products were stored at 4 °C till electrophoresis.

Amplified products were separated on 1.5% agarose gel in 1x TAE buffer with 1 Kb plus ladder (Fermentas) to determine the size of amplified DNA fragments. Gels were run for 2 h at 65 V, stained with ethidium bromide and documented with gel documentation system (Syngene, UK). Polymerase chain reactions (PCR) were repeated thrice to confirm reproducibility of primers. Reproducible bands were scored manually as '1' or '0' for presence or absence of the bands.

Evaluation of fragment patterns was carried out by similarity index. The final RAPD data generated was used to calculate pair-wise similarity co-efficient values (Jaccard 1908) using the similarity for qualitative data (SIMQUAL) format of NTSYS-pc version 2.1 (numerical taxonomy and multivariate analysis system) software package (Rohlf 2002).

Table 2. RAPD primers used for genetic diversity analysis

Primer	Sequence 5'-3'	GC (%)	TB	PB	PP
OPA-01	CAGGCCCTTC	70	4	3	75.0
OPA-02	TGCCGAGCTG	70	5	5	100
OPA-03	AGTCAGCCAC	60	4	4	100
OPA-04	AATCGGGCTG	60	5	1	20.0
OPA-05	AGGGGTCTTG	60	4	3	75.0
OPA-06	GGTCCCTGAC	70	7	3	42.8
OPA-08	GTGACGTAGG	60	6	4	66.7
OPA-09	GGGTAACGCC	70	5	4	80.0
OPA-10	GTGATCGCAG	60	6	6	100
OPA-11	CAATCGCCGT	60	7	7	100
OPA-12	TCGGCGATAG	60	6	5	83.3
OPA-15	TTCCGAACCC	60	7	5	71.4
OPA-17	GACCGCTTGT	60	5	3	60.0
OPA-18	AGGTGACCGT	60	6	2	33.3
OPA-19	CAAACGTCGG	60	5	3	60.0
OPA-20	GTTGCGATCC	60	7	6	85.7
OPE-01	CCCAAGGTCC	60	7	5	71.4
OPE-02	GGTGCGGGAA	70	5	4	80.0
OPE-04	GTGACATGCC	60	4	4	100
OPE-05	TCAGGGAGGT	60	7	5	71.4
OPE-06	AAGACCCCTC	60	4	4	100
OPE-07	AGATGCAGCC	60	6	6	100
OPE-08	TCACCACGGT	60	6	6	100
OPE-09	CTTCACCCGA	60	5	5	100
OPE-10	CACCAGGTGA	60	3	1	33.3
OPE-15	ACGCACAACC	60	6	5	83.3
OPE-16	GGTGACTGTG	60	5	1	20.0
OPE-19	ACGGCGTATG	60	6	5	83.3
OPE-20	AACGGTGACC	60	6	5	83.3
OPN-01	CTCACGTTGG	60	5	5	100
OPN-02	ACCAGGGGCA	70	5	5	100
OPN-03	GGTACTCCCC	70	4	4	100
OPN-04	GACCGACCCA	70	8	7	87.5
OPN-05	ACTGAACGCC	60	5	4	80.0
OPN-12	CACAGACACC	60	5	4	80.0
OPN-13	AGCGTCACTC	60	5	5	100.0
OPN-14	TCGTGCGGGT	70	5	4	80.0
OPN-15	CAGCGACTGT	60	5	5	100.0
OPN-16	AAGCGACCTG	60	4	3	75.0
OPN-17	CATTGGGGAG	60	4	3	75.0
OPN-20	GGTGCTCCGT	70	5	3	60.0
OPAB-07	GTAAACCGCC	60	6	3	50.0
Total			224	172	78.78
Average			5.33	4.09	-

Cluster analysis was performed on the basis of genetic similarity matrix, and the resulting similarity co-efficient values were used for constructing dendrogram using the unweighted pair group method with arithmetic average (UPGMA) with the SAHN module of NTSYS-pc (Sneath and Sokal 1973).

RESULTS AND DISCUSSION

In the present study, initially 60 RAPD primers were screened among 18 biotypess of *P. minima*. Forty two RAPD primers that produced consistently strong amplification products (Fig. 1) and polymorphic banding patterns were selected for further analysis. The polymerase chain reaction was carried out using a single decamer primer at a time.

The sequences of these primers are presented in Table 2. Selected 42 RAPD primers amplified a total of 224 loci. The band size of amplified fragments ranged from 100-2200 bp. Out of 224 bands amplified, 52 were found to be monomorphic (23.2%) and remaining 172 were polymorphic (78.8%). Average numbers of bands per primer was 5.33 while average number of polymorphic band per primer was 4.09. Maximum numbers of bands (8) were scored by primer OPN-04 while minimum numbers of bands (3) were scored by primer OPE-10 (Table 2). Banding patterns by primer OPE-05 and primer OPN-17 have been depicted in Fig. 1. Information on genetic diversity is essential in optimizing both conservation as well as utilization strategies for genetic resources. Molecular markers are preferred over conventional approaches to identify genetic variability among biotypes. Genetic diversity analysis through RAPD markers has been highlighted in a number of medicinally important plants including *Bacopa monnieri* (Tripathi *et al.* 2012) and *Coleus forskohlii* (Tripathi *et al.* 2013). DNA markers provide important data on diversity due to their capability to discover variation at the molecular level (Tripathi *et al.* 2013). The RAPD technique has been used very effectively in the discrimination of the individuals and can measure similarity present between a pair of biotypes.

The similarity coefficient values were obtained after multivariate analysis using Jaccard's value. These similarity coefficient values were then used to construct a dendrogram with the UPGMA method (Fig. 2). Cluster analysis revealed that biotypes of *P. minima* (PM) under study divided into two groups, minor group and major group. Minor group contained only three biotypes namely PM13, PM15 and intermediate PI. Major group comprised 15 biotypes and further divided into two subgroups. First subgroup contained 6 biotypes PM1, PM2, PM3, PM4, PM5 and PM6 while second subgroup contained 9 biotypes namely PM17, PM14, PM7, PM12, PM11, PM9, PM10, PM16 and PM8. Among all biotypes PM1, PM2, PM3, PM4 and PM6 showed higher similarity and grouped together while, PM7, PM18 and PM17 were grouped in a separate group. Among remaining biotypes in major group PM8, PM16 and PM10 were grouped separately. One *P. minima* biotype PM5 grouped distantly. Usaizan *et al.*

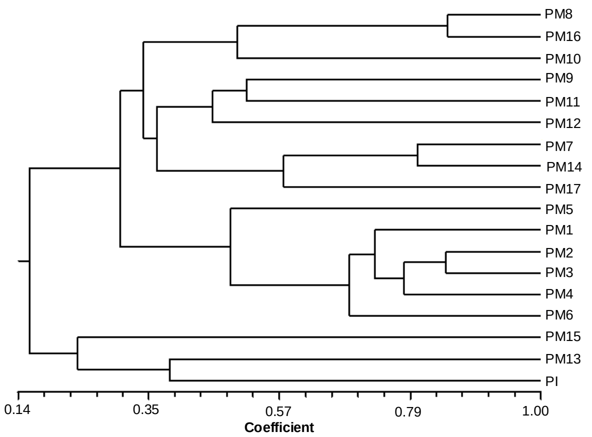

Fig. 2. UPGMA clustering among *Physalis minima* biotypes based on RAPD data

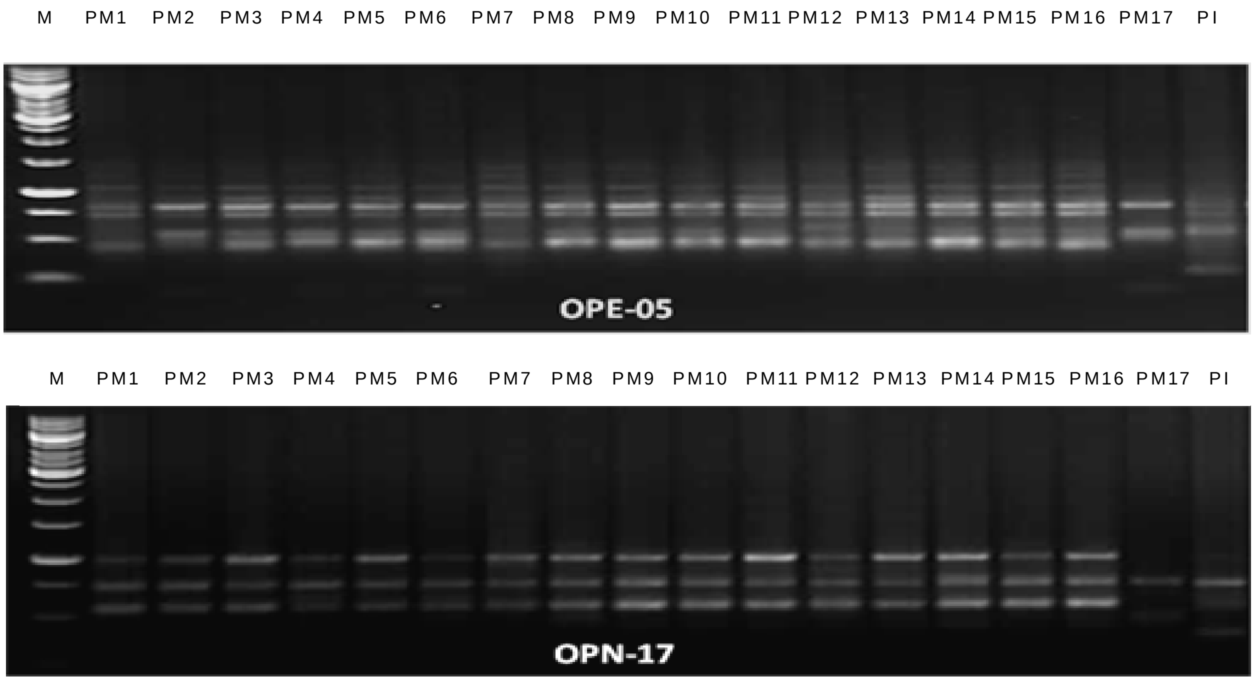

Fig. 1. Electrophoretic banding pattern of different biotypes using OPE-05 and OPN-17 RAPD markers

(2014) reported four clusters while analyzing genetic divergence among *P. minima* biotypes using ISSR markers. Results of this study further inferred that molecular diversity among different biotypes of *P. minima* may or may not be dependent on geographically locations. For example, biotypes from different places (Jabalpur, Jagdalpur and intermediate) fall in a single cluster (minor group). Similarly, first subgroup of major group has 6 bioypes namely PM1, PM2, PM3, PM4, PM5 and PM6. Despite of clustering in same subgroup, these belong to distant geographical locations [PM1 (Jabalpur), PM2 (Raipur, CG)), PM3 (Anand, Gujarat), PM4 (Bengaluru, Karnataka), and PM5, PM6 (Jorhat, Assam). On the other hand, biotypes from Jabalpur (except PM1 and PM15) formed a cluster (second subgroup) exhibiting high degree of genetic similarity. Our results showed the usefulness of RAPD markers for analysis of genetic diversity among biotypes even from same geographical locations or genetic similarity among biotypes from different geographical locations. Two-dimensional and three-dimensional scaling further elaborated the diversity analysis indicating that biotypes of minor groups (PM13, PM 15 and PI) placed at distant positions not only from the biotypes of major group by also within themselves (Fig. 3 and 4).

Component Analysis (PCA) conceded out using the similarity matrices for RAPD primers also produced trends similar to the UPGMA cluster analysis (Fig. 3). Further, in three-dimensional scaling, intermediate biotype showed higher diversity and grouped distantly from other biotypes (Fig. 4).

In conclusion, significant variations were observed among the *P. minima* biotypes after RAPD analysis can be used for genetic diversity analysis for characterization of germplasm at molecular level.

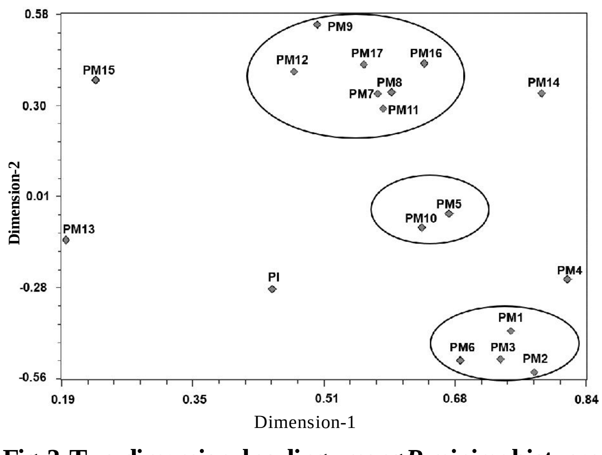

Fig. 3. Two-dimensional scaling among *P. minima* biotypes based on RAPD data

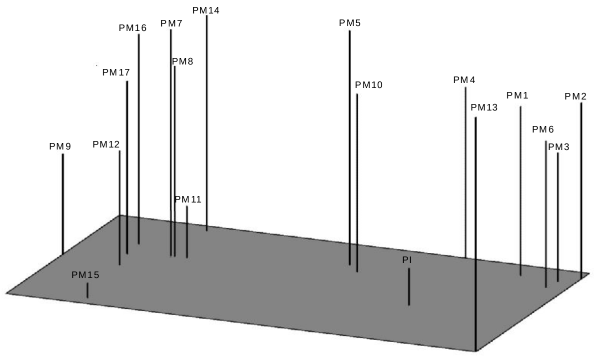

Fig. 4. Three-dimensional scaling among *P. minima* biotypes based on RAPD data

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Nanoemulsions formation from essential oil of *Thymus capitatus* and *Majorana hortensis* and their use in weed control

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ABSTRACT

Essential oil formulation of *Thymus capitatus* L. (wild and cultivated thyme) and *Majorana hortensis* L. (marjoram) were investigated for allelopathic activity against *Convolvulus arvensis* and *Setaria viridis* seeds and seedling growth. Thymol, camphor, carvacrol, thujone, ä-terpinene, borneol, p-cymene, carvacrol, 1,8-cineole, caryophyllene oxide, á-humulene á-pinene, borneol, â-pinene, caryophyllene, caryophyllene oxide, linalol and phellandrene were detected by GC-Ms analysis from the oil contents. Macroemulsion (Mac-E) and nanoemulsion (Nano-E) were formulated from oil by adding co-surfactant and surfactant. These formulations were subjected to stability stresses and were tested for herbicidal activity against *C. arvensis* seeds germination and seedling growth. Nanoemulsion had particle size of 5.3, 12.0 and 22.1 nm for *M. hortensis*, *T. capitatus* wild and *T. capitatus* cultivated, respectively. Depending on ED_{50} *M. hortensis* (oils, Mac-E and Nano-E) exhibited strong allelopathic activity on *C. arvensis,* however, the lowest activity was achieved from *T. capitatus* cultivated followed by *T. capitatus* wild. The Nano-E exhibited pronounced post-emergence properties on (5-7 leaves stage) than others formulation on *C. arvensis* in greenhouse conditions.

Key words: Allelopathy, Constituents, Macro emulsion, Nanoemulsion, *Majorana hortensis* L., *Thymus capitatus* L., Volatile oils

Thyme, *Thymus capitatus* L. (wild and cultivated) and marjoram (*Majorana hortensis* L.) belonging to Family Lamiaceae are native to Mediterranean countries (Harley *et al.* 2004), which are used for medicinal and spice purposes (Morales 2002). The major essential oil constituents of *Majorana hortensis* have been reported as cis-sabinene hydrate (37.05–47.49%), terpinen-4-ol (14.45–16.22%) and trans-sabinene hydrate (5.81–6.97%) (Verma, *et al.* 2010). Other components detected in lower amounts in all oil samples were sabinene and p-cymene (up to 7.4% and 13.9% in autumn), and á-terpinene (up to 13.3% in summer) in *Majorana hortensis* (Soliman *et al.* 2009). The volatile extract compositions of marjoram estimated by GC–MS were terpinen-4-ol, ã-terpinene, trans-sabinene hydrate, linalool, trans-sabinene hydrate acetate, thujanol, terpinolene and thymol (El-Ghorab *et al.* 2004).

Bindweed (*Convolvulus arvensis*) is known to reduce crop value and provide a breeding site for insects attacking adjacent crops (Tamaki *et al.* 1975) and serves as an alternative host for plant viruses. The control of bindweed is difficult because of its vigorous regeneration capacity. The phytotoxic effects of aromatic plants volatile oils have increased the interest in exploring for potential weed management (Dayan *et al.* 2009). Lamiaceae, Myrtaceae, Asteraceae and Anacardiaceae are the most cited plant families with promising essential oils used as herbicide. Individual compounds present in these mixtures with high activity include á-pinene, limonene, 1, 8-cineole, carvacrol, camphor and thymol (Amri *et al.* 2013). The allelopathic effects of thyme essential oil have been tested in vitro on germination percentage (GP), hypocotyl (HL) and radicle (RL) length of *Citrullus colocynthis* L., *Lepidium sativum* L. and *Trigonella foenum-graecum* L. at 20 mg/l (Soliman 2013). In the present study, phytotoxicity of essential oils extracted from wild thyme, cultivated thyme and *Majorana hortensis* and their formulated macroemulsion (Mac-E) and nanoemulation (Nano-E) were investigated.

MATRIALS AND METHODES

Characterization of plant soil and water: The wild *Thymus capitatus* (thyme) shoots were collected from Wadi Habbes, about 18 km of Matrouh city. Cutting (shoots 6-8 cm) of half-ripe wood were taken on March 2014 for cultivation in greenhouse. The seedling of *Majorana hortensis* (marjoram) were obtained from the Experimental Farm of Medicinal and Aromatic plants, Faculty of Pharmacy, Cairo

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University, Egypt. Both seedlings of thyme and marjoram were planted in May and April 2014 in Matrouh Research Station, respectively. The field was incorporated with sheep manure 15 m^3/Feddan and calcium superphosphate 30 kg (P_2O_4)/Feddan before planting. The physical and chemical properties of soil and water of experimental station and sheep manure are presented (Table 1).

Sampling and determination of volatile oil: The shoots of both wild and cultivated thyme and marjoram plants were harvest by cutting in April 2015. Essential oil of air dried canopy samples was extracted by hydro distillation and was subjected to GC-Ms analysis at Department of Medicinal and Aromatic Plants Research, National Research Center with the following specifications: a Trace GC Ultra Gas Chromatographs (Thermo Scientific Corp., USA), coupled with a THERMO mass spectrometer detector (ISQ Single quadrupole Mass Spectrometer). The GC-MS system was equipped with a TG-WAX MS column (30 m x 0.25 mm i.d., 0.25 µm film thickness). The oven temperature was programmed; 60-200 °C (8/min.), injection temperature 150 and 220 °C (20 min.). Helium was the carrier gas with flow rate of 1 ml/min; detection was by (EI, 70 eV. Interface 230). Qualitative identification of the oil constituents was carried out by comparing the retention times and mass fragmentation with computer matching of authentic samples and of published data.

Emulsions preparation: Macro-emulsions (Mac-E) of essential oils were prepared by mixing oil volume (2.5%) with two volumes of surfactant [polyethylene glycol dioleate (nonionic surfactant) + toximol (ionic surfactant)] and water. After that, the mixture was vortex several times and visually evaluated at room temperature, then subjected for stability testing and specifications. Nanoemulations (Nano-E) were prepared by mixing one volume of oil (2.5%) with one volume of chloroform (co-surfactant) and ten volume of surfactant (Tween 20 plus Tween 80) and vortex several time with adding deionized water to the final volume. The obtained formulation was subjected to sonication in ultrasonic bath for two hours and stored at laboratory condition for testing.

Physical and chemical tests of prepared formulation: Stability was studied according to Sinha *et al.* (2015) for thermal and mechanical stress. Formulations (5 ml) was stored at elevated temperature (40 ± 2 °C, 25 ± 2 °C and 4 ± 2 °C) and centrifuged at 2000 rpm for different intervals (20,40,60 and 120 min.) then, visually inspected (phase separation). The pH values of the samples were measured by a pH meter (JENCO, 6010N, USA), at 25 ± 2 °C Electrical conductivity by EC Meter (Orion 150 A of Thermo Electron Corporation, USA) at ambient temperature. The formulation transparency was determined by measuring percentage transmittance at scan mode with purified water taken as blank using UV-VIS spectrophotometers (Thermo, Nicolet evolution 300) according to Date and Nagarsenker (2008). Droplets size of formulations was measured by puting in droplet size analyzer (PSS NICOMP, N3000, Dynamic light scattering, Particle Size Systems, Inc. Santa Barbara, Calif., USA) without diluting the formulation.

Pre-emergence activity under laboratory conditions: *Convolvulus arvensis* and *Staria viridis* (Foxtail, Poaceae) were collected from wheat crop in El-Frafra Oasis, Egypt. Bioassay of *T. capitatus* (wild and cultivation) and *M. hortensis* oils were carried out on *C. arvensis* and *S. viridis*. Seeds were surface-

Table 1. Physical and chemical analysis of soil and water at experiment site

Particles size distribution of the experimental soil					
	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Soil texture
Wadi Habbes	9.87	72.90	16.10	1.13	Sandy loamy
Matrouh	8.83	58.88	28.11	4.18	Sandy loamy

Chemical properties of the experimental soil										
	pH	E.C. (dSm)	Soluble cations (meq./l)				Soluble anions (meq./l)			
			K^+	Na^+	Mg^{++}	Ca^{++}	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
Wadi habbes	7.53	4.16	0.20	4.10	1.00	2.50	-	1.75	3.45	2.60
Matrouh	7.30	4.99	2.7	5.9	4.7	36.6	-	3.00	37.10	9.80

Irrigation water analysis										
	pH	E.C. (dSm)	Soluble cations (meq./l)				Soluble anions (meq./l)			
			K^+	Na^+	Mg^{++}	Ca^{++}	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
Matrouh	7.01	55.9	0.03	0.48	0.24	0.15	-	0.11	0.60	0.19

Sheep manure analysis			
pH	Organic carbon %	N %	C/N ration
7.50	20.10	1.50	13.56

sterilized with 0.3% sodium hypochlorite and washed many times with sterile waters. Ten seeds were placed on filter paper in a sterilized Petridish (9 cm diameter). The concentrations of volatile oil of *M. hortensis* were; 0, 1.0, 2.0, 4.0, 8.0 µl/ml for *C. arvensis* and 0.5, 1, 2.5,5 µl/ml for *S. viridis*, while, *T. capitates* cultivated and *T. capitatus* wild were evaluated with 0, 5, 10, 20, 40 µl/ml concentrations. However, the formulated Mac-E and Nano-E were evaluated at 0.1, 0.2, 0.4, 0.8 µl/ml (*M. hortensis*) and 1.0, 2.5, 5.0, 10.0 µl/ml (*T. capitates* wild and cultivated) on *C. arvensis* seeds and seedling growth. Treated Petri-dishes with oil, Mac-E and Nano-E were sealed with parafilm and kept at 25 ± 2 ^{o}C. Seed germination and seedling growth (radical and hypocotyl) were measured after 7 days.

Post-emergence activity of prepared formulations: Bindweed *C. arvensis* seeds were sown in plastic pots filled with sandy soil and watered two times weekly in the greenhouse. The desired concentration of 10 ml solution was sprayed with the help of glass hand sprayer on each petridish. Survival of seedlings and dry weight were recorded after one week of spraying.

Statistical analysis: Treatment means were compared by Duncan and LSD test at 5% level of probability (Snedecor and Cochran 1990) and the effective dose (ED_{50} values) were calculated by signing the point in a semi-log graph paper. Finally, the reduction percentage was obtained from the below equations. R%=C-T/C*100 [C=Control] [T=Treatment].

RESULTS AND DISCUSSION

Chemical composition of essential oils: Content of essential oils from the dry herb of *T. capitatus* wild, *T. capitatus* cultivated and *M. hortensis* were obtained by 1.85, 0.8 and 2.1% (v/w), respectively. The major compounds identified in *T. capitatus* wild were thymol (34.40%) and á-terpinene (14.67%), followed by1-4-terpineol (9.65%). Compounds of *T. capitatus* cultivated were thymol (23.74%), o-cymene (18.74%), trans caryophyllene (9.82%) followed by á-terpinene (9.13%). Major constituents in oils of *M. hortensis* were trans-sabinene hydrate (19.23%), cis-sabinene hydrate (17.55), terpinen-4-ol (15.66%) followed by á-terpinene (12.06%) as determined by GC/MS (Table 2).

Formulated emulsions: Formulated Nano-E exposed to ultra sonication for 2 hours had minimum dispersion. It was stabilized in the final stage due to decreasing of the hydrodynamic droplet diameters which improved the dispersion quality.

Table 2. GC-mass analysis of *T. capitatus*, *T. capitatus* cultivated and *M. hortensis* essential oils

IUPAC name	*T. capitatus* Wild % (V/W)	*T. capitatus* cultivated % (V/W)	*M. hortensis* % (V/W)	Molecular weight
Thujene	1.13	0.68	-	136
α – pinene	0.90	1.92	0.46	136
Camphene	0.92	1.77	-	136
Sabinene	4.47	-	10.24	136
1-octen-3-ol	0.31	-	-	128
α –myrcene	1.61	1.19	1.03	136
3-octanol	0.40	-	-	130
Phellandrene	0.33	-	3.18	136
α –terpinene	14.67	9.13	12.06	136
o-cymene	5.50	18.74	1.65	134
d-limonene	0.89	-	-	136
trans-sabinene hydrate	1.61	-	19.23	155
α –terpinolene	1.86	-	0.71	154
L- linalool	0.78	3.71	-	154
Cis-sabinene hydrate	4.09	-	17.55	154
1-Terpineol	1.06	-	0.61	154
Borneol	5.00	1.59	-	154
1-4-terpineol	9.65	1.20	-	154
α –terpineol	2.07	-	-	154
Thymol	34.40	23.74	-	150
Iso-thymol	0.34	-	-	150
Carvacryl acetate	3.39	-	-	150
Trans-caryophyllene	3.41	9.82	4.24	204
4-isopropylidene	0.57	-	-	204
Caryophllene oxide	0.63	4.12	-	220
Geraniol	-	1.47	-	154
Geraniol isovalerate	-	3.35	-	138
α –citronellol	-	1.68	-	156
camphor	-	3.05	-	152
1,8-cineole	-	3.87	5.09	154
Humulene	-	0.59	-	204
Iso caryophyllene	-	1.71	-	204
α –cadinol	-	1.36	-	222
pogostol	-	0.49	-	236
1,6,10-Dodecatrien-3-ol,3,7,11-trimethyl	-	3.83	-	122
Terpinen-4-ol	-	-	15.66	154
Linalyl acetate	-	-	2.88	138
Geranyl actate	-	-	1.81	182

Mac-E had higher pH than 7, while *T. capitatus* cultivated had maximum pH value. The EC value ranged from 0.184 to 0.142 m mols/cm (Mac-E) and 0.125 to 0.112 m mols/cm (Nano-E). There was less variation in EC value within Nano-E and Mac-E. These values explained the high steady state of establishing water continuous phase (Table 3).

The nanoemulsions (Nano-E) was characterized with excellent transparency and higher (UV/VIS) transmission percentage as compared with Mac-E, and had milky color and lower transmission percentage ranged from 92, 90 and 88.4% for *T. capitatus* wild, *T. capitatus* cultivated and *M. hortensis* for Nano-E, respectively. In formulated Mac-E, transmittance percentage was 0.71, 11.2 and 0.55% for *T. capitatus* wild and *T. capitatus* cultivated, respectively. On the other hand, λ_{max} in formulated Nano-E was recorded by 222, 247, 243,

Table 3. Characterization of the formulated Mac-E and Nano-E

	Emulsion type	Nano particles (nm)	pH	λ_{max}	EC (m mols/cm)	Transmittance
T. capitatus	Macro-E	1468.6±0.54	7.7±0.1	222, 247, 243, 253 260,	0.165±0.1	0.71%±0.53
wild	Nano –E	12±0.525	6.61± 0.11	272, 282	0.118±0.1	92%±1.3
T. capitatus	Macro-E	15840±1.01	7.71±0.13	225,235,262,	0.184±0.1	11.2%±2.6
cultivated	Nano –E	22.4±0.357	6.49±0.05	266,273,383, 479,486	0.125±0.1	90%±1
M. hortensis	Mac-E	90.7± 0.63	7.59±0.1	248, 262, 272, 486,	0.142±0.1	0.55%±0.5
	Nano –E	5.3± 0.680	5.64±0.15	568, 575, 586	0.112±0.1	88.43%±2.6

253 260, 272, 282 (*T. capitatus* wild), 225,235,262, 266, 273, 383,479,486 (*T. capitatus* cultivated) and 248, 262, 272, 486, 568, 575, 586 (*M. hortensis*) (Table 3).

Particle size of the formulated emulsion: Particle size is the important determiner which influences the characterization of *M. hortensis*, *T. capitatus* wild and *T. capitatus* cultivated formulations. The particle size of Nano-E was measured by 5.3, 12.0 and 22.1 nm for *M. hortensis*, *T. capitatus* wild and *T. capitatus* cultivated, respectively. The particle size of Mac-E was 90.7, 15840 and 1468.6 nm for *M. hortensis*, *T. capitatus* wild and cultivated, respectively. It revealed that *M. hortensis* had nano size only in the presence of its milky color and without any sonication exposure while other formulation appeared in macrosize (Fig. 1).

Mechanical stability of the formulation: The prepared emulsions (Mac-E and Nano-E) were subjected to the stability assessment of centrifugation at 2000 rpm during 20, 40, 60 and 120 min. (Table 4), while thermal stability was implemented at 4±1, 25±1 and 50±1 °C after 1, 5, 10, 20, 30 days. The results showed the stability of Nano-E toward precipitation after 20, 40, 60 minutes centrifugation. However, higher trace precipitation was recorded in *T. capitatus* cultivated at 120 min, followed with *T. capitatus* wild, while it was lowest in *M. hortensis* (Fig. 1). Thermal stability in Mac-E and Nano-E was stable at 4±1, 25±1 and 50±1 °C for thirty days (Table 5), while at laboratory temperature, stability exceeded upto five month without any aggregation and separation.

Biological activity against weeds: The volatile oil at lowest and highest concentration, completely suppressed weeds germination (Table 6). Based on EC_{50}, it had more inhibitory effects upon shoot length of *C. arvensis* and *S. viridis* compared to root length and germination. Phytotoxicity on *C. arvensis* seed germination and seedling growth showed that most sensitive weed parts were root length and shoot length for Mac-E and Nano-E, respectively. The inhibitory effect of *M. hortensis* was highest against

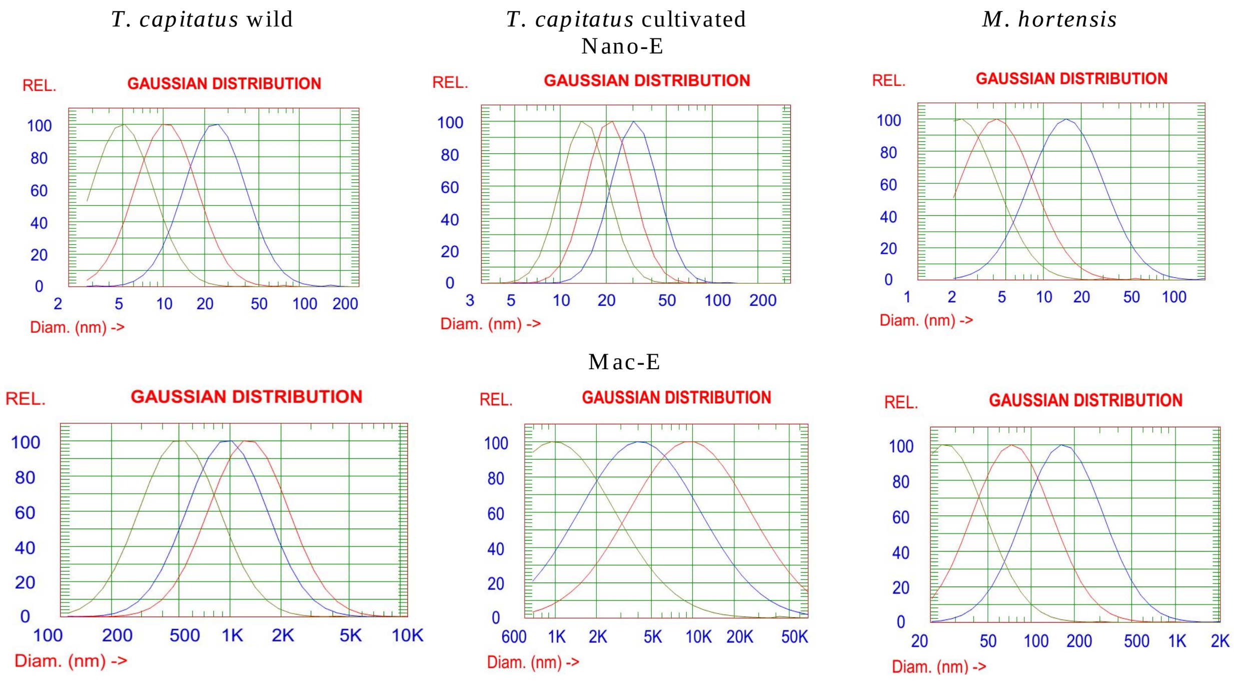

Fig. 1. Emulsions distribution analysis (particle size)

Table 4. Separated phase of emulsions after centrifugation at 2000 rpm

Centrifugation	*T. capitatus* wild		*T. capitatus* cultivated		*M. hortensis*	
Time min.	Mac-E	Nano-E	Mac-E	Nano-E	Mac-E	Nano-E
20	-	-	-	-	-	-
40	-	-	-	-	-	-
60	-	-	-	-	-	-
120	2.25	0.5	4.5%	1.2%	1.5%	0.5

Table 5. Separated phase after thermal exposure of formulated volatile oils emulsion

Temp. °C	days	*T. capitatus* wild		*T. capitatus* cultivated		*M. hortensis*	
		Mac-E	Nano-E	Mac-E	Nano-E	Mac-E	Nano-E
4 ±1,	1	-	-	-	-	-	-
25±1	5	-	-	-	-	-	-
40 ±1	10	-	-	-	-	-	-
	20	-	-	-	-	-	-
	30	-	-	-	-	-	-

C. arvensis and *S. viridis* compared to *T. capitatus* wild and *T. capitatus* cultivated. It was concluded that concentration and emulsion types played considerable role in achieving complete weed suppression. Nano-E exhibited highest inhibition followed by Mac-E. Nevertheless, volatile oils exhibited lowest suppression on germination and growth. This indicates that volatile oils contained growth inhibiting allelochemicals but their effect depended on type of oils and formulation.

Post-emergence herbicidal activities of formulated Mac-E and Nano-E against *C. arvensis* have been shown in Fig. 2. *M. hortensis* Mac-E at 5 and 10 µg/ml concentration caused inhibition of 73.7, 81.7 and 54.3, 60.6 for fresh and dry weight, respectively. Compared with the control, Nano-E caused significant inhibition at 5 and 10 µg/ml concentration amounted to 63.6, 82.9% and 75.3, 62.6% for fresh and dry weight, respectively. *T. capitatus* wild showed its post-emergence activity on total biomass of fresh and dry weight over control by 46.9,70.4% and 22.0,41.0% (Mac-E); 50.5, 77.5% and 37.6, 50.3% (Nano-E), respectively. *T. capitatus* cultivated at 5 and 10 µg/ml caused inhibition in *C. arvensis* fresh and dry weight by18.3,49.9% and 12.8,38.9 (Mac-E); 29.9,64.1% and 20.15, 41.9% (Nano-E), respectively than the control.

The result revealed that Nano-E of *M. hortensis* caused inhibition by 49.0, 59.29% (fresh weight) and 26.4, 38.3% (dry weight) at 5 and 10 µg/ml of *C. arvensis*, respectively. *T. capitatus* wild exhibited 59.54, 65.8% (fresh weight) and 16.38, 38.6% (dry weight) reduction and finally *T. capitatus* cultivated showed inhibition by 45.0, 57.8% (fresh weigh), 17.0 and 33.4% (dry weigh) of *C. arvensis* at 5 and 10 µg/ml, respectively in comparison to control.

The herbicidal activity of essential oils revealed that *M. hortensis* had the greatest inhibitory effects followed by *T. capitatus* wild and *T. capitatus* cultivated on both *C. arvensis* and *S. viridis*. The formulated Mac-E and Nano-E showed post-emergence activity in the early stage of *C. arvensis* (2-3 leaves) on total biomass of fresh and dry weight while Nano-E showed inhibitary effect on *C. arvensis* at 5-7 leaves stage (Table 7). The nano formulation exhibited faster release of active ingredients after application on weed leaves surface and weed seeds (under laboratory) due to pronounced surface properties. Selecting the suitable mixture (type and amount) from oils, water and surfactants macro-emulsion (Mac-E) plus co-surfactant for nano-emulsion (Nano-E) were the critical points that control the prepared formulation suitability to deliver their function. The formulated nanoemulsions size were found close to the standard Nano-E between 1 to 100 nm (Casanova *et al.* (2005) to deliver their

Table 6. Dos response relationship of volatile oils and emulsions (ED_{50}) µg/ml

	Volatile oils *C.arvensis*	Volatile oils *S. viridis*	Mac-E *C. arvensis*	Nano-E *C. arvensis*
T. capitatus wild				
Shoot length	5.764±0.11	7.133±1.31	2.314±0.41	2.514±0.21
Root length	6.115±0.17	10.954±1. 32	2.116±0.51	2.623±0.27
Germination	8.100±0.10	8.215±1.34	2.490±0.34	2.616±0.21
T. capitatus cultivated				
Shoot length	8.516±0.20	7.436±0.44	3.855±0.12	4.013±0.34
Root length	8.632±0.18	12.713±0.12	2.463±0.18	2.577±0.21
Germination	10.211±0.42	8.891±0.87	3.143±0.16	3.465±0.22
M. hortensis				
Shoot length	1.693±0.27	0.863±0.11	0.286±0.08	0.324±0.06
Root length	1.745±0.15	1.788±0.02	0.196±0.09	0.367±0.04
Germination	1.713±0.21	1.536±0.1	0.573±0.12	0.392±0.05

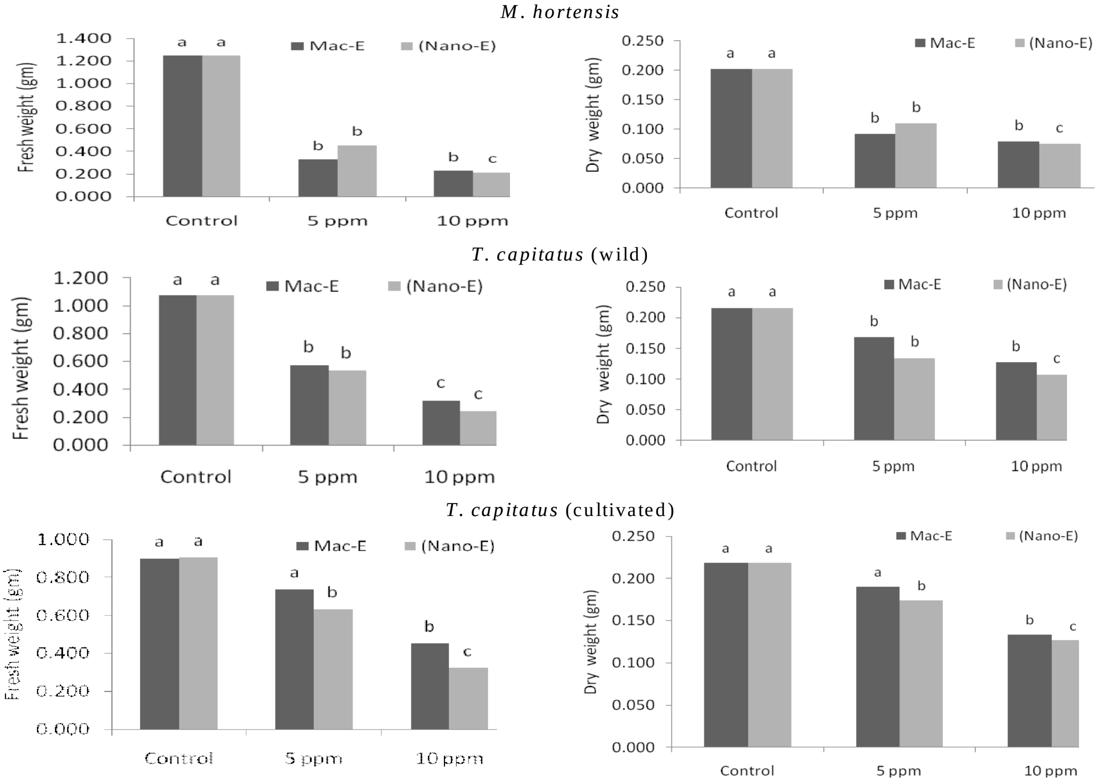

Fig. 2. Post-emergence activity of macroemulsion (Macro-E) and nanoemulsion (Nano-E) on fresh and dry weight of *C. arvensis* (2-4 leaves stage)

Table 7. Post-emergence activity of nano-E on *C. arvensis* at 5-7 leaves stage fresh and dry weight

Treatment	Fresh weight (gm)			Dry weight (gm)		
	T. capitatus wild	*T. capitatus* cultivated	*M. hortensis*	*T. capitatus* wild	*T. capitatus* cultivated	*M. hortensis*
Control	1.13	1.02	1.02	0.26	0.25	0.26
5 ppm	0.46	0.55	0.52	0.22	0.23	0.19
10 ppm	0.38	0.43	0.42	0.16	0.16	0.16
LSD (0.05)						
Plant Oils	0.26	0.27	0.22	0.12	0.10	0.13
Conc.	0.37	0.42	0.35	0.13	0.11	0.13
Interactions	0.52	0.62	0.55	0.141	0.09	0.14

function. Whereas, Nano-E size was not exceeded from 22 nm, while in *M. hortensis* Mac-E was less than 100 nm. These results supported by Owolade *et al.* (2008). Nanoparticles loaded with garlic essential oil were effective against *Tribolium castaneum* Herbst (Yang *et al.* 2009). The phytotoxicity of volatile constituents in *M. hortensis, T. capitatus* wild and *T. capitatus* cultivated was previously reported due to ä-terpinene, p-cymene, carvacrol, 1,8-cineole (Angelini *et al.* 2003, Grosso *et al.* 2010), caryophyllene oxide (Macini *et al.* 2009a), thymol, p-cymene, ä-terpinene (Almeida *et al.* 2010; Grosso *et al.* 2010) á-humulene (Tellez *et al.* 2000), á-pinene, 1,8-cineole, borneol (Angelini *et al.* 2003), carvacrol, p-cymene (Kordali *et al.* 2008), â-pinene (Almeida *et al.* 2010), 1,8-cineole (Mucciarelli *et al.* 2001), (Z)- caryophyllene, caryophyllene oxide (De Martino *et al.* 2010), (Z)-caryophyllene, caryophyllene oxide (De Martino *et al.* 2010), linalol, 1.8-cineole, â-phellandrene, á-pinene (Almeida *et al.* 2010), linalol, 1.8-cineole, â-phellandrene, á-pinene (Almeida *et al.* 2010), cis-thujone, 1,8-cineole, camphor (De Martino *et al.* 2010), camphor, 1,8-cineole, borneol (Kordali *et al.* 2008, Salmaci *et al.* 2007), thymol (Marandino *et al.* 2011) and carvacrol, linalol (Almeida *et al.* 2010). A-pinene, limonene, 1.8.cineole and camphor affected the, respiratory activity of mithochondria of maize and soybean hypocotyl axes and á-pinene has been shown to be most active among the all tested monoterpenes (Abrahim *et al.* 2003). 1,8-cineole inhibited the germination, speed of germination, seedling growth, chlorophyll content and respiratory activity of *Ageratum conyzoides* (Singh *el al.* 2002). The present results showed potential useful role of essential oils for herbicidal constituents. Formulated emulsions may be a good alternative means to synthetic herbicides in weed control.

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Parthenium infestation and yield losses in agricultural crops

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ABSTRACT

Parthenium hysterophorus L. (family Asteraceae), commonly known as *Parthenium* weed is known for its notorious role as an environmental, medical and agricultural hazard. The study was carried out to see the status of *Parthenium* infestation and its effect on yield losses caused to various cereals, oil, pulse, forage, sugar, vegetable, agroforestry and flowering crops cultivated in Haryana and some parts of Punjab, Uttar Pradesh and Delhi. Of the total 25 crops surveyed in different seasons, *Parthenium* was recorded in three cereals *viz*. rice (*Ory za sativa*), wheat (*Triticum aestivum*) and sorghum (*Sorghum vulgare*). However, it was not recorded in maize (*Zea mays*) and pearl millet (*Pennisetum typhoides*), the other commonly grown cereals in the States. Among different crops, the severe infestation of *Parthenium* was recorded in *Saccharum officinarum* (64.15%) followed by *Eruca sativa* (63.35%), *Helianthus annuus* (57.85%), *Brassica campestris* (57.63%), *Trifolium alexandrinum* (56.91%) and *Populus* sp. (54.63%). The vegetable crop infested by *Parthenium* weed included lady's fingers (*Abelmoschus esculentus*), onion (*Allium cepa*), garlic (*A. sativum*), carrot (*Daucus carota*), cucumber (*Cucurbita maxima*), potato (*Solanum tuberosum*) and leguminous fodder Eegyptian clover (*Trifolium alexandrinum*). Maximum losse due to *Parthenium* infestation was observed in *E. sativa* (55%) and sunflower (52.5%).

Key words: *Parthenium hysterophorus*, Infestation, Agriculture crops, *E. sativa*, Yield loss

Parthenium hysterophorus L. weed belongs to the family Asteraceae (tribe: Heliantheae and subtribe: Ambrosiniae). This weed is native to the area of Neotropical origin and has now invaded more than 34 countries globally, including five continents and numerous islands (Adkins and Shabbir 2014). In India *Parthenium* has invaed about 35 million hactares of land (Sushilkumar and Varsheny 2009) since its introducion at Pune in 1955 (Rao 1956).

It has been reported as an extremely aggressive colonizer of crops causing a yield decline upto 40% (Khosla and Sobti 1979) and reducing forage production in grasslands upto 90% (Nath, 1988). The disseminated pollen grains of the weed deposited to the aerial parts of the neighbouring plants are said to cause pollen allelopathy that inhibit pollen germination and fruit setting in *Crotolaria perlida, Desmodium heterocarpon*, brinjal, chilli and tomato (Kanchan and Jaychandra 1980). They also cause reduction in chlorophyll contents in leaves and abnormalities on flower heads and other parts of the plant (Gosal 1988). The allelopathic influence of *Parthenium* plant on succeeding crops like pulses and cereals has also been reported. It is an important weed of upland rice and caused more than 40% yield loss in India (Oudhia 1998). Due to very aggressive in nature, this weed may cause up to 90% loss in pasture production in Australia (Anonymous, 2011). Sorghum grain yield losses were reported between 40 to 97% in Ethiopia, if *Parthenium* is left uncontrolled throughout the season (Tamado *et al*., 2002). Accumulation of *Parthenium* pollen clusters on floral parts of maize cause 50% reduction in grain filling (Mahadebvappa 1997).

Parthenium not only competes with cultivated crops but also deplete the nutrient pool of the soil in which they grow (Aneja *et al*. 2014). Earlier, *Parthenium* was considered a problem in waste and vacant land but reports stared to appear about its infestation in field crops after 1970 (Narasimhan *et al.*1977). *Parthenium* infestation in crops incresed from 0.50 million hactares during 1980 to 14.25 million hactares in 2010 (Sushilkumar and Varshney 2010). The overall average infestation of *Parthenium* varied in different states of India. In general, overall spread in terms of density and infestation level was highest in Andhra Pradesh, Bihar, Chhattisgarh, Delhi, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Punjab, Tamil Nadu and Uttar Pradesh; medium in Assam, Gujrat, Himachal Pradesh, Jharkhand, Jammu & Kashmir, Uttarakhand, Odisha, West Bengal and Rajasthan; low in Andaman & Nicobar, Arunachal Pradesh, Goa Kerala, Lakshadweep, Manipur, Mizoram,

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Mehgalaya, Nagaland, Pondicherry and Sikkim (Sushilkumar 2012, 2014).

Studies showing losses by *Partheniumin* in crops are limited. Das (2008) observed severe *Parthenium* competition between 15 to 45 days after sowing while Tamado *et al.* (2002) found between 5 to 59 days after emergence in sorghum. Grain yield reductions due to infestation of *Parthenium* up to 40% in agricultural crops, like rice, wheat, maize, pigeonpea, blackgram, sorghum *etc*. are known (Khosla and Sobti 1979). Parsons and Cuthbertson (1992) reported that *Parthenium* caused a substantial yield loss in sunflower and sorghum in central Queensland, Australia. Angiras and Saini (1997) reported sorghum grain and forage yield losses of 40 and 90%, respectively by *Parthenium*. The adverse impacts of *Parthenium* weed on environment and agriculture have also been reviewed by Kassa (2016) in context to Ethopia.

This study was carried out to determine the status of *Parthenium* infestation and losses in yield caused in various agricutural crops of North India.

MATERIALS AND METHODS

Surveys were conducted between 2008 to 2014 during different crop seasons to see the infestation status of *Parthenium* in various economically important agricultural crops cultivated in Haryana and some parts of Punjab, Uttar Pradesh and Delhi. A total of 25 different crops including cereal, oil, vegetable, fodder, sugar, agroforestry and flower yielding crops were surveyed to see the per cent occurrence and per cent infestation of *Parthenium* weed. Surveys were also conducted in search of *Parthenium* infestation in orchards of different fruits.The per cent occurrence and infestation of *Parthenium* was calculated as follows:

$$\% \text{ Occurrence} = \frac{\text{No. of fields having } Parthenium}{\text{Total number of fields surveyed}} \times 100$$

$$\% \text{ Infestation} = \frac{\text{Total no. of quadrates in which } Parthenium \text{ weed occurred}}{\text{Total number of quadrates used}} \times 100$$

The per cent infestation of *Parthenium* was determined by presence and absence of the weed in the selected crop fields. The crop fields were selected on the basis of seasons as well as commonly grown crops in that particular area. The no. of fields visited for different crops were ranged between 20 to 200. Quadrates were used to determine number of *Parthenium* in each of the selected fields and 20 quadrates of 50 x 50 cm^2 were randomly located at approximately 2 meter intervals throughout the 50 meter length of the field. The number of *Parthenium* plants was counted within 20 randomly placed quadrates aross 20 x 50 m of the fields. The losses in crop yields were also estimated in different crops fields by collecting information from farmers of the field on average crop production of last three to four years with and without *Parthenium.*

RESULTS AND DISCUSSION

Parthenium infestation

Of the total 25 crops surveyed during 2008 to 2014, *Parthenium* was recorded in three cereals, *viz.* rice (*Oryza sativa*), wheat (*Triticum aestivum*) and sorghum (*Sorghum vulgare*). However, it was not recorded in maize (*Zea mays*) and pearl millet (*Pennisetum typhoides*), the other commonly grown cereals in the states. The vegetables infested by *Parthenium* weed include lady's fingers (*Abelmoschus esculentus*), onion (*Allium cepa*), garlic (*A. sativum*), carrot (*Daucus carota*), cucumber (*Cucurbita maxima*), potato (*Solanum tuberosum*) and fenugreek (*Trigonella foenum graecum*). *Parthenium* weed was found in three oil yielding crops namely sunflower (*Helianthus annuus*), rocket salat or arugula (*Eruca sativa*) and mustard (*Brassica campestris*). Horse gram (*Cicer arietinum*) was the only pulse and Egyptian clover (*Trifolium alexandrinum*) was the only leguminous fodder crop infested by this weed. Sugarcane (*Saccharum officinarum*), the sugar yielding crop; marigold (*Tagetes erecta*) a flowering crop and poplor (*Populus* sp.) a timber yielding crops agro forestry were also found infested by *Parthenium*. Among different crops, the severe infestation of *Parthenium* was recorded in *Saccharum officinarum* (64.15%) followed by *E. sativa* (63.35%), *H. annuus* (57.85%), *B. campestris* (57.63%), *T. alexandrium* (56.91%) and *Poplus* sp. 54.63%) (Table. 1). Tiwari and Bisen (1982) also reported infestation of *Parthenium* in field crops like soybean, millets and paddy. In North America, *Parthenium* weed has been recorded in several crops including sugarcane, maize, cotton, sorghum, onion and citrus orchards (Dale 1981).

Infestation of *Parthenium* in sugarcane was much higher (64.2%) than that recorded in other states such as Karnataka (38%) by Patil *et al.* (1997). *Parthenium* has been found to suppress the yield of sunflower and sorghum in sufficient amount (Parsons and Cuthberston 1992). In Tamil Nadu, crop losses due to heavy infestation of *Parthenium* weed in cotton were found in the range of 300 kg of seeds per ha. Low infestation of *Parthenium* in rice was recoded.

Table 1. Percentage occurrence and infestation of *P. hysterophorus* in various agricultural crops

Crops name	No. of fields visited	No. of fields having weed	% Occurrence of the weed	% Infestation in crops fields
Cereal crops				
Triticum aestivm	200	10	5	52.34
Oryza sativa	200	08	4	11.45
Zea mays	55	0	0	0
Sorghum vulgare	100	25	25	32.45
Pennisetum typhoides	60	0	0	0
Oil crops				
Eruca sativa	30	05	17	63.35
Brassica campestris	100	30	30	57.63
Helianthus annuus	100	20	20	57.85
Pulse crop				
Cicer arietinum	20	03	15	37.40
Vegetable crops				
Pisum sativum	170	0	0	0
Solanum tuberosum	100	05	5	49.79
Allium cepa	75	08	11	30.47
Allium sativum	40	03	8	28.35
Colocasia sp.	35	08	23	15.40
Abelmoschus esculentus	100	05	5	35.48
Cucurbita maxima	100	12	12	12.45
Momordica charantia	100	0	0	0
Cucumismelovar utilissimus	95	0	0	0
Cucumis sativus	100	0	0	0
Daucus carota	25	06	24	13.45
Trigonella foenum-graecum	30	04	14	52.45
Fodder crop				
Trifolium alexandrinum	100	30	30	56.91
Sugar crop				
Saccharum officinarum	100	87	87	64.15
Timber yielding crop				
Populus sp.	50	20	40	54.63
Flower yielding crop				
Tagetes erecta	50	10	20	17.50

Towers *et al.* (1997) reported the infestation of *Parthenium* in vegetables like beans, tomato, lady's fingers, chilli (*Paprica*), brinjal and potato. Later, Basak (1984) reported that the vegetable crops like bean, chilli, tomato, gourd, lady's fingers, brinjal, potato has also been found infested with *Parthenium* weed. In Haryana, the maximum infestation of this weed has been recorded in fenugreek (52.45%) followed by potato (49.79%), while minimum in pumpkin, *Cucurbita maxima* (12.45%). No infestation was recorded in pea (*Pisum sativum*), bitter gourd (*Momordica charantia*), snake cucumber (*Cucumis melo* var. *utilissimus*) and cucumber (*Cucumis sativus*).The reason for no infestation of *Parthenium* in these crops may be due to intensive management practices being adopted because of the low acerage. Patil *et al.* (1977) also reported least spread (8.8%) of *Parthenium* in vegetable crops. In Pakistan, this weed proven to be problematic in a range of agricultural crops namely wheat, rice, sugarcane, sorghum, maize, squash, gourd and watermelon (Shabbir 2012).

Parthenium infestation has also been recorded in the orchards situated at Kandhla town of Muzaffarnagar district in Uttar Pradesh. The orchards of banana (*Musa paradisiaca*), papaya (*Carica papaya*), peach (*Prunus persica*), pear (*Pyrus* sp.), pomegranate (*Punica granatum*) and loquat (*Eriobotrya japonica*) were heavily infested with *Parthenium*. Mahadevappa (1997) also found the profuse growth of *Parthenium* in guava, coconut, grapes, sapota, mango, and cashew; and papaya orchards were weeding was not done frequently and systematically as in the continuous cropped fields. During 2008 - 2009, weed was found infesting sugarcane followed by wheat in succession. In another case, this weed was recorded in rocket salat or arugula (*Eruca sativa*) crop followed by sunflower in the same field.

Losses in crops yield due to *Parthenium*

Study revealed losses in crop yield ranged between 6.5 to 55% (Table 2). The maximum losses were observed in rocket salat or arugula (55%) and sunflower (52.5%). The minimum losses were recorded in *Oryza sativa* (6.5%). The reason for the lowest infestation in rice could be the water logging.

Table 2. Per cent losses in crops yields due to *P. hysterophorus*

Crops name	% Losses in yield
Abelmoschus esculentus	25.0%
Allium cepa	15.0%
Allium sativum	7.5%
Brassica campestris	35.0%
Cicer arietinum	15.0%
Colocasia sp.	7.5%
Cucurbita melo var. *utilissimus*	7.5%
Eruca sativa	55.0%
Helianthus annuus	52.5%
Oryza sativa	6.5%
Populus sp.	52.5%
Saccharum officinarum	22.5%
Solanum tuberosum	35.0%
Sorghum vulgare	25.0%
Trifolium alexandrinum	27.5%
Trigonella foenium-graecum	25.0%
Triticum aestivm	35.0%

Channappagoudar *et al*. (1990) reported that presence of *Parthenium* in irrigated sorghum in India reduced grain yield by 4.2 to 6.47 to tons/hectare and decreased grain weight by almost 30%. A farmer around Hubli-Dharwar area in Karnataka failed to harvest even two bags of sorghum grains due to heavy *Parthenium* infestation (Krishanamurthy *et al.* 1977).

This findings indicated that *Parthenium* infestation will pose a serious threat in future in agricultural, plantation and vegetables crops in our country. No single management option would be adequate to control this weed across all habitats. There is a need to integrate various management strategies like grazing management, competitive displacement, and culture practices under biocontrol as a core management option.

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Short communication

Bioefficacy of herbicides for weed management in transplanted rice

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Key words: Herbicide, Transplanted Rice, Weed control efficiency, Weed density, Yield

In India, rice is cultivated in an area of 44.07 m/ha annually with a production of 103.4 m tonnes with an average productivity only 2.3 t/ha (FAO, 2012). Weed problem is most important that contribute heavily for the loss of rice yields and deteriorate the quality of crop produce and hence reduce the market value (Arif *et al.* 2006). Weeds compete with rice for moisture, nutrient, light, temperature, space and can cause yield reduction up to 28 to 45% in transplanted rice (Singh *et al*. 2007, Manhas *et al*. 2012). Pretilachlor 50% EC is a selective systemic anilide group of herbicide which was tested as pre-emergence herbicide in this experiment for weed management in transplanted rice as a broad spectrum.

The field experiment was conducted at Norman E. Borlaug, Crop Research Centre of GBPUA&T, Pantnagar, during *Kharif* 2014 to evaluate the bio-efficacy of pretilachlor against the weeds in transplanted rice. Rice variety '*Pant Dhan 18'* was transplanted on 2^{nd} July 2014 at spacing of 20 x 10 cm with 35 kg/ha seed rate. Herbicides were applied using knapsack sprayer fitted with flat fan nozzle fitted with boom (3) with a spray volume of 500 l/ha of water.

The data on weed density and weed dry matter were recorded with the help of quadrate of 0.25 m^2. The dry weight of weeds was recorded after air drying and then placing weeds in oven for 3 days up to 65-70 ^{0}C temperature and was expressed in g/m^2. Weed control efficiency (WCE) was calculated by using the formula suggested by Mani *et al.* (1973) and expressed in percentage.

Data recorded were statistically analyzed. There was great difference among the density of weeds within different treatments. So, to reduce the variation in analyzed data, square root transformation had been used.

Effect on weed flora and density

The dominant weed species identified at 60 DAT comprised of *Echinochloa colona, Echinochloa crus-galli, Leptochloa chinensis, Ischaemum rugosum* as grassy, *Caesulia axillaris* as broad-leaf, whereas, *Cyperus difformis* and *Fimbristylis miliaceae* as sedges which account 18.6, 14.2, 7.1, 12.0, 0.4, 30.6 and 13.1%, respectively in the weedy check plot.

At 30 DAT among grassy weeds, complete elimination of *L. chinensis* and *I. rugosum* was obtained with the application of all herbicidal treatments, whereas, population of *E. crus-galli* was completely controlled with pre-emergence application of all the doses of pretilachlor, either sponsor sample (SS) or market sample (MS). Among non-grassy weeds, pretilachlor (SS) applied at 750 to 1500 g/ha and MS at 750 g/ha proved to be very effective in controlling *C. difformis* and *F. miliaceae*. Butachlor applied at 1250 g/ha and pretilachlor (SS) at 500 g/ha were not found much effective in controlling the population of most of the weeds (Table 1).

At 60 DAT, twice hand weeding showed complete control over the density of all grassy and non-grassy weeds except *I. rugosum*. Among the grassy weeds, complete control of *I. rugosum* was observed under all herbicidal treatments, *L. chinensis* was controlled with the application of all doses of pretilachlor (either SS or MS) except at its lower dose (500 g/ha). Among non-grassy weed, complete reduction of *F. miliaceae* was observed with the application of pretilachlor (SS) at 1500 g/ha and pretilachlor (MS) at 750 g/ha (Table 2).

Statistical analysis of data revealed that among the different doses of pretilachlor (SS) and (MS), lowest total dry matter of weeds (1.5 and 4.1 g/m^2) and maximum weed control efficiency (98.0 and 88.8%) was obtained with the application of pretilachlor (SS) at 1500 g/ha at all the crop growth stages *i.e.*, 30 and 60 DAT, respectively, followed by the application of pretilachlor (SS) at 1000 g/ha (Table 1 and 2). This finding is in close conformity with Dharumarajan *et al*. 2009 who also reported the minimum total dry weight of weeds with the application of pretilachlor at 1000 g/ha. However, it was at par with its respective lower dose applied at 750 g/ha.

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Table 1. Effect of herbicides on weed density, total dry weight and WCE at 30 days after transplanting

Treatment	Dose (g/ha)	Weed density (no./m^2) Grassy weeds				Non-grassy weeds			Total dry weight (g/m^2)	WCE (%)
		E. colona	*E. crus-galli*	*L. chinensis*	*I. rugosum*	*C. axillaris*	*C. difformis*	*F. miliaceae*		
Pretilachlor (SS)	500	4.9(24.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.5(5.3)	1.9(2.7)	2.2(4.0)	3.7(12.9)	83.2
Pretilachlor (SS)	750	3.9(14.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.4(4.7)	1.0(0.0)	1.0(0.0)	2.8(6.8)	91.2
Pretilachlor (SS)	1000	3.4(10.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.2(4.0)	1.0(0.0)	1.0(0.0)	2.7(6.3)	91.8
Pretilachlor (SS)	1500	3.4(10.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.2(4.0)	1.0(0.0)	1.0(0.0)	1.5(1.5)	98.0
Pretilachlor (MS)	750	4.4(18.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.2(4.0)	1.0(0.0)	1.0(0.0)	2.9(7.5)	90.2
Butachlor	1250	3.8(13.3)	2.8(6.7)	1.0(0.0)	1.0(0.0)	2.8(6.7)	1.7(2.0)	1.5(1.3)	3.2(10.5)	86.3
Hand weeding (2)	30 and 60 DAT	4.4(18.7)	1.0(0.0)	1.5(1.3)	1.3(0.7)	1.7(2.0)	2.8(6.7)	1.9(2.7)	1.3(0.7)	99.1
Weedy check	-	7.4(53.3)	3.2(9.3)	2.5(5.3)	1.9(2.7)	2.5(5.3)	3.6(12.0)	6.4(40.0)	8.8(76.9)	-
LSD (P=0.05)	-	0.6	0.3	0.3	0.2	0.3	0.4	0.5	0.8	-

SS- Sponsor sample, MS- Market sample, DAT- Days after transplanting, WCE- Weed control efficiency, Value in parentheses was original and transformed to log" X+1 for analysis

Table 2. Effect of herbicides on weed density, total dry weight and weed control efficiency (WCE) at 60 days after transplanting

Treatment	Dose (g/ha)	Weed density (no./m^2) Grassy weeds				Non-grassy weeds			Total dry weight (g/m^2)	WCE (%)
		E. colona	*E. crus-galli*	*L. chinensis*	*I. rugosum*	*C. axillaris*	*C. difformis*	*F. miliaceae*		
Pretilachlor (SS)	500	4.4(18.7)	2.8(6.7)	2.1(3.3)	1.0(0.0)	2.8(6.7)	3.2(9.3)	2.2(4.0)	6.8(44.6)	68.9
Pretilachlor (SS)	750	3.4(10.7)	2.2(4.0)	1.0(0.0)	1.0(0.0)	2.4(4.7)	2.8(6.7)	1.5(1.3)	5.2(26.0)	81.9
Pretilachlor (SS)	1000	2.8(6.7)	1.4(1.3)	1.0(0.0)	1.0(0.0)	2.4(4.7)	2.5(5.3)	1.5(1.3)	4.4(19.2)	86.6
Pretilachlor (SS)	1500	2.8(6.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.8(6.7)	2.2(4.0)	1.0(0.0)	4.1(16.1)	88.8
Pretilachlor (MS)	750	3.9(14.7)	2.8(6.7)	1.0(0.0)	1.0(0.0)	2.4(4.7)	2.4(4.7)	1.0(0.0)	5.7(32.3)	77.5
Butachlor	1250	3.8(13.3)	1.9(2.7)	2.4(4.7)	1.0(0.0)	2.5(5.3)	2.2(4.0)	2.4(4.7)	6.4(40.4)	71.9
Hand weeding (2)	30&60 DAT	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.4(4.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.2(4.0)	97.2
Weedy check		4.9(22.7)	4.3(17.3)	3.1(8.7)	3.9(14.7)	2.5(5.3)	6.1(37.3)	4.1(16.0)	11.9(143.8)	-
LSD (P=0.05)		0.5	0.5	0.3	0.2	0.4	0.7	0.5	1.3	-

SS- Sponsor sample, MS- Market sample, DAT- Days after transplanting, WCE- Weed control efficiency, Values in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis.

Among the different doses of pretilachlor (SS), applications at 1500 as well as 1000 g/ha were found comparable and superior to rest of the doses in controlling the total weed density at both the stages. Whereas, lower dose of pretilachlor (SS) applied at 500 g/ha was found inferior for the same. Sponsor as well as market sample of pretilachlor applied at 750 g/ha were found comparable with each other in minimizing the total weed density (Fig. 1).

Yield and yield attributing characters

All the treatments found significant towards yield of transplanted rice while had no significant effect on number of panicles (no./m^2) and 1000 grain weight (g). However, grain yield under all the herbicidal treatments was significantly superior to the uncontrolled one. Weeds in weedy plot resulted 38.5% reduction in grain yield as compared to butachlor (1250 g/ha). Reduction of 37.5% of grain yield was recorded in uncontrolled plot in comparison to highest dose of pretilachlor (SS) at 1500 g/ha. This reduction in yield was mainly due to highest

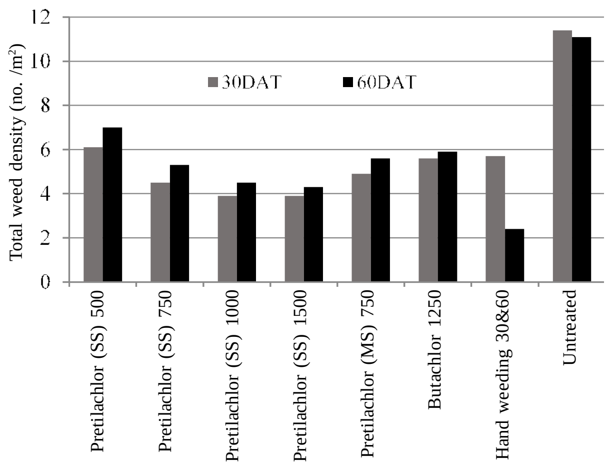

Fig. 1. Effect of treatments on total weed density at 30 and 60 DAT

infestation of weeds. Similar findings have also been reported by Bahar and Rashid (2013).

Among the different herbicidal treatments, maximum net return (` 84790) and benefit: cost ratio (2.63) was gained by the application of pretilachlor at

Table 3. Effect of herbicides on growth yield, yield attributes and economics of rice crop

Treatment	Dose (g/ha)	Panicles (no./m^2)	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Yield increase % over weedy check	Cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C Ratio
Pretilachlor (SS)	500	256	26.7	5.5	9.9	52.1	32.05	109.45	77.40	2.41
Pretilachlor (SS)	750	258	27.4	5.9	10.5	62.0	32.20	116.99	84.79	2.63
Pretilachlor (SS)	1000	261	27.2	5.9	10.6	62.2	32.60	117.34	84.74	2.60
Pretilachlor (SS)	1500	272	27.5	5.8	10.4	60.0	33.15	115.28	82.13	2.48
Pretilachlor (MS)	750	262	27.0	5.6	10.2	54.9	32.32	111.86	79.53	2.46
Butachlor	1250	258	27.4	5.9	10.0	62.5	32.25	115.24	82.99	2.57
Hand weeding (2)	30 and 60 DAT	273	27.5	5.9	10.7	62.0	34.00	117.69	83.69	2.46
Weedy check	-	218	24.9	3.6	6.7	-	31.00	72.41	41.41	1.34
LSD (P=0.05)	-	NS	NS	387.3	862.1	-				

SS- Sponsor sample, MS- Market sample, DAT- days after transplanting, NS- non significant

750 g/ha due to increased grain yield and lesser cost of the herbicides.

It may be concluded that application of pretilachlor applied at 750 g/ha may be recommended for achieving higher grain yield, net return and B:C ratio.

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SUMMARY

A field trial was conducted to evaluate different doses of herbicides for weed control in transplanted rice during *Kharif* season 2014 at Pantnagar. Experiment was laid out in a randomized block design with three replications. Results showed that all the herbicides were effective in reducing the total density of weeds at all the growth stages and enhancing the rice yield. Application of pretilachlor (SS) 1000 and 1500 g/ha applied as pre-emergence proved to be most effective followed by its lower doses applied at 750 g/ha in decreasing the density of weeds (30 and 60 DAT) than the other treatments. None of the herbicides found phytotoxic to rice crop.

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Short communication

Occurrence of fringe-rush in *Kharif* rice in Assam

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Key words: *Kharif* season, *Fimbristylis*, Transplanted rice, Weed

Out of about 14 different rice cultures practiced in the plains of river Brahmaputra and Barak in Assam, transplanted *Kharif* rice is most commonly practiced. Presently 23.2 lakh hectares (Islam 2012) land is under rice cultivation in the state Assam and weed cause up to 60% yield loss (Anon. 1995 to 2015). Sedges are considered as the integral part of the vegetation of rice ecosystems in the entire Eastern and North-Eastern India to China and South East Asia (Londo *et al.* 2006, Rao *et al.* 2007). The members of *Cyperaceae* are the common occurrence in moist upland to medium low land situations; among them *Fimbristylis* spp. fringe-rush were reported as most problematic weeds of different irrigated and non-irrigated crops in India (Anon. 1995 to 2015, Murty and Venkaiah 2011). Apart from India, *F. miliacea* is among the three most dominant weeds in the rice fields of Bangladesh, Ceylon, Guyana, Indonesia, Malaysia, Surinam and Taiwan (Rao *et al.* 2007).

Depending upon the management practices and the predominant weed flora, the yield loss caused by weeds varied from one place to another. In India, 30-90% loss occurred in rice production due to weed infestation in the critical period of the crop growth. Ramzan (2003) reported 48% yield reduction due to weed in transplanted rice. Juraimi *et al.* (2013) reported *Fimbristylis miliacea* as a notorious weed of rice ecosystems causing 9-43% reduction of rice yield offering high magnitude competition for nutrients and space, in addition to its allelopathic effect on rice (Siddique *et al.* 2013). Based on such a background, the present study was undertaken to explore the dominant weed flora in transplanted *Kharif* rice in Jorhat district of Assam and to determine the status of *Fimbristylis* amongst the weeds.

The study area was situated in the Upper Brahmaputra Valley Zone of Assam (20°10A N – 27°20A N, to 93°37A E – 93°57A E) and comprised of 2851.00 sq. km area, where rice is the only major crop. The area experienced sub-tropical climate with average temperature ranged from 8 to 36 °C and around 2100 mm average rainfall. The relative humidity varied from 78 to 98%.

The present study was carried out in all the eight developmental blocks (DB) of Jorhat district, Assam during 2014-15. Farmers and agricultural officers of different regions were interviewed and based on their opinion study sites were selected; finally, 32 rice fields were surveyed (4 fields from each DB) in entire Jorhat district. During the survey, the age of the rice seedling was 45-60 days after transplanting and the water level was 5-10 cm above ground. Both quadrat and line transect methods (Akwee *et al.* 2010) were used to collect data from study area. Quadrats of 1 × 1 m size were plotted in random systematic design for collection of data from the study area by following the method as described by Kent and Coker (1994). Line transacts were laid towards the centre of each crop field. 8 to 12 numbers of quadrats (Fig. 1) were plotted in each field (altogether 290 quadrat were placed in the entire Jorhat district). All the plant species, enumerated in each quadrat, identified and counted. Herbarium specimens were prepared by following standard method given by Jain and Rao (1977). The mounted specimens were identified consulting different regional floras and standard Herbaria (‘Assam’ and ‘Cal’).

Ecological analysis of weed flora was done following quantitative measures as density,

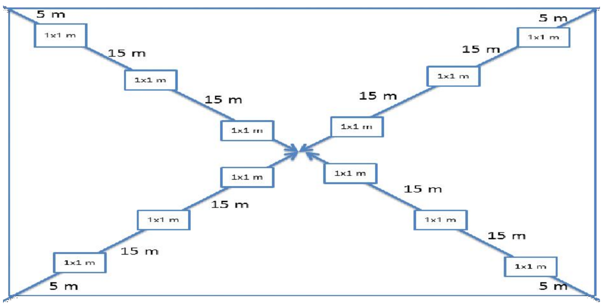

Fig. 1. Diagrammatic layout of quadrat for data collection

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frequency, and dominance and their absolute and relative values the importance value index (IVI) was calculated from the relative values. Summed dominance ratio (SDR) was calculated to simplify the dominance spectrum (IVI) of the weed species (Raju 1987).

A total of 58 different weed species, belonging to18 sedges, 11 grasses and 29 broad-leaved weed (BLW) species, were recorded in transplanted *Kharif* rice in Jorhat district during the study (Table 1). The five dominating families in the studied area were Cyperaceae, Poaceae, Onagraceae, Asteraceae and Fabaceae.

Status of sedges amongst the weeds

The study revealed that sedges were the dominant group of weeds in six out of the eight developmental blocks. The East Jorhat DB had the highest species diversity (13 species) (Fig. 2) and dominance (76.2%), which was 82.8% more than next largest group (BLW) (Fig. 3). This DB shared almost half of its border with the Nagaland Hills and nearly 50% of its land area is covered by forest and tea gardens, unlike the other developmental blocks. That might be one of the factors responsible for the dominance of sedges in the rice fields. Next highest sedge diversity (11 species) was recorded in Jorhat and Titabar developmental blocks, which are adjacent to East Jorhat DB and possessed considerable uplands covered with homestead woodlands and tea gardens. Sedge dominance in Jorhat DB was 51.73% higher than the BLW in the rice fields.

In the Central Jorhat DB, where the rice fields experience regular flooding from streams and tributaries, the species diversity and dominance of sedges were slightly lesser than the BLW. Species diversity of sedges in Majuli was considerably lower; it was 8 and 5 in Ujoni Majuli DB and Majuli DB, respectively. The dominance of sedges was almost equal to BLW in the Majuli DB, where the rice fields were affected by flood from river Brahmaputra and Lohit. On the other hand, in Ujoni Majuli DB, where the river originated flood was least in rice fields, the grasses were more dominant than the sedges and BLW weeds.

Status of *Fimbristylis* among the sedges

All together, 11 species belonging to *Cyperaceae* and one species belonging to *Xyridaceae* represented the sedge populations in the study area. Amongst sedges, *Fimbristylis* was the largest genus, with 5 species: *F. miliacea* (L.) Vahl, *F. littoralis* Gaudich., *F. bisumbellata* (Forssk.) Bubani, *F. tristachya* R. Br. and *F. ovata* (Burm. f.) J. Kern. The key for identification of these species indicated that the closely identical *F. miliacea* and *F. littoralis* can be identified in the field condition by carefully observing the stem. The stem is triangular in *F. littoralis* and triquetrous in *F. miliacea*. The five *Fimbristylis* species can be distinguished in the field condition by following the key:

Taxonomic "Key" for identification of *Fimbristylis* species:

1 a. Stem and leaves are extremely narrow and thread like, (plant height less than 12 cm.) ..…………………………………………***F. ovata***

1 b. Stem and leaves are wider, never thread like, (plant height more than 12 cm.) …….......... (2)

2 a. Anthela often reduced to 1-2 spikelets, rarely more; bract setaceous, as long as or shorter than spikelet … ……….……...….…. ***F. tristachya***

2 b. Anthela with many spikelets; bracts usually foliaceous ……………...….……………….... (3)

3a. Spikelet 2-5 mm long, in supra-decompound (less often decompounds) anthella; stigma 3; nuts trigonal .... (4)

3b. Spikelets longer than 6 mm, in compound or decompounds (less often supra-decompound) anthella; stigma 2; nuts lenticular ....…***F. bisumbellata***

4 a. Stem triangular, Spikelet subglobose, obtuse; leaves equitant laterally flattened .. ***F. littoralis***

4 b. Stem triquetrous, Spikelet ovoid-oblong, acutish; leaves not equitant dorsoventrally flattened………………………***F. miliacea***

Out of five species of *Fimbristylis, F. miliacea* was recorded amongst the four dominant weeds in North West Jorhat, East Jorhat and Jorhat developmental blocks (Table 2). In the rice fields of Kaliapani DB and Ujoni Majuli DB *F. littoralis* was one of the four most dominant species. Prevalence of *Fimbristylis* in Majuli DB and Titabar DB was much lower compared to other developmental blocks.

In this study, *F. miliacea* was found to have the highest density in entire Jorhat District while *F. ovata* has the lowest (Fig. 3). Out of five *Fimbristylis* species, *F. miliacea* and *F. littoralis* jointly dominated the weed vegetation of transplanted *Kharif* rice in the entire district during critical period of crop weed competition. On the contrary, the moderately deep rooted problematic weed *F. bisumbellata* showed its presence in East Jorhat, Ujoni Majuli, Kaliapani, Titabar and Central Jorhat developmental blocks. The

Table 1. Estimated dominance indicating parameters of weed species in the study area

Species	Relative Density	Relative Frequency	Relative dominance	IVI	SDR
Cyperus brevifolius (Rottb.) Hassk.	0.15	0.46	0.27	0.88	0.29
Cyperus compressus L.	0.07	0.14	0.72	0.92	0.31
Cyperus difformis L.	0.32	1.30	3.50	5.12	1.71
Cyperus digitatus Roxb.	0.07	1.30	0.76	2.13	0.71
Cyperus haspan L.	1.11	3.29	0.48	4.88	1.63
Cyperus iria L.	4.45	2.78	17.36	24.58	8.19
Cyperus tenuispica Steud.	0.79	3.06	0.34	4.18	1.39
Xyris capensis Thunb.	0.09	0.46	0.04	0.59	0.20
Eleocharis acicularis (L.) Roem. & Schult.	25.35	4.68	2.75	32.78	10.93
Eleocharis acutangula (Roxb.) Schult.	2.91	2.18	5.05	10.13	3.38
Eleocharis dulcis (Burm.f.) Trin. ex Hensch.	1.72	1.85	2.99	6.57	2.19
Eleocharis geniculata (L.) Roem. & Schult.	4.19	2.13	1.82	8.13	2.71
Fimbristylis bisumbellata (Forssk.) Bubani	0.34	1.48	0.59	2.42	0.81
Fimbristylis littoralis Gaudich.	6.31	3.98	2.74	13.02	4.34
Fimbristylis miliacea (L.) Vahl	9.10	9.81	3.95	22.86	7.62
Fimbristylis ovata (Burm.f.) J.Kern	0.12	0.19	0.01	0.32	0.11
Fimbristylis tristachya R.Br.	0.85	1.34	1.47	3.66	1.22
Scirpus juncoides Roxb.	4.60	4.44	7.98	17.02	5.67
Cynodon dactylon (L.) Pers.	1.45	1.62	0.63	3.70	1.23
Cyrtococcum patens (L.) A.Camus	0.04	0.09	0.02	0.15	0.05
Dichanthium annulatum (Forssk.) Stapf	1.75	2.27	0.76	4.78	1.59
Digitaria setigera Roth	1.10	1.30	0.48	2.87	0.96
Echinochloa colona (L.) Link	0.01	0.14	0.02	0.17	0.06
Eragrostis unioloides (Retz.) Nees ex Steud.	2.18	1.53	0.95	4.65	1.55
Isachne himalaica Hook.f.	12.62	6.39	5.47	24.49	8.16
Oryza rufipogon Griff.	0.13	0.51	0.23	0.87	0.29
Paspalum conjugatum P.J.Bergius	0.65	0.65	1.12	2.42	0.81
Paspalum distichum L.	0.08	0.46	0.13	0.67	0.22
Sacciolepis myosuroides (R.Br.) A.Camus	1.16	2.45	2.02	5.64	1.88
Ammannia peploides Spreng.	0.01	0.23	0.00	0.24	0.08
Anthocephalus cadamba (Roxb.) Miq.	0.03	0.51	0.13	0.67	0.22
Alternanthera sessilis (L.) R.Br. ex DC.	1.18	1.94	4.61	7.74	2.58
Ageratum houstonianum Mill.	0.31	1.25	2.18	3.74	1.25
Corchorus capsularis L.	0.01	0.19	0.04	0.23	0.08
Commelina diffusa Burm.f.	0.00	0.09	0.01	0.10	0.03
Drymaria cordata (L.) Willd. ex Schult.	0.01	0.09	0.03	0.13	0.04
Desmodium triflorum (L.) DC.	0.14	0.79	0.06	0.99	0.33
Eriocaulon abyssinicum Hochst.	1.84	0.93	0.80	3.56	1.19
Eclipta prostrata (L.) L.	0.00	0.05	0.02	0.07	0.02
Hydrolea zeylanica (L.) Vahl	0.02	0.46	0.03	0.51	0.17
Ludwigia perennis L.	0.03	0.28	0.21	0.52	0.17
Ludwigia linifolia Poir.	0.75	5.79	5.21	11.74	3.91
Limnophila heterophylla (Roxb.) Benth.	0.01	0.28	0.00	0.29	0.10
Limnophila heterophylla (Roxb.) Benth.	0.03	0.09	0.01	0.14	0.05
Ludwigia adscendens (L.) H.Hara	0.29	0.42	2.03	2.74	0.91
Lindernia anagallis (Burm.f.) Pennell	0.59	1.71	1.03	3.34	1.11
Marcelia minuta L.	1.22	2.73	0.53	4.49	1.50
Murdannia nudiflora (L.) Brenan	0.53	1.62	0.93	3.08	1.03
Monochoria vaginalis (Burm.f.) C.Presl	0.07	1.06	2.07	3.20	1.07
Melochia corchorifolia L.	0.00	0.14	0.01	0.15	0.05
Oldenlandia diffusa (Willd.) Roxb.	0.70	3.19	0.31	4.20	1.40
Oxalis debilis Kunth	0.21	1.16	0.37	1.74	0.58
Phyllanthus niruri L.	0.04	0.74	0.25	1.03	0.34
Rotala rotundifolia (Buch.-Ham. ex Roxb.) Koehne	4.64	6.71	8.05	19.41	6.47
Rotala indica (Willd.) Koehne	3.51	4.72	6.09	14.32	4.77
Scoparia dulcis L.	0.01	0.14	0.01	0.16	0.05
Sonchus oleraceus (L.) L.	0.00	0.14	0.00	0.14	0.05
Unknown species	0.10	0.28	0.38	0.76	0.25

Table 2. Estimated dominance indicating parameters of weed species in transplanted *Kharif* rice of eight developmental blocks of Jorhat district (Assam) during 2015

Weed groups and most dominant species		Relative Density	Relative Frequency	IVI	SDR
N.W. Jorhat DB					
1	*Cyperus iria* L.	25.96	6.97	89.54	29.85
2	*Fimbristylis miliacea* (L.) Vahl	20.89	11.85	37.80	12.60
3	*Ludwigia linifolia* Poir.	1.39	9.06	15.83	5.28
4	*Isachne himalaica* Hook.f.	9.93	8.36	20.70	6.90
Central Jorhat DB					
1	*Eleocharis acicularis* (L.) Roem. & Schult.	52.96	9.94	71.92	23.97
2	*Rotala rotundifolia* (Buch.-Ham. Ex Roxb.) Koehne	6.54	6.41	30.80	10.27
3	*Rotala indica* (Willd.) Koehne	7.42	6.41	34.06	11.35
4	*Eriocaulon abyssinicum* Hochst.	8.45	6.41	20.62	6.87
East Jorhat DB					
1	*Eleocharis acicularis* (L.) Roem. & Schult.	43.93	7.85	58.23	19.41
2	*Eleocharis acutangula* (Roxb.) Schult.	11.50	16.23	54.72	18.24
3	*Fimbristylis miliacea* (L.) Vahl	8.94	13.61	27.79	9.26
4	*Scirpus juncoides* Roxb.	15.06	13.61	64.01	21.34
Jorhat DB					
1	*Fimbristylis miliacea* (L.) Vahl	18.45	10.06	33.04	11.01
2	*Eleocharis acicularis* (L.) Roem. & Schult.	9.01	3.25	12.82	4.27
3	*Cyperus iria* L.	23.34	6.21	81.04	27.01
4	*Isachne himalaica* Hook.f.	9.01	7.40	18.62	6.21
Kaliapani DB					
1	*Rotala rotundifolia* (Buch.-Ham. ex Roxb.) Koehne	8.83	6.80	34.66	11.55
2	*Rotala indica* (Willd.) Koehne	6.80	8.06	29.53	9.84
3	*Fimbristylis littoralis* Gaudich.	17.40	7.30	34.09	11.36
4	*Eleocharis acicularis* (L.) Roem. & Schult.	19.63	7.56	29.83	9.94
Majuli (Lower) DB					
1	*Cyperus difformis* L.	6.31	8.42	44.69	14.90
2	*Scirpus juncoides* Roxb.	14.24	11.39	36.45	12.15
3	*Alternanthera sessilis* (L.) R.Br. ex DC.	20.36	7.43	62.61	20.87
4	*Cynodon dactylon* (L.) Pers.	20.05	9.90	33.76	11.25
Titabar DB					
1	*Eleocharis geniculata* (L.) Roem. & Schult.	24.62	8.10	46.25	15.42
2	*Eragrostis unioloides* (Retz.) Nees ex Steud.	15.49	8.45	32.45	10.82
3	*Isachne himalaica* Hook.f.	31.43	4.93	53.64	17.88
4	*Ludwigia adscendens* (L.) H.Hara	2.13	3.17	24.08	8.03
Ujoni Majuli DB					
1	*Fimbristylis littoralis* Gaudich.	23.82	2.68	38.29	12.76
2	*Paspalum conjugatum* P.J.Bergius	9.60	6.71	35.33	11.78
3	*Isachne himalaica* Hook.f.	35.55	10.07	63.21	21.07
4	*Rotala rotundifolia* (Buch.-Ham. ex Roxb.) Koehne	3.81	10.07	21.42	7.14

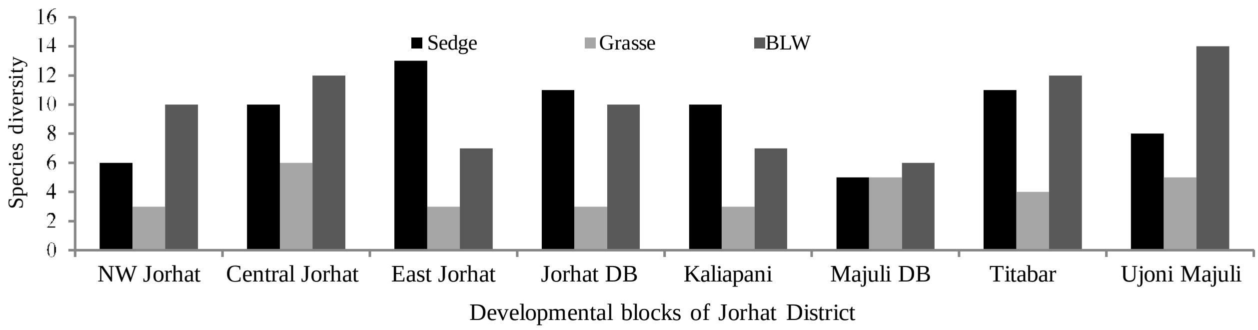

Fig. 2. Sedges, grasses and broad-leaved weed (BLW) weeds species diversity in transplanted *Kharif* rice in eight developmental blocks of Jorhat district, Assam

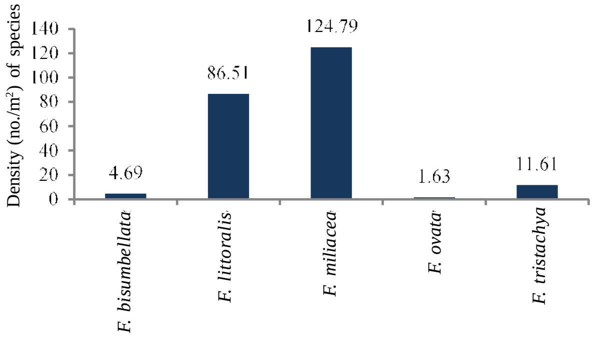

Fig. 3. Density (no./m^2) of *Fimbristylis* species in Jorhat District

other two *Fimbristylis* species namely *F. ovata* and *F. tristachya* had occasional appearance in the rice fields.

SUMMARY

Among the sedges *Fimbristylis* are considered as very problematic weed in both irrigated and non irrigated rice ecosystems as it was reported to reduce rice yield by 9-43%. This work was undertaken, in 2014 and 2015, to assess the status of *Fimbristylis* species in transplanted *Kharif* rice at Jorhat district, Assam. Weed flora was surveyed following standard weed survey protocol. A taxonomic key for identification of these 5 taxa was developed for their easy reorganization in field condition. The moderately deep rooted problematic weed *F. bisumbellata* recorded in East Jorhat, Ujoni Majuli, Kaliapani, Titabar and Central Jorhat developmental blocks, as one of the most problematic weeds of upland autumn rice and other field crops of marshy situation during summer season. High frequency and population density of *Fimbristylis* species may be attributed to suitability of agro-climatic condition of Jorhat district for their growth and development and their occurrence has always caused yield reduction in rice due to higher magnitude of competition for nutrient and space in addition to its allelopathic effect on rice.

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Short communication

Bio-efficacy of post-emergence herbicides in transplanted rice

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Pre-emergence herbicides with high application rates are commonly used for the management of weeds in transplanted rice. However, recent trend in chemical weed management in rice is the use of low dose high efficacy herbicides, which will not only reduce the dose but also make the application easier and economical to the farmer. With this back ground, the present investigation was undertaken to assess the bio efficacy of two new generation post-emergence herbicides, *viz*. fenoxaprop-p-ethyl and carfentrazone-ethyl in transplanted rice.

A field investigation was conducted in farmer's field in Kanjirathady Padashekaram in Kalliyoor panchayat of Nemom block of Thiruvananthapuram district of Kerala. The soil was sandy clay loam in texture, slightly acidic in reaction, medium in available N and K and high in available P and organic carbon content. The experiment was conducted during third crop season from December 2011 to April 2012 in randomized block design with eight treatments and three replications. The treatments comprised of fenoxaprop-p-ethyl 60 and 90 g/ha, carfentrazone-ethyl 20 and 25 g/ha, fenoxaprop-p-ethyl 60 g/ha + carfentrazone-ethyl 20 g/ha, bispyribac-sodium 30 g/ha, hand weeding twice at 20 and 40 DAT and weedy check. The gross plot size was 20 m^2 (5 x 4 m) and the net plot area was 4.2 x 3.6 m. Medium duration rice variety '*Uma* (*MO 16*)' was used as the test crop. Eighteen days old seedlings were transplanted in the main field two to three seedlings per hill with a spacing of 20 x 10 cm. The fertilizer recommendation adopted was 90:45:45 kg N, P and K/ha. The tested herbicides were applied at 20 DAT using knapsack sprayer fitted with flat nozzle. The quantity of spray fluid used for the study was 500 l/ha.

Observation on weed density was recorded by placing a quadrate of size 0.5 m x 0.5 m at 40 and 60, and total weed dry weight was recorded by uprooting the weeds in the same area where weed density was recorded at 60 DAT. Weed control efficiency and weed index were worked out by standard procedures. The data on weed density and weed dry weight were transformed using square root transformation. Productive tillers/m^2 was recorded by placing a quadrate of size 0.5 x 0.5 m randomly at two spots in the net plot area and the mean values were worked out. Grain (1000) weight from each plot was also recorded. The grain yield from the net plot area of each treatment was recorded at 14% moisture level and expressed in kg/ha. The data were statistically analyzed using Analysis of Variance technique (ANOVA).

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Weed flora

The major weed flora present in the experimental area were *Echinochloa colona* (L). Link (jungle rice) among the grasses, *Cyperus difformis* L. (slender sedge) and *Scirpus grossus* L.f. (Greater club rush) among the sedges and *Limnocharis flava* (L.) Buchenau (water cabbage), *Ludwigia parviflora* Roxb. (water primrose), *Ipomoea aquatica* Forsk. (water spinach), *Lindernia rotundifolia* blanc vert (Baby tears), *Salvinia molesta* D.S.Mitch. (Kariba weed), *Marsilia quadrifolia* Linn. (Airy pepper wort) and *Pistia stratiotes* L. Royale (water lettuce) among the broad-leaf weeds.

Effect of weed density

The weed control treatments significantly influenced the total density of weeds at 40 and 60 DAT (Table 1). At 40 DAT, the lowest weed density was recorded by carfentrazone-ethyl 25 g/ha, which was at par with bispyribac-sodium 30 g/ha and carfentrazone-ethyl 20 g/ha. At 60 DAT, the lowest total density of weeds was recorded by carfentrazone-ethyl 20 g/ha, which was at par with its higher dose 25 g/ha and bispyribac-sodium 30 g/ ha. Among the weed control treatments, the highest total weed dry weight and the lowest weed control efficiency were recorded by fenoxaprop-p-ethyl60 g/ ha. The highest total weed density, weed dry weight and the lowest weed control efficiency recorded in fenoxaprop-p-ethyl 60 and 90 g/ha might be due its lesser efficacy in controlling sedges and broad-leaf weeds, the predominant group of weed flora present in the experimental field. The effectiveness of carfentrazone-ethyl for weed control in transplanted rice was also reported by Glomski and Getsinger 2006). Yadav *et al*. (2009) reported the effectiveness of bispyribac-sodium against weeds in transplanted

Table 1. Effect of weed control treatments on total weed density and dry weight, weed control efficiency, weed index, yield attributes, grain yield and B:C ratio

Treatment	Total weed density (no./m^2)		Total weed dry weight (g/m^2)	WCE (%)	Weed index	Panicles /m^2	1000 grain weight (g)	Grain yield (t/ha)	B: C ratio
	40 DAT	60 DAT							
Fenoxaprop-p-ethyl 60 g/ha	7.54 (56)	9.62 (92)	8.28 (68)	42.58	28.54	388	20.97	4.96	1.50
Fenoxaprop-p-ethyl 90 g/ha	6.62(43)	9.65(93)	7.94(62)	47.53	19.27	417	21.23	5.60	1.65
Carfentrazone ethyl 20 g/ha	4.06(16)	5.46(29)	4.64(21)	82.32	6.03	515	21.99	6.68	2.00
Carfentrazone ethyl 25 g/ha	3.39(11)	5.58(30)	4.75 (22)	81.53	0.00	537	22.12	6.79	2.03
Fenoxaprop-p-ethyl 60 g/ha + carfentrazone-ethyl 20 g/ha	5.70(32)	6.57(43)	5.56(30)	74.57	16.61	449	21.27	5.79	1.72
Bispyribac sodium 30 g/ha	3.44(11)	5.84(34)	5.05(25)	79.03	7.79	477	21.56	6.40	1.86
Hand weeding twice at 20 and 40 DAT	8.24(67)	7.27(52)	6.84(45)	61.80	11.98	463	21.40	6.11	1.46
Weedy check	12.09(146)	12.72(161)	10.95(119)	-	42.66	376	20.72	3.98	1.27
LSD (P=0.05)	0.274	0.236	0.297	9.107	3.966	45.07	0.854	0.36	0.09

DAT- Days after transplanting, WCE- Weed control efficiency, Data on weed count and dry weight subjected to $\sqrt{x+0.5}$ transformation and values in parentheses are original values

rice. The weedy check recorded the highest total weed density at 40 and 60 DAT and total weed dry weight at 60 DAT. Similar observations were made by Subramanian *et al.* (2006) and Dixit and Varshney (2008).

Yield attributes and yield

The yield attributes were also significantly influenced by the weed control treatments. Carfentrazone-ethyl 25 g/ha recorded the highest value of panicles/m^2 and 1000-grain weight, which was at par with its lower dose (20 g/ha) and bispyribac-sodium 30 g/ha. The better expression of yield attributes in the above treatments was mainly due to the broad spectrum control of weeds resulting in comparatively low competition from weeds. The competition free environment might have allowed the crop to express its full genetic potential.

The highest grain yield (6.79 t/ha) was recorded by carfentrazone-ethyl 25 g/ha, which was statistically at par with its lower dose (20 g/ha) and bispyribac-sodium 30 g/ha. The percentage increase in grain yield in carfentrazone-ethyl 25 and 20 g/ha and bispyribac-sodium 30 g/ha over weedy check were 70.33, 67.70 and 60.79, respectively. Hand weeding treatment recorded a grain yield of 6.11 t/ha which was at par with bispyribac-sodium 30 g/ha. In rice, grain yield is the function of productive tillers per m^2, number of grains per panicle, percentage filled grains and thousand grain weight. The higher values for these yield attributes registered in the treatments, carfentrazone-ethyl at 25 and 20 g/ha and bispyribac-sodium 30 g/ha might have contributed to higher grain yield in these treatments.

Weed index gives a measure of yield loss due to weeds. Among the weed control treatments, the highest weed index was recorded by fenoxaprop-p-ethyl 60 g/ha and the lowest in carfentrazone-ethyl 25 and 20 g/ha. Season long weed infestation in weedy check caused a yield reduction of 42.66%. Weed control treatments significantly influenced the B: C ratio also. The highest B:C ratio (2.03) was recorded in carfentrazone-ethyl at 25 g/ha and it was at par with its lower dose (20 g/ha). Similar results were also reported by Raj and Syriac (2015).

SUMMARY

A field experiment was conducted to assess the bio efficacy of two new generation post emergence herbicides, *viz.* fenoxaprop-p-ethyl and carfentrazone ethyl in transplanted rice along with bispyribac-sodium, hand weeding twice and weedy check. The weed flora was dominated by broad-leaf weeds, followed by sedges and grasses. The lowest total weed density and weed dry weight, the highest weed control efficiency, net returns and B: C ratio, were recorded in carfentazone-ethyl 25 g/ha, which was at par with its lower dose (20 g/ha).

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Short communication

Impact of different herbicides and their combinations on production economics of winter rice in West Bengal

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Rice is the life-blood of the Asia-Pacific Region where 56% of humanity lives, producing and consuming more than 90% of the world rice. Rice contributes 43% of total food grain production and 46% of the cereal production of India. Rice is the staple food of about 3.5 billion people and demand is expected to continue to grow as population increases (GRiSP 2013). Among different states of India, West Bengal is the leading state in rice production. During the year 2007-08, the average productivity of *Aus*, *Aman* and *Boro* was 2009 kg/ha, 2.31 t/ha and 3.26 t/ha, respectively and the state average of rice productivity was 2.57 t/ha (Samanta and Mallik 2004). Weeds are greatest constraint in rice crop and impose a serious negative effect on crop production and market value. On an average, farmers lose 37% of their rice yield to pests and diseases, and that these losses can range between 24% and 41% depending on the production situation (IRRI 2015). Herbicides are being widely looked as an alternatve of manual labour. Hence, different herbicides were tested to see their effect on economics of rice production.

The field experiment was conducted at the Instructional Farm of Bidhan Chandra Krishi Viswavidyalaya, new alluvial zone (NAZ) of West Bengal under the sub-tropical humid climate during *Kharif* Season (July to November) of 2015 on soil with medium fertility status, having sandy loam in texture (pH- 6.7). The experiment was laid out at randomized block design (RBD) having thirteen treatments, *viz*. butachlor 1.5 kg/ha (granules) as pre-emergence (PE) at 2 days after transplanting (DAT) with one hand weeding (40 DAT), pyrazosulfuron-ethyl 25 g/ha as PE (2 DAT) with one hand weeding (40 DAT), bensulfuron-methyl + pretilachlor 10 kg (granules)/ha as PE (2 DAT) with one hand weeding (40 DAT), bispyribac-sodium 10% SC 25 g/ha as post-emergence (POE) at 20 days after transplanting (DAT), metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as POE (20 DAT), butachlor (PE - 2 DAT) + bispyribac-sodium (POE – 20 DAT), pyrazosulfuron-ethyl (PE - 2 DAT) + bispyribac-sodium (POE – 20 DAT), (bensulfuron-methyl + pretilachlor) as PE (2 DAT) + bispyribac-sodium (POE - 20 DAT), butachlor (PE - 2DAT) + (metsulfuron-methyl + chlorimuron-ethyl as POE (20 DAT)), pyrazosulfuron-ethyl (PE-2 DAT) + (metsulfuron-methyl + chlorimuron-ethyl as POE (20 DAT)), (bensulfuron-methyl 0.6% + pretilachlor as PE - 2 DAT) + (metsulfuron-methyl + chlorimuron-ethyl as POE (20 DAT)), two hand weeding at 20 and 40 DAT, weedy check, replicated thrice. Herbicides were sprayed using knapsack sprayer fitted with a flat fan nozzle at a spray volume of 500 l/ha except the granular herbicides, which were applied by mixing with sand 50 kg/ha. The variety '*Swarna (MTU-7029)*' was grown with recommended package of practices followed uniformly.

The observations on yield and yield attributes like grain yield, straw yield, no. of panicles/m^2, filled grains/panicle and 1000-seeds weight were recorded at harvest. Weed and crop biomass at different growth stages of rice, weed index and economics were worked out. All the collected data was analyzed statistically to the design RBD by following the procedure laid out by Gomez and Gomez (1984).

The observations revealed that the predominant weed species were *Cynodon dactylon*, *Leersia hexandra*, *Echinochloa colona*, *Commelina benghalensis*, *Brachiaria mutica*, *Echinochloa Crusgalli*, *Cyperus rotundus*, *Cyperus difformis*, *Fimbristylis dichotoma*, *Scirpus validus*, *Ammannia baccifera*, *Ageratum haustonianum*, *Spilanthus paniculata*, *Marsilea quadrifolia*, *Scoparia dulcis*, *Sphenoclea zeylenica*, *Xanthium strumarium*, *Ludwigia parviflora*, *Ipomoea reptens*, *Lindernia ciliata*, and *Nymphoides indica*.

Effect on rice biomass

Dry matter accumulation increased progressively from 30 to 60 DAT. But, variations were observed in different treatments. The better weed control made the availability of soil moisture,

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nutrients *etc*. to crop by reducing the crop-weed competition. Twice hand weeding at 20 and 40 DAT treatment resulted maximum biomass accumulation of rice crop followed by bensulfuron-methyl + pretilachlor 10 kg/ha as PE 2 DAT 1 HW 40 DAT and bensulfuron-methyl + pretilachlor as PE 2 DAT + bispyribac-sodium POE at 20 DAT. Reddy *et al*. (2012) reported that pre-emergence application of bensulfuron methyl + pretilachlor 75 + 750 g/ha at 5 DAT effectively controlled sedges, grasses and broad-leaf weeds (Table 1).

Effect on rice yield attributes

During the first year of the experiment, statistically significant differences were noticed between treated and untreated plots (Table 1). There were no significant differences among different treatments because it was a genetical character and thus was not affected by crop-weed competition or moisture and nutrients present into the soil.

Hand weeding twice at 20 and 40 DAT, bensulfuron-methyl + pretilachlor as PE with one hand weeding at 40 DAT, combined application of bensulfuron-methyl + pretilachlor as PE + bispyribac -sodium as POE gave more numbers of panicles/m^2 and filled grains/panicles (Table 1). Although the number of panicles was not much lesser in control (weedy check), yet it was significantly different from the treated plants.

Effect on rice yield

Highest rice straw and grain yield (5.80 and 4.53 t/ha) was recorded with hand weeding twice at 20 and 40 DAT, which gave significantly higher grain yield of transplanted rice over all the treatments tested followed by bensulfuron-methyl + pretilachlor 10 kg/ ha as PE at 2 DAT + 1 HW at 40 DAT (5.57 and 4.20 t/ha) and bensulfuron-methyl + pretilachlor as PE at 2 DAT + bispyribac-sodium POE at 20 DAT (5.53 and 4.17 t/ha). All the cultural and herbicidal treatments gave significantly higher grain yield than weedy check. Hand weeding twice (20 and 40 DAT) performed best and increased the grain yield, the straw yield and the biological yield by 42, 24 and 32%, respectively over weedy check. Herbicide combinations (bensulfuron-methyl + pretilachlor as PE + bispyribac-sodium as POE also showed a broad spectrum management of both annual and perennial weeds. Similar observation was also made by Teja *et al.* (2015).

Economics

The application of bensulfuron-methyl + pretilachlor 10 kg (G)/ha as PE and metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as POE was the most cost saving and environmentally sound treatment followed by the application of PE (bensulfuron-methyl + pretilachlor) + POE (bispyribac-sodium). The maximum cost of cultivation was observed in hand weeding at 20 and 40 DAT compared to other treatments. Pre-emergence application of bensulfuron-methyl + pretilachlor 10 kg (G)/ha + one hand weeding at 40 DAT was also found to be effective in weed control. Similar results were also opined by Reshma *et al.* (2015). Among herbicidal treatments, the highest B: C

Table 1. Effect of weed control treatments on rice biomass and grain yield attributes

Treatment	Rice biomass (g/m^2)			Yield attributes		
	30 DAT	45 DAT	60 DAT	No. of panicles /m^2	No of filled grains /panicle	1000-seed weight (g)
Butachlor 1.5 kg/ha as PE at 2 DAT + 1 HW at 40 DAT	92.3	154.2	221.2	318.8	116.7	17.62
Pyrazosulfuron-ethyl 25 g/ha as PE at 2 DAT + 1 HW at 40 DAT	86.1	138.1	182.5	287.5	104.0	17.91
Bensulfuron-methyl + pretilachlor 10 kg/ha as PE at 2 DAT + 1 HW at 40 DAT	96.7	173.9	252.5	350.0	140.3	18.47
Bispyribac-sodium 25 g/ha as POE at 20 DAT	85.8	122.0	160.7	285.4	101.3	17.34
Metsulfuron-methyl + chlorimuron-ethyl 4 g/ha POE at 20 DAT	82.6	117.4	160.7	277.1	99.0	17.31
Butachlor 1.5 kg/ha (PE at 2 DAT) + bispyribac-sodium 25 g/ha (POE at 20 DAT)	77.6	109.6	150.2	245.8	83.7	17.31
Pyrazosulfuron-ethyl 25 g/ha (PE at 2 DAT) + bispyribac-sodium 25 g/ha (POE at 20 DAT)	90.5	145.8	194.8	310.4	114.3	17.66
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE 2 DAT) + bispyribac-sodium 25 g/ha POE - 20 DAT	95.2	162.2	231.8	331.3	138.3	17.85
Butachlor 1.5 kg/ha (PE at 2 DAT) + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha (POE 20 DAT)	80.0	113.1	155.7	264.6	91.7	17.32
Pyrazosulfuron-ethyl 25 g/ha (PE at 2 DAT) + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha (POE at 20 DAT)	89.2	143.0	190.5	304.2	108.0	17.59
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE 2DAT) + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha (POE 20 DAT)	93.2	156.7	223.8	325.0	135.8	18.38
Two hand weeding at 20 and 40 DAT	99.5	192.1	279.2	370.8	153.0	18.41
Weedy check	74.2	104.3	135.5	225.0	77.0	16.59
LSD (P=0.05)	3.48	11.07	13.99	19.34	11.15	NS

PE - Pre-emergence; POE - Post-emergence; DAT - Days after transplanting; HW - Hand weeding

Table 2. Effect of weed control treatments on rice yield, weed index and economics of rice production

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Weed index (%)	Return from straw (x10^3 `)	Return from grain (x10^3 `)	Gross return (x10^3 `)	Cost of cultivation (x10^3 `)	Net return (x10^3 `)	B:C
Butachlor 1.5 kg/ha as PE at 2 DAT + 1 HW at 40 DAT	3.63	5.20	19.85	8.29	50.82	59.11	33.86	25.25	1.74
Pyrazosulfuron-ethyl 25 g/ha as PE at 2 DAT + 1 HW at 40 DAT	3.23	4.83	28.68	7.60	46.62	54.22	33.72	20.50	1.61
Bensulfuron-methyl + pretilachlor 10 kg/ha as PE at 2 DAT + 1 HW at 40 DAT	4.20	5.57	7.35	8.85	54.18	63.03	34.06	28.97	1.85
Bispyribac-sodium 25 g/ha as POE at 20 DAT	3.10	4.73	31.62	7.50	50.40	57.90	31.40	26.50	1.84
Metsulfuron-methyl + chlorimuron-ethyl 4 g/ha POE at 20 DAT	2.87	4.63	36.76	7.39	42.95	50.34	30.30	20.04	1.66
Butachlor 1.5 kg/ha (PE at 2 DAT) + bispyribac-sodium 25 g/ha (POE at 20 DAT)	2.33	4.47	48.53	7.15	38.22	45.37	32.50	12.87	1.40
Pyrazosulfuron-ethyl 25 g/ha (PE at 2 DAT) + bispyribac-sodium 25 g/ha (POE at 20 DAT)	3.53	5.17	22.06	7.95	49.42	57.37	32.36	25.01	1.77
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE 2 DAT) + bispyribac-sodium 25 g/ha POE - 20 DAT	4.17	5.53	8.09	8.50	53.62	62.12	32.70	29.42	1.90
Butachlor 1.5 kg/ha (PE at 2 DAT) + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha (POE 20 DAT)	2.67	4.53	41.18	7.24	43.82	51.06	31.39	19.67	1.63
Pyrazosulfuron-ethyl 25 g/ha (PE at 2 DAT) + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha (POE at 20 DAT)	3.27	4.87	27.94	7.80	48.02	55.82	31.25	24.57	1.79
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE 2DAT) + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha (POE 20 DAT)	4.07	5.47	10.29	8.40	52.22	60.62	31.59	29.03	1.92
Two hand weeding at 20 and 40 DAT	4.53	5.80	-	9.19	58.80	67.99	36.73	18.92	1.85
Weedy check	2.23	4.30	50.74	6.94	33.60	40.54	28.81	11.74	1.41
LSD (P=0.05)	0.71	0.94	-	-	-	-	-	-	-

value (1.92) was obtained from the treatment bensulfuron-methyl + pretilachlor as PE at 2 DAT + metsulfuron-methyl + chlorimuron-ethyl as POE at 20 DAT followed by bensulfuron-methyl + pretilachlor as PE at 2 DAT + bispyribac-sodium POE at 20 DAT treatment (1.90). Singh *et al.* (2007) also reported that metsulfuron-methyl 8 g/ha provided higher profitable returns and B: C which corroborated the present findings. Bensulfuron-methyl + pretilachlor 10 kg/ha as PE at 2 DAT + 1 HW at 40 DAT and bispyribac-sodium 25 g/ha as POE at 20 DAT also resulted higher B: C values that were 1.85 and 1.84 respectively compared to other treatments. In case of hand weeding twice at 20 and 40 DAT treatment, B: C value was 1.85.

This study indicated that use of herbicides in combination may profitably replace the time consuming and expensive hand weeding for weed control in transplanted winter rice. So, the application of bensulfuron-methyl + pretilachlor as pre-emergence (PE) with bispyribac-sodium as post-emergence (POE) was more superior over hand weeding twice (20 and 40 DAT).

SUMMARY

Hand weeding twice at 20 and 40 days after transplanting (DAT) gave best results in reducing both weed density and biomass and ultimately increased the grain (4.53 t/ha) and straw yield (5.80 t/ha). Next highest grain (4.20 t/ha) and straw yield (5.57 t/ha) was obtained with bensulfuron-methyl + pretilachlor (granules) 10 kg/ha as pre-emergence + one hand weeding at 40 DAT treatment followed by combined herbicidal treatment bensulfuron-methyl + pretilachlor (granules) 10 kg/ha as PE + bispyribac-sodium 25 g/ha as post emergent gave grain yield 4.17 t/ha and straw yield 5.53 t/ha. Considering the benefit: cost ratio, the highest value (1.92) was obtained with the performance of bensulfuron-methyl + pretilachlor as PE + metsulfuron-methyl + chlorimuron-ethyl as POE.

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Short communication

Effect of weed management practices on productivity of wheat

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Key words: Herbicides, Wheat, Weed management

Wheat is an important crop worldwide. Its production increased from a mere 11.0 million tones during 1960-61 to 95.85 million tones during 2013-14. This is more than eight-fold increase in wheat production mainly due to the adoption of short stature high yielding varieties, increased fertilizers use, irrigation and herbicides. Weed infestation is one of the major biotic constraints in wheat production. It is infested with diverse type of weed flora under diverse agro-climatic conditions. The yield losses due to weeds vary depending on the weed species, their density and environmental factors. Use of herbicides and their mixtures become inevitable due to industrialization (Yadav and Malik 2005).

A field study was conducted during winter season of 2014-15 at Instructional Farm, Rajasthan College of Agriculture, Udaipur. The soil of the experimental field was clay loam in texture with alkaline in reaction. The available N, P and K were 259.5, 20.6 and 399.3 kg/ha, respectively. Ten treatments were taken consisting of 2,4-D (0.5 kg/ha), metsulfuron (4 g/ha), isoproturon (1.0 kg/ha), sulfosulfuron (25 g/ha), 2,4-D + isoproturon (0.25 kg/ha + 0.75 kg/ha), 2,4-D + sulfosulfuron (0.25 kg/ha + 20 g/ha), metsulfuron + isoproturon (3 g/ha + 0.75 kg/ha), metsulfuron + sulfosulfuron (3 g/ha + 20 g/ha), weed free and weedy check. The experiment was conducted in randomized block design with 3 replications. Wheat variety '*Raj. 4037*' was sown in rows 22.5 cm apart on 6 December in 2014 with seed rate of 150 kg/ha using package of practices available for "Sub-Humid Southern Plain and Aravalli Hills'' of Rajasthan. All the herbicides were sprayed at 35 DAS by knapsack sprayer using a spray volume of 600 liters/ha. Data on weed count and weed biomass from an area enclosed in a quadrate of 0.25 m^2 under different herbicides were recorded 90 days after sowing (DAS). All the weeds inside the quadrate were collected for dry matter accumulation after counting category-wise. The dried samples after oven drying were weighed and expressed in g/m^2. Weed control efficiency was calculated at 90 DAS on the basis of total weed dry matter and expressed in percentage. Weed index was calculated in relation to seed yield in weed free treatment and expressed in percentage. Data on category-wise total weed density, weed dry weight were subjected to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution.

Wheat crop was infested with complex weed flora, consisting of broad-leaf weeds and grassy weeds, *viz. Phalaris minor, Cyperus rotundus, Cynodon dactylon, Chenopodium album, Chenopodium murale, Convolvulus arvensis, Anagallis arvensis, Cichorium intybus, Avena ludoviciana etc*. Broad-leaf weeds were dominant in the experimental site, accounting for 78.2% of density and 71.9% dry matter of total weeds in weedy check at 90 DAS (Table 1). Significant variation in weed density and dry weight of weeds were recorded due to different weed management practices. Among different herbicidal treatments, minimum grassy and broad-leaf weed density and their dry weight of 3.09, 3.11, m^2 and 1.64, 1.35, g/m^2 were recorded under metsulfuron + sulfosulfuron, respectively. Amongst sole application of herbicides, sulfosulfuron and isoproturon were found statistically at par to each other in controlling total weed density and both of these treatments were found superior over 2,4-D and metsulsulfuron (Table 1).

Weed control indices influenced considerably due to weed management practices. Among different herbicidal treatments, the highest weed control efficiency (91.5 %) was recorded in metsulfuron + sulfosulfuron (Table 1). The results corroborate with the finding of Bharat and Kachroo (2007) and Khokhar and Nepalia (2010). Different weed management treatment significantly affected the grain yield of wheat crop as compared to weedy check. Grain yield increased significantly due to metsulfuron + sulfosulfuron closely followed by metsulfuron + isoproturon, 2,4-D + isoproturon and 2,4-D +

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Table 1. Effect of herbicides on weed density, weed dry weight and weed control efficiency at 90 DAS

Treatment	Weed density ($/m^2$)		Weed dry weight (g/m^2)		Weed control efficiency (%)		Grain yield (t/ha)
	Broad-leaf weeds	Grassy weeds	Broad-leaf weeds	Grassy weeds	Broad-leaf weeds	Grassy weeds	
2,4-D	4.47 (19.67)	6.87 (46.67)	2.23 (4.51)	2.73 (7.01)	75.5	2.8	4.17
Metsulfuron	3.80 (14.21)	6.86 (46.67)	2.04 (3.78)	2.74 (7.03)	79.5	2.5	4.22
Isoproturon	5.17 (26.33)	3.43 (11.33)	3.13 (9.29)	1.73 (2.52)	49.6	65.0	4.13
Sulfosulfuron	4.85 (23.00)	3.15 (9.67)	3.28 (10.29)	1.59 (2.05)	44.2	71.6	4.24
2,4-D + isoproturon	3.81 (14.33)	3.28 (10.33)	1.86 (2.96)	1.55 (1.92)	83.9	73.4	4.58
2,4-D + sulfosulfuron	3.94 (15.00)	3.38 (11.00)	1.81 (2.78)	1.46 (1.62)	84.9	77.5	4.41
Metsulfuron + isoproturon	3.71 (13.33)	3.18 (9.67)	1.73 (2.51)	1.38 (1.42)	86.4	80.3	4.86
Metsulfuron + sulfosulfuron	3.09 (9.67)	3.11 (9.67)	1.64 (2.21)	1.35 (1.33)	88.0	81.5	5.22
Weedy check	13.63 (185.33)	7.22 (51.67)	4.35 (18.45)	2.77 (7.21)	0.0	0.0	3.55
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	100.0	100.0	5.35
LSD(P=0.05)	0.79	0.68	0.37	0.29	-	-	0.91

Data subjected to $\sqrt{x + 0.5}$ transformation and figures in parenthesis are original weed count $/m^2$

sulfosulfuron. The extent of increase in grain yield was 47.2, 37.1, 29.0 and 24.4% as compared to weedy check, respectively. Amongst sole application of herbicides, plots treated with sulfosulfuron recorded the highest grain yield. However, these results were at par with each other. Weed managements treatments might have significantly reduced the uptake of nutrients by weeds, which concurrently provided better environment for crop growth characteristics and yield attributes. The results so obtained for the higher grain yield under different treatments are in close conformity with the finding of Bharat and Kachroo (2010).

SUMMARY

Application mixture of metsulfuron 3 g/ha + sulfosulfuron 20 g/ha as post-emergence spray (35 DAS) was found best in controlling grassy and broad-leaf weeds and recorded the highest yield amongst all the weed management treatments with the 47.2% increase in grain yield of wheat as compared to weedy check.

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Short communication

Pre- and post-emergence herbicides for weed management in finger millet

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Finger millet (*Eleusine coracana* Gaertn.) commonly known as (*ragi*), is one of the important staple food crops of South India. It is drought tolerant crop and widely grown in rainfed and dry land conditions in red soil area. In India, the crop occupies an area of 1.31 million hectares with a production of 1.93 million tonnes and productivity of 1.64 t/ha. Among finger millet growing states, Karnataka stands first with an area of 0.79 million hectares, with an annual production of 1.27 million tonnes and productivity of 1.87 t/ha (Anonymous 2014). The finger millet crop is slow growing during initial stages due to which weeds pose severe problem. If weeds are not controlled in early period up to four weeks after transplanting, yield is reduced drastically by 34 to 61% (Nanjappa and Hosmani 1985). Delayed weeding will be less effective because sufficient damage would have occurred at the critical period. In present days, apart from expensive labour charges, timely availability of labour is a limitation for undertaking cultural operations like hand weeding. In such situations, suitable technology with less labour requirement will be most helpful to farmers for controlling weeds effectively and chemical weed control is one of such measures. However, environmental pollution due to application of higher doses of herbicides is a concern. Some low dose herbicides have emerged. Further, broad spectrum weed control is another limitation in finger millet crop. Hence it is needed to test the available pre-mix formulation of herbicides to control diversified weed flora in finger millet.

A field experiment was conducted at College of Agriculture, V.C. Farm, Mandya, during *Rabi*, 2013. The soil texture of the experimental site was red sandy loam with a neutral pH (7.1) and was medium in organic carbon content (0.53%). The available nitrogen, phosphorus and potassium status in soil was 282.24, 29.77 and 243.6 kg/ha, respectively.

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The experiment was laid out in a randomized block design with three replications consisting of 10 treatments, *viz.* butachlor 50 EC 0.75 kg/ha as pre-emergence at 2 days after transplanting (DAT), oxyfluorfen 23.5 EC at 80 g/ha as pre-emergence application (2 DAT), oxadiargyl 80 WP at 60 g/ha as early post-emergence application (8 DAT), oxadiargyl 80 g/ha as early post-emergence application (8 DAT), bensulfuron-methyl 45 g + pretilachlor 450 g/ha (6.6% G pre-mix formulations) as pre-emergence application (2 DAT), bensulfuron-methyl at 60 g + pretilachlor at 600 g/ha (6.6% G pre-mix formulations) as pre-emergence application (2 DAT), bispyribac-sodium 10% SC at 20 g/ha as a post-emergence application (13 DAT), bispyribac sodium 10% SC at 25 g/ha as a post-emergence application (13 DAT), one intercultivation at 20 DAT followed by one hand weeding at 30 DAT and un-weeded check

The variety used was '*Indaf-7*', developed by Zonal Agricultural Research Station, Mandya, University of Agricultural Sciences, Bangaluru, suitable for winter season. The variety is having medium plant height, ear head is semi compacted cox comb type and comes to maturity in 115 to 120 days. Variety is having moderate resistance to pest and diseases. It is having higher grain yield potential of 5 to 6 t/ha. The 22 days old seedlings were transplanted in the main field at 22.5 x 15 cm spacing at 2-3 seedlings per hill. Equal quantity of farm yard manure at the rate of 7.5 t/ha was applied to each plot three weeks prior to sowing. The fertilizer nitrogen, phosphorus and potassium were applied as per recommended dose 100:50:50 N, P_2O_5 and K_2O kg/ha through urea, single super phosphate and muriate of potash. Fifty per cent of nitrogen and entire dose of P and K were applied at the time of planting. Remaining half nitrogen was top-dressed at 30 days after transplanting. Butachlor, oxyfluorfen and bensulfuron-methyl + pretilachlor were applied as pre-emergence herbicides as per the respective treatments at 2 DAT. Whereas, oxadiargyl was applied as early post-emergence at 8 DAT and bispyribac-sodium was applied as post-emergence at

13 DAT. The visual toxicity ratings were recorded at 5, 10, and 14 days after spraying of herbicides. The scores were given from 0 to 10 scales by comparing crop tolerance to a particular herbicide treatment and weedy check plot as outlined by Gupta (2010). The visual weed control ratings were recorded at 14, 28 and 35 DAT and scores were given from 0 to 10 scales. Statistical analysis was done as per the procedure outlined by Gomez and Gomez (1984). Weed control efficiency and weed index were calculated using standard formulae as quoted by Sunil *et al.* (2010).

Weed flora

The predominant weed flora observed in the experimental field during investigation includes *Dactyloctenium aegyptium* L., *Cynodon dactylon* L., *Digitaria marginata* L., *Panicum miliacea* L., *Eleusine indica* L. and *Echinochloa colona* L., among grasses*; Portulaca oleracea* L., *Parthenium hysterophorus* L., *Ageratum conyzoides* L., *Commelina benghalensis* L., *Mollugo disticha* L., *Phyllanthus niruri* L.*, Alternanthera spp*, *Sida acuta* L., *Sida cardifolia* L.*, Amaranthus viridis* L.*, Mimosa pudica* L., *Bidens pilosa* L. and *Achyranthes aspera* L. among broad-leaved weeds and *Cyperus rotundus* L. and *Cyperus esculentus* L. were major sedges in transplanted finger millet system. Similar weed flora was also observed by Kumar *et al.* (2013) and Sunil and Shankaralingappa (2014).

Weed control efficiency

At 5, 10 and 14 days after spraying of herbicides, oxadiargyl 60 g and 80 g/ha as early post-emergence application and bispyribac-sodium 20 g and 25 g/ha as post-emergence application showed slight to moderate crop toxicity. However, at later stages plant recovered from the effect. At 14, 28 and 35 DAT, the excellent control of weeds were noticed with pre-emergence application of bensulfuron-methyl at 60 g + pretilachlor 600 g/ha (6.6% G pre-mix formulations) as pre-emergence application (2 DAT), bensulfuron-methyl 45 g + pretilachlor 450 g/ha (6.6% G pre-mix formulations) as pre-emergence application (2 DAT), followed by oxyflurofen 80 g/ha as pre-emergence application. These results were comparable with one interculticvation at 20 DAT. The highest weed control efficiency and lowest weed index was recorded with pre-emergence application of bensulfuron-methyl at 60 g + pretilachlor 600 g/ha (6.6% G pre-mix formulations) as pre-emergence application (Table 1). These results were in conformity with the findings of Srivastava *et al.* (2008) and Patil *et.al.* (2013).

Weed attributes and yield

Among different weed management practices, bensulfuron-methyl at 60 g + pretilachlor at 600 g/ha (6.6% G pre-mix formulations) applied as pre-emergence herbicide recorded significantly higher growth and yield parameters, *viz.* plant height, leaf area (cm^2/hill), number of productive tillers/hill, and ear head weight, ear head length, and thousand grain weight and was followed by one intercultivation at 20 DAT and one hand weeding at 30 DAT and oxyfluorfen 80 g/ha as pre-emergence application (2 DAT). This increase in crop growth and yield parameters in these treatments were due to better control of weeds resulting in minimum competition of weeds with finger millet for resources during crop growth period and helped in better utilization of nutrients, moisture, space and light by the crop.

Table 1. Effect of weed control treatments on crop toxicity rating, weed control rating, WCE and weed index in transplanted finger millet

Treatment	Crop toxicity rating			Weed control ratings			WCE (%)	Weed index (%)
	5 DASp	10 DASp	14 DASp	14 DAT	28 DAT	35 DAT		
Butachlor 50 EC at 0.75 kg/ha as PE application (2 DAT)	0.50	0.40	0.40	9.00	6.80	6.00	66.54	23.65
Oxyfluorfen 23.5 EC at 80 g/ha as PE application (2 DAT)	0.10	0.20	0.10	9.80	9.40	9.40	87.67	1.82
Oxadiargyl 80 WP at 60 g/ha as early POE application (8 DAT)	2.00	2.00	3.00	9.00	8.20	8.00	75.99	6.56
Oxadiargyl 80 WP at 80 g/ha as early POE application (8 DAT)	3.00	3.00	4.00	9.10	8.50	8.90	80.04	8.44
Bensulfuron-methyl at 45 g + pretilachlor at 450 g/ha (6.6% G premix formulations) as PE application (2 DAT)	0.10	0.10	0.00	9.50	9.20	9.20	86.87	4.92
Bensulfuron-methyl at 60 g + pretilachlor at 600 g/ha (6.6% G premix formulations) as PE application (2 DAT)	0.10	0.10	0.00	9.80	9.70	9.80	91.57	-2.51
Bispyribac-sodium 10% SC at 20 g/ha as a POE application (13DAT)	2.00	2.50	4.00	0.00	7.90	8.60	74.71	5.74
Bispyribac-sodium 10% SC at 25 g/ha as a POE application (13 DAT)	2.00	2.60	4.50	0.00	8.50	8.80	80.26	7.38
One intercultivation at 20 DAT followed by one hand weeding at 30 DAT	0.00	0.00	0.00	0.00	9.00	9.90	84.26	0.00
Unweeded check	0.00	0.00	0.00	0.00	0.00	0.00	0.00	63.27

WCE- Weed control efficiency; DAT- Days after transplanting; PE- Pre-emergence; POE- Post-emergence; DAT- Days after spraying

Scale of crop toxicity (0.0 = None, 1.0-3.0 = Slight, 4.0 – 6.0 = Moderate, 7.0 – 9.0 = Severe, 10.0 = Complete)

Scale of weed control rating (0.0 = No control, 1.0-3.0 = Poor controlt, 4.0 – 6.0 = Fair control, 7.0 – 9.0 = Good control, 10.0 = Excellent control)

Table 2. Effect of weed control treatments on growth, yield parameters and yield of transplanted finger millet

Treatment	Plant height (cm) at harvest	Leaf area at 60 DAT (cm^2/hill)	Productive tillers (no./hill)	Ear head length (cm)	Ear head weight (g/hill)	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Butachlor 50 EC at 0.75 kg/ha as PE application (2 DAT)	74.10	538	2.6	12.2	20.01	2.85	3.19	4.63
Oxyfluorfen 23.5 EC at 80 g/ha as PE application (2 DAT)	82.13	1034	4.2	15.3	49.54	2.95	4.11	6.15
Oxadiargyl 80 WP at 60 g/ha as early POE application (8 DAT)	77.00	849	3.3	13.6	40.27	2.91	3.91	5.89
Oxadiargyl 80 WP at 80 g/ha as early POE application (8 DAT)	78.47	807	2.8	12.6	37.17	2.88	3.83	5.60
Bensulfuron-methyl at 45 g + pretilachlor at 450 g/ha (6.6% G premix formulations) as PE application (2 DAT)	80.04	949	4.2	14.0	48.46	2.95	3.98	5.86
Bensulfuron-methyl at 60 g + pretilachlor at 600 g/ha (6.6% G premix formulations) as PE application (2 DAT)	86.80	1432	4.5	16.6	54.73	3.02	4.29	6.45
Bispyribac-sodium 10% SC at 20 g/ha as a POE application (13DAT)	79.13	804	3.2	13.9	38.70	2.93	3.94	6.03
Bispyribac-sodium 10% SC at 25 g/ha as a POE application (13 DAT)	79.17	773	2.9	12.6	30.48	2.87	3.87	5.93
One intercultivation at 20 DAT followed by one hand weeding at 30 DAT	85.90	1251	4.3	15.5	51.74	2.99	4.18	6.13
Unweeded check	67.07	424	1.9	08.5	7.82	2.53	1.54	2.24
LSD (P=0.05)	7.13	137	0.4	3.2	7.13	0.25	0.88	1.09

However, un-weeded check recorded significantly lower plant height (cm), number of tillers/hill, leaf area (cm^2/hill) and dry matter production (g/hill) (Table 2). This might be due to severe crop weed competition for the same growth resources. These results were in line with the findings of Saha (2009) and Kumar *et al.* (2013).

The grain and straw yield of transplanted finger millet also followed the similar trend as above. The better yield and yield components was due to reduced crop weed competition for nutrients, light, moisture and space and provided better environment for crop growth and development (Singh and Singh 2010).

SUMMARY

Significantly higher grain yield and straw yield (4.29 and 6.45 t/ha, respectively), was recorded with pre-emergence application of bensulfuron-methyl (0.6% G) + pretilachlor (6.0% G) at 1.0 kg/ha as compared to pre-emergence application of butachlor 50 EC at 0.75 kg/ha (3.19 and 4.63 t/ha, respectively) and un-weeded check (1.54 and 2.24 t/ha, respectively). Similar trend was also observed with respect to the growth and yield parameters of fingermillet.

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Short communication

Evaluation of pre- and post-emergence herbicides in groundnut

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Groundnut is the most prominent and important crop among all oil seed crops. It is one of the chief foreign exchange earning crops for India. However, owing to lack of appropriate management practices, production and area under cultivation of groundnut have remained low. It is grown on 4.70 million ha area with a total production of 6.60 million tonnes and an average productivity of 1400 kg/ha in our country. (Department of Agriculture, Cooperation and Farmers Welfare, 2014-15). Currently used tillage practices common to groundnut production favor germination, growth, and development of weeds. Weeds compete with crop plants for nutrients and remove 30 to 40% of applied nutrients resulting in significant yield reductions (Dryden and Krishnamurthy 1977). Reduction in groundnut crop yield due to weed alone is estimated to be 16-42% depending on crop and location (Rangasamy *et al.* 1993). In *Kharif* season, weeds cause greater loss compared to insects or other plant diseases. Depending on weed intensity, the yield reduction in groundnut ranged between 40-50% (Mishra 1997). Successful production of groundnuts demands that maximum economic yields be harvested from each field. Because of the growth habits of groundnut, weed removal is extremely difficult once weeds become established between the rows. Mechanical removal by tractor mounted cultivators becomes impossible. Manual weeding requires huge labour force and accounts for about 25% of total labour requirement of about 900-1200 man hours/ha (Nag and Dutt 1979). Concequently, it is obvious to accept chemical weed control practices in groundnut to control annual and perennial weeds. In this view, this experiment was conducted to evaluate suitable herbicides and herbicide combinations for *Kharif* *g*roundnut.

A field experiment was carried out at research farm of Zonal Agricultural Research Station Khargone, JNKVV, Jabalpur during *Kharif* (rainy season June-October) of 2007 and 2008. The site of the experimental field having clayey loam texture with the pH of 7.7. The soil had 0.42% organic carbon content, high available N (258 kg/ha), medium available P (14.2 kg/ha) and high K (375 kg/ha), respectively. The recommended dose of NPK and Zn for groundnut crop was 25:50:30:05:N:P:K:Zn kg/ha. The experiment had seven treatments, set in a randomized complete block design with 3 replications in fixed plots. Treatments comprised unweeded control, weed free check, pendimethalin 1.0 kg/ha as pre-emergence (PE) + 1 hand weeding at 30 DAS, post-emergence quizalofop-ethyl 50 g/ha at 20 DAS, post-emergence imazathypyr 75 g/ha at 20 DAS, pre-emergence pendimethalin 1.0 kg/ha + post-emergence quizalofop-ethyl 50 g/ha (750 ml/ha) at 20 DAS and pre-emergence pendimethalin 1.0 kg/ha + post-emergence imazathypyr 75 g/ha at 20 DAS. The crop variety '*JGN*-3' was sown during first week of July with spacing of 30 x 10 cm with seed rate of 100 kg/ha. Agronomic practices other than treatments were performed evenly to all the plots as per-recommended package of practices. Different observations were recorded during the course of investigation. Net return and B C Ratio was computed on the basis of cost of cultivation and pod yield at prevailing market prices. Statistical analysis of the data was carried out using analysis of variance technique as applicable to RCBD.

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Effect on haulm and pod yield

The total plant population at harvest was not significantly influenced under different weed control treatments (Table 1). The maximum plant population was observed with application of pre-emergence pendimethalin 1.0 kg/ha + post-emergence quizalofop-ethyl 50 g/ha (750 ml/ha) at 20 DAS (289/m^2), which was followed by weed free check (283/m^2); whereas lowest plant population was observed in unweeded check (264/m^2). Dry haulms yield was observed significantly higher in all the treatments compared to unweeded check. The highest dry haulms yield was recorded under influence of treatment where pre-emergence pendimethalin 1.0 kg/ha + post-emergence imazathypyr 75 g/ha was applied at 20 DAS (2.40 t/ha) followed by weed free check (2.35 t/ha) and post-emergence imazathypyr 75 g/ha (750 ml/ha) at 20 DAS (2.09 t/ha). Pre-emergence pendimethalin 1.0 kg/ha + post-emergence imazathypyr 75 g/ha at 20 DAS, weed free check and post-emergence imazathypyr 75 g/ha at 20 DAS were at par to each other but were significantly superior to other treatments in reference to dry haulms yield. Pre-emergence application of pendimethalin 1.0 kg/ha recorded lower weed population, higher pod and haulm yields due to control of weeds at early stage (Bhatt *et al.* 2008).

In groundnut nodule formation, weed control index and pod yield were maximum with pre-emergence application of pendimethalin 1.0 kg/ha (Deshmuk and Dev 1995). Jain *et al.* (2000) confirmed that pre-emergence application of pendimethalin 1.5 kg/ha reduced the weed density, weed biomass and increased the weed control efficiency as well as number of pods/plant and weight of pods in groundnut crop. Whereas, Nayak *et al.* (2000) reported that the higher weed control efficiency was found in pendimethalin 1.0 kg/ha, which was at par with two hand weeding at 25 and 40 DAS.

Dry pod yield was recorded maximum in weed free check (1.52 t/ha) followed by application of pre-emergence pendimethalin 1.0 kg/ha + post-emergence imazathypyr 75 g/ha at 20 DAS (1.21 t/ha) and was minimum in un-weeded check (0.61 t/ha). This might be due to minimized competition of weeds with main crop for resources, *viz.* space, light, nutrients and moisture due to effective weed control. Singh and Giri (2001) have also concluded that proper weed control was responsible for increase in plant height and dry matter production in groundnut. Weed free environment in crop also 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/ha. Higher profitable pod yield of summer groundnut was also reported by Raj *et al.* (2008) with keeping the crop in weed free condition.

All the treatments produced significantly higher dry pod yield in comparison to un-weeded control, while yields of pre-emegence pendimethalin 1.0 kg/ha + post-emergence imazathypyr 75 g/ha at 20 DAS, post-emergence imazathypyr 75 g/ha at 20 DAS and pre-emegence pendimethalin 1.0 kg/ha + post-emergence quizalofop-ethyle 50 g/ha at 20 DAS were found to be at par with each other. These results are generally in agreement with those obtained by Kumar *et al.* (2003a) and Kumar *et al.* (2003b). Gnanamurthy and Balasubramaniyan (1998) have also stated that the uncontrolled weed reduce groundnut yield up to 75%.

Economics

Economic evaluation of different weed control treatments showed maximum net return in weed free check (`16712/ha) followed by pre-emergence pendimethalin 1.0 kg/ha + post-emergence imazathypyr 75 g/ha (750 ml/ha) at 20 DAS (` 16270/ha). While maximum B:C ratio was observed in pre-emergence pendimethalin 1 kg/ha + post-emergence imazathypyr 75 g/ha at 20 DAS (2.2) followed by post-emergence imazathypyr 75 g/ha at 20 DAS (2.1) and post-emergence quizalofop-ethyl 50 g/ha at 20 DAS (1.9). This might be due to the cost of cultivation of groundnut crop was increased in treatment weed free check because of the higher involvement of labours and their higher wages. This cost was reduced in treatment pendimethalin 1.0 kg/ha as pre-emergence + imazethapyr 0.15 kg/ha as post-emergence by using herbicides to effective control of weeds with less number of labors. Sasikala *et al.* (2004), Tomar *et al.* (2009) and Rao *et al.* (2011) have also reported higher net return and B:C

Table 1. Evaluation of post-emergence herbicide in groundnut crop (mean of 2007-08 and 2008-09)

Treatment	Final Plant population/m^2	Dry haulum yield (t/ha)	Dry pod yield (t/ha)	Cost of cultivation (x10^3 `/ha)	Net income (x10^3 `/ha)	B:C ratio
Pre-emergence pendimethalin 1.0 kg/ha + one hand weeding at 30 DAS	259	1.78	1.10	14.02	10.43	1.7
Post-emergence quizalofop-ethyle 50 g/ha at 20 DAS	279	1.89	0.90	12.02	10.70	1.9
Post-emergence imazathypyr 75 g/ha at 20 DAS	283	2.09	1.11	12.50	14.96	2.1
Pre-emergence pendimethalin 1.0 kg/ha + post-emergence quizalofop-ethyle 50 g/ha at 20 DAS	289	1.64	1.15	12.52	10.53	1.8
Pre-emergence pendimethalin 1.0 kg/ha + post-emergence imazathypyr 75 g/ha at 20 DAS	277	2.40	1.21	13.87	16.27	2.2
Unweeded check	264	1.15	0.61	10.52	4.50	1.4
Weed free check	283	2.35	1.52	19.52	16.71	1.8
LSD (P=0.05)	NS	0.33	0.17	-	-	-

ratio with integration of pre- and post-emergence application of herbicides with hand weeding in groundnut.

It could be concluded that application of pre-emergence pendimethalin 1.0 kg/ha + post-emergence application of imazathypyr 75 g/ha at 20 DAS gave higher pod and haulm yields and maximum net return on per rupee invested. The results confined that use of herbicides to weed control is a cheaper and economical method of weed control. It is also a best option to reduce the constraints of labour scarcity in Indian agriculture.

SUMMARY

The experiment comprised 7 treatments *i.e*. un weeded control, weed free check, pendimethalin 1.0 kg/ha (PE) + 1 hand weeding at 30 DAS, post emergence quizalofop-ethyl 50 g/ha at 20 DAS, post-emergence imazathypyr 75 g/ha at 20 DAS pre-emergence pendimethalin 1.0 kg/ha + post-emergence quizalofop-ethyl 50 g/ha at 20 DAS and pre emergence pendimethalin 1.0 kg/ha + post emergence imazathypyr 75 g/ha at 20 DAS. The experiment was set in a randomized-complete block design (RCBD) with 3 replications, in fixed plots and the crop variety '*JGN-3'* was sown 100 kg/ha during first week of July with spacing of 30 x 10 cm. Application of pendimethalin 1.0 kg/ha + imazathypyr 75 g/ha (750 ml/ha) at 20 DAS gave comparable pod yield (1.21 t/ha) and maximum net returns on per rupee invested. The results confined that the use of pre and post emergence herbicides in combination to groundnut crop is a practically efficient and economically feasible method to control weeds and fetch higher returns.

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Short communication

Efficacy of different herbicides for weed control in soybean

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Soybean [*Glycine max* (L.) Merrill] is an important oil seed crop. In India, it is cultivated in 9.60 million ha with the annual production of 12.74 million tonnes. Madhya Pradesh contributes nearly 5.56 mha area with the production of 6.68 mt (Anonymous 2012). The soil and climate of Madhya Pradesh are congenial for soybean production but being a rainy season crop it suffers severely due to weed infestation, resulting reduction in yield to the tune of 20 to 71% depending upon the type and intensity of weeds and their occurrence. Unavailability of labour and high wages during season are the main limitations of manual weeding. Under such situations, farmers may use different pre- and post-emergence herbicides to control annual grass and broad-leaved weeds effectively in soybean. Therefore, the experiment was aimed to find out the efficacy of herbicides on weeds and yield of soybean.

The study was carried out at Research Farm, College of Agriculture, Tikamgarh during *Kharif*, 2014-15. The soil of the experimental site was clayey loam, which was medium in organic carbon (0.62 g/kg), low in available nitrogen (233 kg/ha) and medium in phosphorus (19.7 kg/ha) and potassium content (347 kg/ha) having neutral pH (7.2) and normal electrical conductivity (0.26 dS/m). The experiment was laid out in randomized block design with nine treatments and replicated thrice. The treatments comprised of glyphosate 41% SL 1.0 kg/ha as pre-plant incorporation (PPI), pendimethalin 1.0 kg/ha as pre-emergence (PE) and alachlor 1.0 kg/ha PE and imazethapyr + imazamox (Odyssey) 70 g/ha, quizalofop-ethyl 50 g/ha, chlorimuron-ethyl 9 g/ha and quizalofop-ethyl 50 g/ha at 20 DAS followed by (*fb*) chlorimuron-ethyl 9 g/ha as post-emergence at 20 DAS, two hand weeding at 20 and 40 DAS and weedy check. The soybean variety "*JS-95-60*" was sown on July 14, 2014 at seed rate of 80 kg/ha in rows 30 cm apart with fertilizer dose of 20:60:20 kg N, P_2O_5 and K_2O/ha. Pre-emergence herbicides were applied on next day of sowing. The herbicides were applied in 500 liters of water/ha by knapsack sprayer, using flat fan nozzle.

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Weed flora

There was prevalence of dicot weeds in the experimental field as these weeds constituted the higher relative density of 66.1% as compared to monocot weeds which had only 33.9% relative density. In the dicot weeds, the intensity of *Phyllanthus niruri* was the highest (23.7%) followed by *Digera arvensis* (15.8%) and *Trianthema monogyna* (10.8%) whereas *Echinochloa colona* (15.3%) and *Cyperus rotundus* (11.1%) were seen as dominant monocot weeds in the field.

Weed growth

The lowest mean weed intensity was recorded under two hand weeding at 20 and 40 DAS (2.79/m^2) followed by pendimethalin (5.91/m^2), imazethapyr + imazamox (6.11/m^2) and quizalofop-ethyl *fb* chlorimuron-ethyl (6.40/m^2) being at par with alachlor (6.79/m^2) whereas post-emergence application of quizalofop-ethyl (11.3/m^2) and pre-plant incorporation application of glyphosate (10.1/m^2) was not effective as pre-emergence *fb* pendimethalin and alachlor and post-emergence imazethapyr + imazamox and quizalofop-ethyl *fb* chlorimuron-ethyl. The total weed intensity was recorded maximum under weedy check (13.2/m^2). The lowest total weed dry weight was recorded under two hand weeding at 20 and 40 DAS (1.91 g/m^2) followed by post-emergence application of imazethapyr + imazamox (3.55 g/m^2), quizalofop-ethyl *fb* chlorimuron-ethyl (4.09 g/m^2), chlorimuron-ethyl (5.00 g/m^2) and pre-emergence application of pendimethalin (5.44 g/m^2) and alachlor (5.68 g/m^2) whereas pre-plant incorporation of glyphosate (6.89 g/m^2) registered significantly the highest dry weight among herbicidal treatments. However, among all the treatments, total weed dry weight was recorded maximum under weedy check (8.22 g/m^2).

The weed control efficiency (WCE) among herbicides and its combination varied from 27.5-82.4%. The highest WCE was recorded under hand weeding twice at 20 and 40 DAS (96.3%) followed by post-emergence application of imazethapyr + imazamox (82.4%), whereas it was the lowest under glyphosate (27.5%).

Table 1. Influences of different herbicides on weed intensity, weed dry weight, weed control efficiency, yield attributes, seed yield and economics of soybean

Treatment	Weed intensity (no./m^2)	Weed dry weight (g/m^2)	Weed control efficiency (%)	No. of pods/ plant	No of seeds/ pod	Test weight (g)	100-seed yield (kg/ha)	Net monetary return ($x10^3$ `/ha)	B:C ratio
Glyphosate 41% SL 1 kg/ha (pre-plant incorporation)	10.10 (102)	6.89 (47.0)	27.51	16.40	2.00	8.06	589	8.42	1.55
Pendimethalin 1.0 kg/ha (pre-emergence)	5.91 (34.7)	5.44 (29.1)	63.86	22.67	2.53	8.60	686	13.79	2.00
Alachlor 1.0 kg/ha (pre-emergence)	6.79 (45.6)	5.68 (31.8)	55.61	20.80	2.33	8.40	665	13.52	2.03
Imazethapyr + imazamox 70 g/ha at 20 DAS	6.11 (36.8)	3.55 (12.1)	82.40	26.40	3.00	9.25	797	18.25	2.33
Quizalofop-p-ethyl 50 g/ha at 20 DAS	11.33 (128)	6.78 (45.6)	31.32	18.40	2.13	8.15	644	12.44	1.93
Chlorimuron-ethyl 9 g /ha at 20 DAS	8.40 (70.1)	5.00 (24.5)	67.88	24.73	2.73	8.99	742	17.13	2.35
Quizalofop-p-ethyl 50 g/ha at 20 DAS *fb* chlorimuron ethyl 9 g/ha at 20 DAS	6.40 (40.5)	4.09 (16.4)	79.18	25.80	2.93	9.08	769	16.74	2.19
Two hand weeding at 20 and 40 DAS	2.79 (7.2)	1.91 (3.1)	96.27	26.80	3.20	9.67	922	17.55	1.91
Weedy check	13.21 (174)	8.22 (67.0)	0.00	14.07	1.80	7.63	436	5.60	1.47
LSD (P=0.05)	0.47	0.41	7.14	3.12	0.45	0.49	78	-	-

* Values in parentheses are original values

Yield attributes and economic yield

The highest number of seeds/pod was recorded under hand weeding twice at 20 and 40 DAS followed by herbicidal application of imazethapyr + imazamox quizalofop-ethyl *fb* chlorimuron-ethyl and chlorimuron-ethyl apparently owing to higher WCE under these treatments. All the herbicidal treatments and hand weeding produced heavier 100-seeds (8.06 to 9.67 g) than weedy check (7.63 g) on account of favorable conditions under the reduced weed stress in these treatments than weedy check.

Yield was significantly higher under all the herbicidal treatments (589-797 kg/ha) compared to weedy check (436 kg/ha). Two hand weeding (20 and 40 DAS) gave significantly the highest seed yield (922 kg/ha) among all the treatments. Among all the herbicides, imazethapyr + imazamox produced significantly higher seed yield followed by quizalofop-ethy *fb* chlorimuron-ethyl and chlorimuron-ethyl. Halvankar *et al.* (2005) also reported that application of imazamox + imazethapyr 75 g/ha effectively controlled the weeds over weedy check and also increased the yield of soybean.

Maximum net monetary return (NMR) was recorded under imazethapyr + imazamox (` 18249/ha) followed by hand weeding twice (` 17549/ha) and other herbicidal treatments, *viz.* chlorimuron-ethyl (` 17127/ha), quizalofop-ethyl *fb* chlorimuron-ethyl (` 16738/ha), pendimethalin (` 13788/ha), alachlor (` 13516/ha) and quizalofop-ethyl (` 12438/ha) and lowest NMR was recorded under weedy check (` 5604/ha) followed by glyphosate (` 8416/ha). Pathak (2007) observed that the maximum net-return (` 14796/ha) was recorded in quizalofop-ethyl 50 g + chlorimuron-ethyl 9 g/ha followed by two hand weeding and imazethapyr 150 g/ha being the minimum (` 2609/ha) under untreated plot.

Benefit cost ratio was higher under chlorimuron-ethyl (2.35). Imazethapyr + imazamox and quizalofop-ethyl *fb* chlorimuron-ethyl gave higher profit with B:C ratio of 2.33 and 2.19, respectively than other herbicidal treatments due to lower cost and higher seed yield over other weed control treatments, whereas the weedy check gave least B:C ratio (1.47). Pathak (2007) revealed that combined application of quizalofop-ethyl 50 g + chlorimuron-ethyl 9 g/ha fetched the highest, B:C ratio (2.26), whereas, it was minimum (1.7) under weedy check plots.

SUMMARY

The seed yield of soybean was significantly higher under two hand weeding at 20 and 40 DAS followed by imazethapyr + imazamox, quizalofop-ethyl *fb* chlorimuron-ethyl and chlorimuron-ethyl than pre-plant incorporation of glyphosate, pre-emergence application of pendimethalin and alachlor and post-emergence application of quizalofop-ethyl and weedy check. Uncontrolled weeds in weedy check resulted yield loss of 52.25% in soybean.

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Short communication

Weed management in sesame with sequential application of herbicides

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Sesame (*Sesamum indicum* L.) is one of the most important oilseed crops next to groundnut, rapeseed and mustard in India. It is the oldest oilseed crop known to human being and used by man since antiquity. In India, sesame was cultivated in an area of 1.70 million hectares with a production of 0.68 million tonnes and average productivity of 402 kg/ha. Among the several constraints in sesame production, heavy weed infestation is one of the major factors limiting the yield of sesame. The loss of seed yield due to uncontrolled weed growth in sesame has been reported as high as 70% in sandy loam soils (Dungarwal *et al.* 2003). Pre-emergence application of pendimethalin 1000 g/ha is recommended for line sown sesame to control the weeds, but the selectivity of pendimethalin is mainly depends on soil type and depth of sowing of crop. In broadcasted sesame, most of the crop seeds are placed at shallow depth, hence applied pre-emergence herbicides comes in close contact with crop seeds results in phytotoxicity or stand loss of sesame. In order to achieve the broad spectrum and season long weed control in broadcasted sesame, the present experiment was undertaken to identify the suitable pre-and post-emergence herbicide in sandy loam soils.

A field experiment was conducted during summer season of 2015 at S.V. Agricultural College, Tirupati campus of Acharya N.G. Ranga Agricultural University, Andhra Pradesh. The soil of the experimental field was sandy loam in texture with low in organic carbon, available nitrogen and available phosphorus and medium in available potassium with a soil P^H of 6.4. The experiment was laid out in a randomized block design with eleven treatments and three replications. The treatments consisted of pre-emergence application of pendimethalin 750 g/ha, oxyfluorfen 75 g/ha, oxadiargyl 75 g/ha alone and sequential application of these pre-emergence herbicides with post-emergence herbicides *viz*., quizalofop 50 g/ha and propaquizafop 60 g/ha applied at 20 DAS including two hand weedings at 20 and 40 DAS and unweeded check (Table 1). Sesame seed variety '*YLM-66*' at 7 kg/ha was broadcasted on 12th January, 2015 by mixing the seed with sand (1:3) for uniform distribution of seed. The crop was harvested on 9th April, 2015. The recommended dose of 60, 20 and 20 kg N, P_2O_5 and K_2O/ha was applied in the form of urea, single super phosphate and muriate of potash, respectively. The half of the dose of nitrogen along with entire dose of phosphorus and potassium were applied as basal at the time of sowing and the remaining half of the dose of nitrogen was top dressed at 30 DAS. The crop was irrigated whenever needed. The pre-and post-emergence herbicides were applied at one and 20 DAS, respectively with the help of knapsack sprayer fitted with flat fan nozzle by using spray fluid at 500 l/ha. The category wise weed density and dry weight of weeds associated with crop were recorded at harvest and subjected to square root ($\sqrt{x+0.5}$) transformation before statistical analysis. The economics was calculated on the basis of prevailing market price of sesame seed. All the recommended management practices, except weed management were adopted to raise the broadcasted sesame.

Effect on weeds

The major weed flora observed in the experimental field was *Cyperus rotundus* (40.0%), *Commelina benghalensis* (10.0%), *Cleome viscosa* (8.0%), *Boerhavia diffusa* (5.0%), *Phyllanthus niruri* (5.0%), *Dactyloctenium aegyptium* (5.0%) and *Digitaria sanguinalis* (4.0%) in broadcasted sesame. The density and dry weight of grasses, sedges and broad-leaved weeds were significantly influenced by the application of pre-and post-emergence herbicides. Among the sequential application of herbicides, the lowest density and dry weight of grasses was recorded with pre-emergence application of pendimethalin 750 g/ha + quizalofop 50 g/ha applied at 20 DAS, which was statistically similar to pre-emergence application of pendimethalin 750 g/ha + propaquizafop 60 g/ha applied at 20 DAS. However, hand weeding twice at 20 and 40 DAS recorded

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significantly lesser density and dry weight of grasses than rest of the weed management practices (Table 1). Pendimethalin controlled most of the annual grasses and broad-leaved weeds at the time of germination of weed seeds and the late coming grassy weeds were effectively controlled by application of quizalofop or propiquizafop. These results were in conformity with the findings of Sivasankar and Subramanyam (2011). The lowest density and dry weight of sedges and broad-leaved weeds were recorded with pre-emergence application of oxyfluorfen 75 g/ha + propiquizafop 60 g/ha or quizalofop 50 g/ha applied at 20 DAS and both the sequential application of herbicides were comparable with each other, among the chemical weed management practices. This might be due to effective control of annual sedges and broad-leaved weeds by the pre-emergence application of oxyfluorfen 75 g/ha, which was more effective in suppressing the weed growth compared to pendimethalin 750 g/ha or oxadiargyl 75 g/ha. Pendimethalin 750 g/ha was failed to control *Commelina benghalensis* more effectively than rest of the pre-emergence herbicides tried. The lowest total weed dry weight with higher weed control efficiency was recorded with hand weeding twice at 20 and 40 DAS due to complete removal of all the categories of weeds more effectively including the tubers of *Cyperus rotundus* as it accounts for 40% of the total weed density in the experimental field. The next best weed management practice in recording lower weed dry weight and higher weed control efficiency was the pre-emergence application of oxyfluorfen 75 g/ha + quizalofop 50 g/ha applied at 20 DAS. These results were in conformity with the findings of Vafaei *et al*. (2013) in sesame. Pre-emergence application of oxadiargyl 75 g/ha alone or in combination with post-emergence herbicides *i.e.* quizalofop or propaquizafop applied at 20 DAS were not effective as that of oxyflurfen or pendimethalin alone or in combination with post-emergence herbicides applied in broad casted sesame.

Effect on crop

The yield components and seed yield of broadcasted sesame were significantly influenced by the sequential application of pre-and post-emergence herbicides (Table 2). The highest number of capsules/plant, number of seeds/capsule, test weight and seed yield of sesame were recorded with two hand weedings at 20 and 40 DAS and it was closely followed by pre-emergence application of oxyfluorfen 75 g/ha + quizalofop 50 g/ha applied at 20 DAS. The yield increased in these weed management practices was 71.39% and 61.13% compared to unweeded check. This might be due to decreased competition for growth resources by weeds resulting

Table 1. Weed density, weed dry weight and weed control efficiency (%) as influenced by different pre-and post- emergence herbicides in broadcasted sesame

Treatment	Dose (g/ ha)	Time of application (DAS)	Weed density (no./ m^2)				Weed dry weight (g /m^2)				Weed control efficiency (%)
			Grasses	Sedges	BLWs	Total	Grasses	Sedges	BLWs	Total	
Pendimethalin	750	1	16.27 (4.23)	126.70 (11.36)	55.90 (7.54)	198.87 (14.19)	15.46 (4.00)	44.82 (6.75)	38.02 (6.14)	98.30 (9.98)	31.97 (34.41)
Oxyfluorfen	75	1	18.44 (4.50)	118.90 (11.01)	51.40 (7.23)	188.74 (13.83)	17.51 (4.24)	43.54 (6.65)	37.89 (6.13)	98.94 (10.01)	31.52 (34.13)
Oxadiargyl	75	1	22.67 (4.97)	130.60 (11.53)	60.8 (7.86)	214.07 (14.73)	19.62 (4.49)	45.02 (6.77)	38.24 (6.16)	102.88 (10.20)	28.80 (32.43)
Pendimethalin + quizalofop	750 + 50	1 + 20	6.01 (2.63)	76.80 (8.85)	39.40 (6.34)	122.21 (11.13)	3.91 (2.10)	32.60 (5.77)	32.42 (5.68)	68.93 (8.36)	52.30 (46.30)
Oxyfluorfen + quizalofop	75 + 50	1 + 20	7.89 (2.99)	64.30 (8.11)	30.10 (5.55)	102.29 (10.19)	4.57 (2.25)	29.50 (5.49)	23.78 (4.88)	57.85 (7.67)	59.97 (50.73)
Oxadiargyl + quizalofop	75 + 50	1 + 20	10.80 (3.47)	86.80 (9.41)	44.70 (6.75)	142.30 (12.01)	6.24 (2.60)	35.87 (6.05)	35.84 (5.96)	77.95 (8.89)	46.06 (42.72)
Pendimethalin + propaquizafop	750 + 60	1 + 20	6.82 (2.79)	80.90 (9.08)	38.40 (6.26)	126.12 (11.31)	4.08 (2.14)	33.94 (5.88)	34.92 (5.89)	72.94 (8.60)	49.53 (44.71)
Oxyfluorfen + propaquizafop	75 + 60	1 + 20	8.04 (3.02)	63.00 (8.02)	29.20 (5.47)	100.24 (10.09)	4.92 (2.33)	30.08 (5.55)	25.82 (5.08)	60.82 (7.86)	57.92 (49.54)
Oxadiargyl + propaquizafop	75 + 60	1 + 20	12.04 (3.66)	84.8 (9.30)	46.30 (6.86)	143.14 (12.05)	6.94 (2.73)	37.45 (6.18)	36.08 (5.99)	80.47 (9.03)	44.32 (41.72)
Two hand weedings	-	20 + 40	5.24 (2.47)	53.80 (7.42)	16.60 (4.15)	75.64 (8.77)	5.32 (2.41)	8.00 (2.92)	5.05 (2.33)	18.37 (4.36)	87.28 (69.26)
Unweeded check			44.8 (6.96)	147.20 (12.24)	92.40 (9.67)	284.40 (16.97)	42.75 (6.57)	51.05 (7.18)	50.72 (7.16)	144.52 (12.04)	-
LSD (P=0.05)			0.22	0.58	0.520	1.23	0.31	0.42	0.40	0.75	-

Figures in parentheses are the square root transformed ($\sqrt{x+0.5}$) values

Table 2. Effect of different pre-and post-emergence herbicides on yield attributes, seed yield and economics of broadcasted sesame during summer, 2015

Treatment	Dose (g/ha)	Time of application (DAS)	Number of capsules/ plant	Number of seeds/ capsule	Test weight (g)	Seed yield (kg/ ha)	Net returns (Rs./ha)	Benefit-cost ratio
Pendimethalin	750	1	30.6	43.2	2.80	554	13380	1.67
Oxyfluorfen	75	1	31.9	45.4	2.82	582	16310	1.88
Oxadiargyl	75	1	28.9	41.0	2.78	527	13044	1.70
Pendimethalin + quizalofop	750 + 50	1 + 20	35.2	52.5	2.90	752	22990	2.04
Oxyfluorfen + quizalofop	75 + 50	1 + 20	37.2	59.0	2.93	784	26160	2.25
Oxadiargyl + quizalofop	75 + 50	1 + 20	33.6	48.4	2.85	677	19774	1.95
Pendimethalin + propaquizafop	750 + 60	1 + 20	34.8	51.2	2.89	751	23200	2.06
Oxyfluorfen + propaquizafop	75 + 60	1 + 20	36.8	57.4	2.92	779	26130	2.27
Oxadiargyl + propaquizafop	75 + 60	1 + 20	33.1	47.2	2.84	666	19384	1.94
Two hand weedings	-	20 + 40	40.1	61.4	2.98	833	24620	1.97
Unweeded check			25.4	38.9	2.76	486	11500	1.65
LSD (P=0.05)			0.53	1.65	0.05	25.0	1115	0.03

in better photosynthesis and resultant partitioning in crop manifested to increase all the yield components. These results were in conformity with those of Sootrakar *et al.* (1995). The highest net returns were obtained with pre-emergence application of oxyfluorfen 75 g/ha + quizalofop 50 g/ha applied at 20 DAS and the highest benefit-cost ratio was obtained with pre-emergence application of oxyfluorfen 75 g/ ha + propaquizafop 60 g/ha applied at 20 DAS and both the weed management practices obtained maximum net returns and benefit-cost ratio than hand weeding twice due to reduced cost of cultivation and increased seed yield. Among the herbicidal treatments, the lowest yield components, seed yield and net returns were recorded with pre-emergence application of oxadiargyl 75 g/ha alone or in combination with quizalofop/propiquizafop due to reduced stature of yield components as a result of poor weed control. Further, pre-emergence application of oxadiargyl 75 g/ha showed phytotoxicity rating of 4.0 in 0-10 scale where, '0' indicates no injury and normal growth and '10' indicates complete destruction of broadcasted sesame. Nethra and Jagannath (2011) also reported the phytotoxicity effect of oxadiargyl on germination and early seedling growth of sunflower and maize.

SUMMARY

A field experiment was conducted at S.V. Agricultural College Farm, Tirupati during summer, 2015 in a randomized block design with eleven weed management practices consisting of pre-emergence application of pendimethalin 750 g/ha, oxyfluorfen 75 g/ha, oxadiargyl 75 g/ha alone and in combination with post-emergence application of quizalofop 50 g/ha and propaquizafop 60 g/ha at 20 DAS, two hand weedings and unweeded check. The lowest density and dry weight of weeds with higher weed control efficiency, higher stature of yield components and seed yield of broadcasted sesame were registered with two hand weedings at 20 and 40 DAS. The next best weed management practice for broad spectrum weed control and increased seed yield of broadcasted sesame was with pre-emergence application of oxyfluorfen 75 g/ha + quizalofop 50 g/ha applied at 20 DAS. Pre-emergence application of oxadiargyl 75 g/ ha alone or in combination with post-emergence herbicides failed to control the weeds as the pre-emergence application of oxadiargyl recorded phytotoxicity rating of 4.0 on sesame seedlings in 0-10 scale in sandy loam soils.

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Short communication

Weed dynamics and weed control efficiency under different weed management practices for increased productivity of mustard

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Brassica juncea is the third important oilseed crop in the world after soybean and oilpalm. In India, as mustard is exclusively grown under irrigated conditions, problem of weeds poses a serious threat to its potential production. Among the factors responsible for low productivity of Indian mustard, poor weed management ranged from 10-58% yield loss (Banga and Yadav 2001). Weed management is necessary to achieve higher yield as weeds compete for water, nutrients, light, oxygen and carbon dioxide and space. At present, hand weeding is the only method employed for controlling weeds in this crop. But most of the farmers of India do not adopt weed management in mustard field, because of unavailability of adequate labour at peak period of crop weeds competition and rising in labour wages. Manual weeding is effective but, it is cumbersome, time consuming and uneconomical. Herbicide would be one of the possible options to minimize weed menace, and may also increase the profit, better weed control and save time and labour. Hence, keeping in view above considerations, the present study was undertaken to study the effect of weed management on weed dynamics and yield of mustard.

An experiment was conducted during *Rabi* season of 2014-15 at Rajasthan College of Agriculture, Udaipur to study effect of weed management practices on weed dynamics and productivity of mustard (*Brassica juncea* L.). The soil of experimental site was clay loam in texture, having slight alkaline reaction (pH 8.2), medium in available nitrogen (281.4 kg/ha), phosphorus (24.5 kg/ha) and potassium (238 kg/ha). The experiment consisted of weedy check, one hand weeding at 20 days after sowing (DAS), two hand weeding at 20 and 40 DAS, fenoxaprop-p-ethyl 0.075 kg/ha at 10 DAS, fluazifop-p-butyl 0.055 kg/ha at 10 DAS, quizalofop-p-ethyl 0.050 kg/ha at 30 DAS, fenoxaprop-p-ethyl 0.075 kg/ha at 10 DAS + one hoeing at 40 DAS, fluazifop-p-butyl 0.055 kg/ha at 10 DAS + one hoeing at 40 DAS, isoproturon 1.25 kg/ha at 30 DAS and weed free check. The experiment was laid out in a randomized block design and replicated four times. Mustard variety '*Bio-902*' was sown on 1st Nov, 2014 at 40 x 10 cm row and plant to plant spacing with a seed rate of 3 kg/ha. The 1/3 dose of nitrogen and full dose of phosphorus was applied at the time of sowing and remaining 2/3 nitrogen was top dressed in two equal splits at first (35 DAS) and second irrigation (70 DAS), respectively. Herbicides were sprayed by knapsack sprayer fitted with flat fan T-jet nozzle using a spray volume of 500 l/ha. Weedy check plots remained infested with native population of weeds till harvest. Observations on weeds were recorded with the help of quadrate 0.5 x 0.5 m placed randomly at 2 spots in each plot at 60 DAS. The data on weeds were subjected to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution (Gomez and Gomez 1984). Weed indices like weed control efficiency was calculated by using the formulae suggested by Varshney (1990).

The experimental crop was infested with *Phalaris minor, Cyperus rotundus, Cynodon dactylon, Chenopodium album, Chenopodium murale, Rumex acetosella, Convolvulus arvensis, Parthenium hysterophorus, Anagallis arvensis* and *Cichorium intybus*. The above data showed that dicot weeds were dominant at the experimental site.

Significantly the lowest weed density and dry weight and highest weed control efficiency were observed in two hand weeding at 20 and 40 DAS followed by fluazifop-p-butyl 0.055 kg/ha at 10 DAS + hoeing at 40 DAS and fenoxaprop-p-ethyl 0.075 kg/ha at 10 DAS + hoeing at 40 DAS. The results were also supported by the results of Chauhan *et al.* (2005) and Degra *et al.* (2011).

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Table 1. Effect of weed control on weed density, dry matter accumulation and weed control efficiency at 60 DAS in Indian mustard

Treatment	Weed density ($no./m^2$)			Weed dry matter (kg/ha)			Weed control efficiency (%)		
	Monocot	Dicot	Total	Monocot	Dicot	Total	Monocot	Dicot	Total
Fenoxaprop-p-ethyl 0.075 kg/ha at 10 DAS	3.6(12.7)	6.8(45.7)	7.6(58.5)	75.0	101.9	176.9	60.0	18.3	43.5
Fluazifop-p-butyl 0.055 kg/ha at 10 DAS	3.6(12.6)	6.7(44.7)	7.6(57.3)	74.6	100.3	174.8	60.4	19.5	44.2
Quizalofop-p-ethyl 0.050 kg/ha at 30 DAS	3.2(10.0)	6.7(44.5)	7.4(54.5)	64.9	89.8	154.5	65.5	28.0	50.6
Fenoxaprop-p-ethyl 0.075 kg/ha at 10 DAS + one hoeing at 40 DAS	1.6(2.0)	1.9(3.5)	2.4(5.5)	17.9	15.4	33.4	90.5	87.6	89.3
Fluazifop-p-butyl 0.055 kg/ha at 10 DAS + one hoeing at 40 DAS	1.6(2.1)	1.9(3.2)	2.4(5.4)	14.6	15.2	29.8	92.3	87.7	90.4
Isoproturon 1.25 kg/ha at 30 DAS	4.4(18.6)	6.4(40.0)	7.7(58.6)	93.8	86.9	180.7	50.2	30.6	42.3
One hand weeding at 20 DAS	3.4 (11.2)	6.4(41.0)	7.3(52.2)	71.5	64.6	136.1	62.0	48.4	56.6
Two hand weeding at 20 and 40 DAS	1.6(2.1)	1.9(3.0)	2.4(5.1)	12.6	14.5	27.1	93.3	88.4	91.3
Weedy check	8.6* (73.0)	9.3(85.7)	12.6(158.7)	188.3	125.2	313.6	0.00	0.0	0.0
Weed free check	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.0	0.0	0.00	100.0	100.0	100.0
LSD (P=0.05)	0.3	0.4	0.4	8.9	9.9	13.3	-	-	-

Figures in parentheses are original value subjected to square root transformation ($\sqrt{x + 0.5}$)

Table 2. Effect of weed control on yield of Indian mustard

Treatment	Yield (t/ha)			Harvest index (%)
	Seed	Straw	Biological	
Fenoxaprop-p-ethyl 0.075 kg/ha at 10 DAS	1.49	4.69	6.18	24.1
Fluazifop-p-butyl 0.055 kg/ha at 10 DAS	1.50	4.70	6.20	24.3
Quizalofop-p-ethyl 0.050 kg/ha at 30 DAS	1.52	4.80	6.32	24.0
Fenoxaprop-p-ethyl 0.075 kg/ha at 10 DAS + one hoeing at 40 DAS	1.91	5.20	7.12	26.8
Fluazifop-p-butyl 0.055 kg/ha at 10 DAS + one hoeing at 40 DAS	1.91	5.22	7.14	26.8
Isoproturon 1.25 kg/ha at 30 DAS	1.39	4.56	5.95	23.5
One hand weeding at 20 DAS	1.65	4.89	6.55	25.3
Two hand weeding at 20 and 40 DAS	1.95	5.57	7.52	26.0
Weedy check	1.17	3.94	5.11	22.8
Weed free check	1.98	5.78	7.76	25.5
LSD (P=0.05)	0.18	0.47	0.46	NS

Different weed management treatments significantly affected the seed and straw yield of mustard. Seed yield increased significantly in absence of crop-weed competition, which was created due to two hand weeding at 20 and 40 DAS followed by fluazifop-p-butyl 0.055 kg/ha at 10 DAS + hoeing 40 DAS and fenoxaprop-p-ethyl 0.075 kg/ha at 10 DAS + hoeing at 40 DAS. The results so obtained for highest seed and straw yield under weed free check were in close conformity with the findings of Chauhan *et al.* (2005) and Kour *et al.* (2014).

SUMMARY

The lowest weed density and weed dry weight, and highest weed control efficiency was recorded in two hand weeding at 20 and 40 DAS. However, it was also noticed that herbicides along with one hand hoeing were equally good in terms of suppressing weed population at 60 DAS. The maximum seed yield was observed under two hand weeding at 20 and 40 DAS.

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Short communication

Biocontrol efficiency of *Zygogramma bicolorata* at different growth stages of *Parthenium hysterophorus*

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Key words: Biocontrol efficiency, Biological control, Parthenium, *Zygogramma bicolorata*

Parthenium hysterophorus L. is a highly invasive plant of global significance. It is a herb of neotropical origin which now has spread to many parts of the world (Adkins and Shabbir 2014). The weed was accidentally introduced to India in 1955 through the imported food grains and at present it has invaded throughout India in about 35 million hactares of land (Sushilkumar and Varshney 2009, Sushilkumar 2014). It is notorious for causing allergic reacions (Kologi *et al.* 1997) besides a threat to biodiversity and loss of crop productivity (Adkins and Shabbir 2014, Sushilkumar, 2014). In Pakistan, this weed has been spreading very fast since last couple of decades and it has become a major weed of wastelands, fallow lands, roadsides and protected areas where it is rapidly replacing the native flora (Shabbir *et al.* 2012, Mujahid 2015). It is also reported from some cereal and vegetable crops (Safdar *et al.* 2015, Javaid and Anjum 2005) and ornamental plant nurseries (Shabbir *et al.* 2012).

Different control approaches have been used for the management of *Parthenium*. Although manual and chemical methods are effective strategies to control the weed in agricultural fields, but these are not economical in pastures and large natural areas or wastelands (Krishnamurthy *et al.* 1977). Biological control of *Parthenium* weed is considered to be the most cost effective, environmentally safe and ecologically viable method (Dhileepan *et al.* 2000). It was documented to control *Parthenium* worth of Rs 10 million in terms of herbicide cost after initial release of bioagent *Zygogramma bicolorata* Pallister at Jabalpur, India (Sushsilkumar 2006) and it was estimated that this bioagent has checked the spread of Parthenium in about eight million hactares of land since its release in India (Sushikumar and Yaduraju, 2015). In Pakistan, *Z. bicolorata* fortuitously arrived from India to Pakistan, by either flying or eggs or beetles carried on vehicles like it has been suspected in Nepal (Shrestha *et al.* 2015). Its possible entry in Pakistan was surmised by Sushilkumar (2005) due to its presence in abundance near Wagah border of India and Pakistan (Sushilkumar 2014). This beetle was first reported form the Changa Manga plantation near the district of Lahore (Javaid and Shabbir 2007) and more recently in six more districts including the capital Islamabad (Shabbir *et al.* 2012). *Zygogramma bicolorata* was first introduced to India in 1984 where it became abundant within 3 years after its release, resulting in a significant reduction in *Parthenium* weed densities in localized areas (Jayanth 1987, Jayanth and Bali 1994, Jayanth and Ganga-Visalakshy 1996).

It has been observed in Pakistan that *Parthenium* weed emerges earlier and present well in advance stages of its growth before *Z. bicolorata* appears in mid spring (March). Further, there is no information available on the response of the weed to feeding caused by *Z. bicolorata* in Pakistan. Hence, in this study we assessed the effectiveness of *Z. bicolorata* as a biological control agent, with an emphasis on the response of the weed to the different defoliation pressures and at different growth stages of *Parthenium* weed grown under glasshouse conditions.

Parthenium were sown at a depth of about 2 cm in the fertilized soil contained in porous rectangular trays (50 × 23 × 6 cm l/w/h). After germination, 2-weeks old seedlings of *Parthenium* weed were transplanted from the trays into three sets of earthen pots each containing 6 kg of the fertilized garden soil. One seedling of *Parthenium plant*/pot was transplanted carefully in the middle of pots. First set was labelled as "flowering' because the aim was to apply the biological control agent, *Z. bicolorata* at a time when these plants would be at the flowering stage of their growth. There were four treatments, 1, 2 and 3 pairs of *Z. bicolorata* adults to be applied on replicated *Parthenium* plants and fourth one was kept

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as a control. A total of twelve pots with 3 replicates for each treatment were distributed randomly on the concrete platforms inside the glass house.

Second set was labelled as 'pre-flowering' and third set was designated as "young plants'. Same four treatments were made as described above. After six weeks of initial transplantation, plant batches in three different growth stages, *viz.* flowering, pre-flowering and young were available for further experimentation.

In order to apply *Z. bicolarata,* several field visits were made around the wastelands of Lahore for the collection of adult beetles. Once collected, the adult beetles were applied in three different pairs (1-pair, 2-pairs and 3-pairs) and at three different growth stages (Flowering, pre-flowering and young) of *Parthenium* weed at a same time in the first week of May 2015. To stop the escape of adult beetles, the individual pots were covered with an insect proof net cage. Three replicates at each growth stage (flowering, pre-flowering and young) were kept as control where no beetle was applied but plants were caged.

Throughout the experiment, the level of insect damage inflicted upon the *Parthenium* weed plants was monitored on a weekly basis. A scale was developed to assess the degree of defoliation damage (%) caused by the beetle and its larvae. This was based on the number of leaves per plant damaged at the various growth stages (*i.e.* if two leaves were found to be eaten at the six-leaf stage, a 33% damage level was designated, similarly 50 and 66% level designated if three or four leaves being damaged, respectively at six leaf stage. After 12-weeks of agent application, harvesting of the *Parthenium* weed plants was done manually by uprooting the complete plant carefully along with roots. After that plant height, shoot length, root length, number of flowers was recorded. After this individual treatment plants were packed in brown paper bags and placed in an oven set at 60°C for dry biomass determination.

Impact on *Parthenium*

The defoliation level of *Parthenium* increased gradually with the time and this effect was seen in all treatment pairs of the agent applied. The damage (defoliation %) recorded ranged 44-57% at flowering, 40-54% at pre-flowering and 100% at young stage of the weed (Fig. 1). At the end of experiment, on average the biological control agent in different pairs inflicted a defoliation of 69.3, 68.3 and 97.6% when applied at the flowering, pre-flowering and young stages, respectively (Fig. 1).

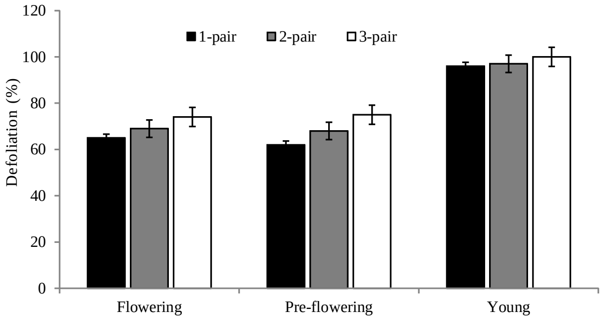

Fig. 1. Graphical representations of damage caused by the different pairs (1, 2 and 3) of the biological control agent, *Z. bicolorata* when applied at different growth stages (flowering, pre-flowering and young) of *Parthenium* weed

The number seeds produced per plant gradually decreased as the density (number of pairs) of *Z. bicolorata* adults increased. The number of seeds produced by *Parthenium* weed was reduced to 60.8, 73.9 and 81.6% when *Z. bicolorata* was applied at flowering stage in ratios of 1, 2 and 3 pairs, respectively (Fig. 2). No seed was produced even when *Z. bicolorata* applied in the lowest ratio (1-pair/ plant) at the young stage of weed growth (Fig. 2). In *Lythrum salicaria* (L.) defoliation due to Chyrsomelid beetles resulted in significant reduction in seed production by more than 99% (Blossey 1992).

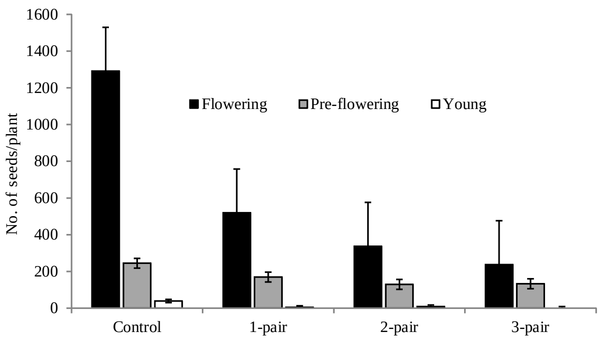

Fig. 2. Effect of different pairs (1, 2 and 3) of the biological control agent, *Z. bicolorata* on total number seeds/plant produced by *Parthenium* weed when applied at different growth stages (flowering, pre-flowering and young)

All three different pairs (1, 2 and 3) of *Z. bicolarata* exhibited suppressive effects on the shoot length of the *Parthenium* weed (Fig. 3). When *Z. bicolarata* was applied in 3-pairs at the flowering, pre-flowering and young stages, the shoot length was decreased to 37, 19.4 and 43%, respectively as compared to the control plants. The above ground dry biomass of *Parthenium* weed plants grown at the different growth stages was significantly and progressively reduced with increasing density of the biological control agent, *Z. bicolorata*. This gradual trend in biomass reduction was similar at flowering and pre-flowering growth stages of *Parthenium* weed as compared to control. The dry biomass of *Parthenium* weed was reduced to 41.3, 62 and 70.6% when *Z. bicolorata* was applied at flowering stage in ratios of 1, 2 and 3 pairs, respectively (Fig. 3). However, at the young stage *ca*. 90% reduction in biomass was recorded in all three densities of the *Z. bicolorata* applied (Fig. 3). The effectiveness of the agent was found to be density dependent, as defoliation and seed suppression was highest when three pairs of *Z. bicolorata* were applied at different growth stages of the weed. In field this will depend upon the population dynamics of agent and suitable climatic conditions as exhibited by *Z. saturalis* on rag weed (*Ambrosia artimissifolia* L.) a close relative of *Parthenium* weed (Reznik *et al.* 1994).

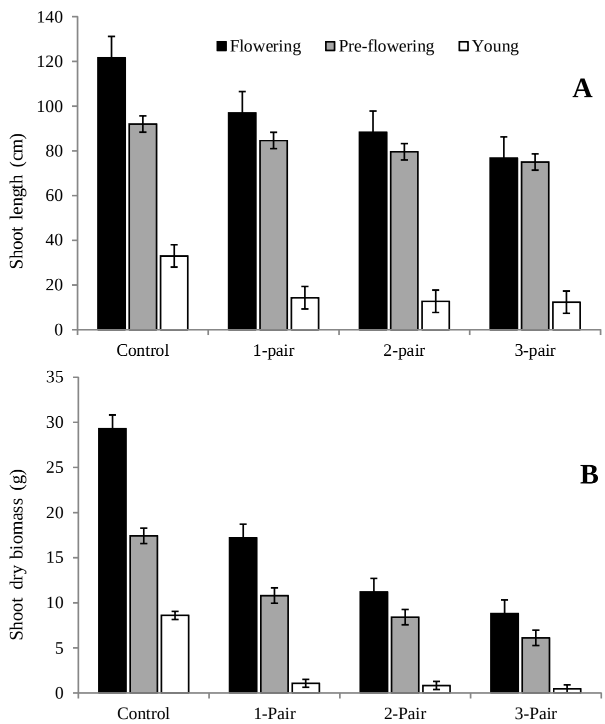

Fig. 3. Effect of different pairs (1, 2 and 3) of the biological control agent, *Z. bicolorata* on (a) shoot length and (b) shoot dry biomass of *Parthenium* weed when applied at different growth stages (flowering, pre-flowering and young).

The defoliation caused by *Z. bicolorata* had an immediate negative effect upon the weed performance and as a consequence the growth, reproduction and fitness of the *Parthenium* weed can be negatively affected. Prins and Verkaar (1992) also found similar trends in their study on *Z. bicolorata*. In the current study, *Z. bicolorata* caused 90-100% defoliation resulting in significant reduction in weed height, biomass and seed production. In central Queensland, Australia, some similar results were also documented by Dhileepan *et al.* (2000). Likewise, feeding by an introduced *Z. saturalis* reduced the biomass and plant height in ragweed (Kovalev and Medvedev 1983).

Zygogramma bicolorata is an effective biocontrol agent that can significantly reduce the vegetative and reproductive growth of *Parthenium* weed. However, the effectiveness of the biological control *Z. bicolarata* can be further enhanced if it is applied at the early growth stages (young or pre-flowering) of *Parthenium* weed.

SUMMARY

Parthenium hysterophorus L. (Asteraceae) commonly known as *Parthenium* weed, is a highly invasive weed that is considered as environmental, medical, and agricultural hazard. The objectives of this study was to test the impact of *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae), a classical biocontrol agent, in different ratios (1-pair, 2-pairs and 3-pairs) at three different growth stages (flowering, pre-flowering and young) of *Parthenium* weed to estimate the effectiveness of this agent in reducing its growth and reproduction potential. The damage (defoliation %) recorded was between 44-57% at flowering, 40-54% at pre-flowering and 100% at young stage of the weed. The defoliation significantly reduced the weed biomass, height and seed production. The damage inflicted by *Z. bicolorata* was more pronounced when it was applied in higher density and at early growth stages of the weed.

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Short communication

Herbicide tolerance of *Rabi* sorghum varieties and germplasm

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Sorghum (*Sorghum bicolor* (L.) Moench) is a staple cereal grown under moisture stress conditions with low inputs during rainy and post-rainy (*Rabi*) seasons. With the threat of climate change looming large on the crop productivity, sorghum being a drought hardy crop will play an important role in food, feed and fodder security in dry land economy. Weeds are a major deterrent in increasing the sorghum productivity as they compete with crop for soil moisture and nutrients, which are the major limiting factors in semi-arid areas. Therefore, efficient weed management becomes even more important under rainfed conditions. Atrazine (as pre-emergence) is the most widely used herbicide for weed control in grain sorghum. It has a low effectiveness on grasses (Dan *et al.* 2011) and its efficacy decreases under moisture stress conditions (Tapia *et al.* 1997). Atrazine may also cause carry over effects in subsequent sensitive crops under some conditions, so alternative treatments are needed (Ishaya *et al.* 2007, Keeling *et al.* 2013). Sensitivity of grain sorghum to currently available post-emergence herbicides is one of the major concerns to manage weeds that emerge after crop establishment (Archangelo *et al.* 2002). Presently, 2,4-D is the only post-emergence herbicide used to control broad-leaved weeds with varying degree of weed control and sensitivity in sorghum hybrids. Herbicide-tolerant crops make it possible to control weeds with non-selective herbicides. ALS-inhibitor herbicides *viz*., nicosulfuron and nimsulfuron are widely used to control broad-leaf and grassy weeds in corn (*Zea mays*), but the sorghum is susceptible to these herbicides. However, by transferring a major resistance gene from wild sorghum relative, researchers at Kansas State University (KSU), USA developed a grain sorghum that is resistant to several ALS-inhibiting herbicides as Steadfast (nicosulfuron), Accent (nicosulfuron), Resolve (rimsulfuron) and Ally (metsulfuron) (Tuinstra and Al-Khatib 2007, Tuinstra *et al.* 2009). Keeping these facts in view, the present experiment was conducted to evaluate the relative performance of *Rabi* sorghum germplasm and varieties to quizalofop ethyl, metsulfuron-methyl and carfentrazone-ethyl herbicides.

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A field experiment was conducted during *Rabi* 2010-11 at the Indian Institute of Millets Research, Hyderabad (Telangana) to screen the *Rabi* sorghum germplasm and varieties tolerant to quizalofop-ethyl, metsulfuron-methyl and carfentrazone-ethyl herbicides. The climate of the area is semi-arid and tropical, with an average annual rainfall of 618 mm (75-80% of which is received during June-September), minimum temperature of 8-10 ^{0}C in December, and maximum temperature of 40-42 ^{0}C in May. The soil was an Alfisol, Udic Rhodustalf, sandy loam (66% sand, 13% silt and 21% clay), with 7.82 pH, 0.18 dS/m electrical conductivity, low in available N (143 kg/ha) and phosphorus (19 kg P_2O_5 /ha) and medium in potassium (260 kg K_2O/ha) content. Sixty three germplasm (*PEC 2, PEC 5, PEC 7, PEC 15, PEC 22, PEC 26, EP 1, EP 9, EP 11, EP 12, EP 13, EP 14, EP 16, EP 17, EP 22, EP 24, EP 37, EP 41, EP 42, EP 45, EP 46, EP 52, EP 54, EP 55, EP 57, EP 59, EP 64, EP 65, EP 68, EP 78, EP 80, EP 81, EP 82, EP 84, EP 91, EP 92, EP 93, EP 94, EP 95, EP 97, EP 102, EP 103, EP 104, EP 105, EP 106, EP 107, EP 114, EP 115, EP 117, EP 120, EP 124, EP 127, EP 138, SEVS 2, SEVS 3, SEVS 20, EA 10, EA 11, EC 11, EC 12, EC 21, EC 33, EC 34*) collected from different agro-ecological regions of the country along with five *Rabi* sorghum cultivars (*DSV 6, M 35-1, CSV 216 R, Phule Chitra* and *Phule Maulee*) were evaluated for their relative tolerance to quizalofop-ethyl (40 g/ha), metsulfuron-methyl (4 g/ha), and carfentrazone-ethyl (20 g/ha). A control plot was also kept to compare the yield loss and herbicide injury. The experiment was conducted in micro-plots (1 m^2) and replicated thrice in a strip-plot design. The crop was sown in rows at 45 cm apart on 17th

November 2010. The herbicides were applied as post-emergence at 30 days after sowing (DAS) with knapsack sprayer fitted with flat-fan nozzles using spray volume of 500 liter water/ha. Fertilizer (60 kg N, 30 kg P_2O_5 and 20 kg K_2O/ha) was applied as recommended for *Rabi* grain sorghum in the area. All the phosphorus as single super phosphate and potassium as muriate of potash were applied as basal on the day of planting. Nitrogen as urea was applied in 2 splits, 50% at sowing and remaining at 35 DAS. The crop was raised under irrigated conditions and total three irrigations were applied during crop season. Sorghum panicles were manually harvested from 5 randomly selected plants in each plot, threshed, sun dried, weighed, and grain yield was adjusted to 14% moisture content. Weed count, for estimating weed density was recorded 20 days after herbicide application (50 DAS) with the help of a quadrate (0.50 x 0.50 m) placed in the centre of each plot. All the data were subjected to analysis of variance (ANOVA) by 'STATISTICS 8.1' software and the main effects and interactions were tested for significance. Treatment means obtained by ANOVA were compared using critical difference (LSD) at P=0.05 level of significance.

Effect on weeds

The field was infested mainly with *Parthenium hysterophorus* (43.36%), *Cyperus rotundus* (19.91%), *Celosia argentea* (20.38%), *Euphorbia geniculata* (12.42%) and others (*E. hirta* and *Digitaria sanguinalis*) (3.93%). Application of quizalofop-ethyl (40 g/ha) was found to be highly phytotoxic to the sorghum crop and resulted in to complete mortality of all the test genotypes and germplasm. None of the herbicides controlled *C. rotundus* (Table 1). Application of carfentrazone-ethyl (20 g/ha) being at par with metsulfuron-methyl (4 g/ha) significantly reduced the population of *E. geniculata* as compared to control. But carfentrazone-ethyl was less effective on *P. hysterophorus*. Application of metsulfuron-methyl at 4 g/ha significantly reduced the density of *P. hysterophorus* compared to control. Both the herbicides caused significant reduction in the population of *Celosia argentea*. Application of herbicides significantly brought down the population of total weeds as compared to control, but metsulfuron was superior in its efficacy than carfentrazone. Weed dry weight recorded at the harvest was however, not affected due to application of these herbicides. Different genotypes and germplasm had variable effects on various weeds. The lowest total weed density (23.56/m^2) was recorded with '*EP 11*' and the highest (62.44/m^2) with '*DSV 6*'. Weed dry weight differed significantly with genotypes. Maximum weed dry weight at harvest (92.67 g/m^2) was recorded with '*CSV 216R*' and minimum (48.0 g/m^2) with 'PEC 15'.

Effect on crop

Plant population did not vary significantly with application of herbicides (Table 2). Application of metsulfuron-methyl at 4 g/ha caused significant reduction in plant height (24. 3 cm) as compared to carfentrazone-ethyl at 20 g/ha (38.42 cm) and control (39.08 cm). Similar trend in plant height was observed at harvest. Panicle length increased significantly due to metsulfuron-methyl (14.51 cm) as compared to control (14.0 cm), but 100-seed weight decreased. Stover yield decreased significantly due to application of metsulfuron-methyl as compared to control. Reduction in plant height and stover yield due to metsulfuron-methyl indicates it toxicity on sorghum germplasm/genotypes. Harvest index also decreased due to metsulfuron, but the differences were not significant. Among genotypes, significantly the highest plant population/m row length (9.0) was recorded with '*EP 14*' and the lowest (3.22) with '*EC 33*'. Plant height at 25 days after herbicide spray varied significantly and ranged from 16.28 cm with '*DSV 6*' to 49.84 cm with '*EP 80*'. However, at harvest, '*EA 11*' recorded the maximum plant height (221 cm). Panicle length ranged from 8.73 cm with '*EC 34*' to 26.47 cm with '*EA 11*'. The other genotype with longer panicle length was '*EA 10*' (24.11 cm). The 100-seed weight of '*EP 105*', '*EA 11*' and '*CSV 216 R*' was quite low (1.87-1.97 g), whereas it was as high as 4.03 to 4.08 g in '*EP 93*', '*EP 91*', '*PEC 7*', '*PEC 15*', '*EP 117*'. The lowest stover yield (76 g/m^2) was recorded with '*DSV 6*' mainly due to shorter plant height. The highest stover yield (461 g/m^2) was recorded with '*EA 13*' followed by '*EP 45*' (437 g/m^2). The harvest index varied from 7.38% with '*EP 45*' to 38.4% with '*EC 11*'.

Post-emergence application of metsulfuron-methyl at 4 g/ha caused significant reduction (32.77%) in grain yield of sorghum (67.36 g/m^2) as compared to control (100.2 g/m^2). This might be due to significant reduction in 100-seed weight (4.94%) and plant dry biomass (15.03%). The grain yield with carfentrazone-ethyl (95.51g/m^2) was at par with control (Table 3). Among genotypes, '*EP 52*' produced the highest (163.60 g/m^2) and '*EP 107*' the lowest (21.53 g/m^2) grain yield. The herbicide tolerance of genotypes in terms of increased grain yield over control varied with different herbicides. Of the 68 genotypes evaluated, Phule Maulee, '*PEC 22*',

Table 1. Effect of herbicides and genotypes on weeds

Treatment	Weed density (no./m^2)						Total weed dry weight (g/m^2)
	Cyperus rotundus	*Euphorbia geniculata*	*Parthenium hysterophorus*	*Celosia argentea*	Others	Total	
Herbicide							
Metsulfuron-methyl 4 g/ha	10.32	2.08	5.55	1.04	2.31	21.30	64.65
Carfentrazone-ethyl 20 g/ha	12.25	1.49	22.00	4.70	1.31	41.75	70.02
Control	8.75	5.22	27.43	13.06	4.85	59.31	65.14
LSD (P=0.05)	NS	3.54	9.67	3.50	NS	16.15	NS
Genotypes							
DSV 6	28.67	1.78	24.00	5.78	2.22	62.44	77.33
M 35-1	21.33	1.33	19.11	8.89	2.22	52.89	86.17
CSV 216R	18.22	1.33	16.44	3.11	2.67	41.78	92.67
Phule Chitra	10.67	3.56	27.56	6.67	4.44	52.89	74.33
P. Maulee	15.11	3.56	19.56	4.00	3.56	45.78	68.33
PEC 26	29.33	1.78	16.89	2.67	1.33	52.00	72.33
PEC 22	19.11	1.33	21.33	2.22	2.67	46.67	71.33
EP 95	20.00	4.44	28.00	8.00	1.78	62.22	66.67
EP 94	9.33	2.22	24.89	7.11	3.11	46.67	55.00
EP 93	5.33	2.67	26.67	7.56	1.78	44.00	59.33
EP 92	1.78	4.00	23.11	3.56	1.78	34.22	79.83
EP 91	4.44	1.78	23.56	7.56	2.67	40.00	73.67
SEVS 3	2.67	2.67	22.22	4.44	2.22	34.22	64.67
SEVS 2	10.22	1.78	30.67	5.33	2.22	50.22	77.67
EA 11	14.67	3.11	22.67	4.89	3.11	48.44	68.00
EA 10	12.44	3.56	25.33	7.56	4.00	52.89	75.00
SEVS 20	8.44	4.44	20.00	5.78	5.33	44.00	72.00
PEC 2	2.67	4.89	16.00	4.89	2.67	31.11	83.00
PEC 5	1.78	4.44	17.33	6.67	3.11	33.33	57.33
PEC 7	0.89	3.56	17.78	5.33	2.67	30.22	61.67
PEC 15	3.11	5.33	14.22	5.33	1.78	29.78	48.00
EP 97	0.00	7.56	16.44	3.11	0.89	28.00	64.33
EP 102	9.33	1.33	14.22	7.11	4.00	36.00	68.67
EP 105	6.67	3.56	18.67	4.00	2.22	35.11	69.17
EP 103	12.89	3.56	15.11	4.89	1.78	38.22	57.00
EP 104	13.33	3.11	12.22	2.22	1.33	34.22	68.00
EC 11	18.22	0.89	13.78	5.78	1.33	40.00	58.33
EC 12	12.00	1.78	12.44	6.22	2.22	34.67	63.67
EC 21	35.56	0.44	12.44	5.33	5.33	59.11	73.67
EC 33	31.11	3.11	8.00	6.22	3.11	51.56	62.67
EC 34	14.67	3.56	11.11	6.22	1.78	37.33	76.67
EP 120	12.89	1.33	19.56	4.89	1.78	40.44	88.67
EP 124	20.44	2.67	23.11	5.78	2.67	54.67	87.33
EP 127	24.44	0.89	20.89	5.78	2.67	54.67	74.33
EP 138	13.78	1.78	22.22	4.44	1.33	43.56	73.00
EP 117	11.56	2.22	27.11	6.67	2.67	50.22	67.00
EP 115	6.67	3.56	25.33	5.78	4.44	45.78	52.67
EP 114	6.22	5.33	21.78	8.89	2.67	44.89	65.33
EP 107	8.44	4.44	23.11	5.78	1.33	43.11	77.83
EP 106	12.44	3.56	22.67	4.89	3.56	47.11	77.67
EP 78	8.00	4.44	28.44	7.11	2.22	50.22	68.33
EP 68	5.33	2.67	25.78	4.89	2.22	40.89	79.50
EP 65	10.67	2.22	25.78	5.78	3.56	48.00	67.00
EP 64	9.78	6.22	26.22	5.78	4.89	52.89	82.17
EP 59	12.67	4.00	19.56	3.67	8.89	48.78	72.00
EP 84	1.33	3.56	19.56	3.56	4.00	32.00	64.33
EP 82	3.11	4.44	17.33	5.33	4.44	34.67	57.67
EP 81	3.56	8.89	18.67	8.44	4.44	44.00	57.67
EP 80	2.22	8.89	14.22	5.78	2.22	33.33	52.33
EP 52	2.67	6.22	15.56	5.33	2.67	32.44	49.33
EP 46	9.78	0.89	18.22	8.44	1.78	39.11	58.17
EP 57	6.22	3.11	15.11	7.11	2.22	33.78	55.00
EP 54	11.11	1.33	14.67	6.22	2.67	36.00	63.67
EP 55	10.67	1.33	10.22	4.00	1.33	27.56	59.33
EP 42	10.22	0.89	12.44	3.56	1.33	28.44	66.67
EP 24	7.11	0.44	14.22	4.89	0.44	27.11	56.00
EP 37	8.00	1.33	16.00	7.11	3.89	37.33	69.33
EP 41	4.89	3.11	15.11	8.89	2.67	34.67	56.33
EP 45	10.22	0.44	10.67	9.11	3.11	33.56	61.00
EP 1	6.89	1.33	10.67	6.67	1.78	27.33	66.00
EP 11	0.00	0.89	11.11	9.78	1.78	23.56	52.33
EP 12	20.22	0.00	12.00	6.67	2.67	41.56	59.00
EP 13	21.78	1.78	14.22	9.79	4.89	52.44	54.33
EP 9	1.33	2.67	13.33	12.44	5.33	35.11	62.00
EP 16	3.56	2.67	14.22	13.78	4.00	38.22	67.00
EP 17	1.78	4.89	13.33	8.00	2.67	30.67	79.33
EP 22	3.11	0.44	9.78	9.78	2.44	25.56	55.33
EP 14	2.67	1.78	10.22	12.89	2.22	29.78	50.00
LSD (P=0.05)	7.43	4.95	8.69	5.57	3.64	19.58	13.27

Table 2. Effect of herbicides and genotypes on growth and yield attributes

Treatment	Plant population/ m row	Plant height (cm)		Panicle length (cm)	100-seed weight (g)	Stover yield (g/m^2)	Harvest index (%)
		25 days after herbicide spraying	At harvest				
Herbicides							
Metsulfuron-methyl 4 g/ha	6.43	24.30	155	14.51	3.08	226	22.96
Carfentrazone-ethyl 20 g/ha	6.69	38.42	171	14.31	3.21	255	27.25
Control	6.72	39.08	167	14.00	3.24	266	27.36
LSD (P=0.05)	NS	8.14	13	0.37	NS	30	NS
Genotypes							
DSV 6	5.33	16.28	118	16.90	2.73	76	35.45
M 35-1	6.11	29.09	150	14.70	3.28	192	25.62
CSV 216R	3.44	18.74	173	15.78	1.97	127	27.71
Phule Chitra	6.00	38.11	185	17.31	3.65	235	31.38
P. Maulee	7.22	30.91	164	14.48	3.53	201	22.23
PEC 26	5.33	24.68	161	15.66	3.11	193	18.00
PEC 22	5.33	37.51	171	10.17	3.01	337	20.61
EP 95	5.22	33.51	170	16.17	3.78	255	21.13
EP 94	4.78	28.28	163	15.99	3.42	140	26.32
EP 93	5.67	37.51	194	11.64	4.04	369	28.81
EP 92	3.00	26.56	181	13.65	3.00	232	15.61
EP 91	6.11	30.40	163	16.20	4.03	254	26.70
SEVS 3	8.33	48.91	187	9.38	2.93	291	27.38
SEVS 2	6.22	28.41	177	18.31	2.31	177	29.11
EA 11	5.44	27.24	221	26.47	1.96	194	23.78
EA 10	6.22	25.38	111	24.11	2.24	132	36.82
SEVS 20	6.11	37.41	185	11.62	2.91	257	25.31
PEC 2	5.44	32.49	167	15.44	3.32	298	18.01
PEC 5	5.44	40.02	164	11.40	3.47	283	27.26
PEC 7	7.11	47.32	184	15.62	4.08	302	33.08
PEC 15	5.00	35.53	182	14.16	4.05	277	32.06
EP 97	7.00	33.25	162	14.81	3.23	214	26.61
EP 102	6.44	38.66	164	14.70	3.45	163	36.86
EP 105	6.44	31.33	171	17.77	1.87	150	33.07
EP 103	7.44	31.04	145	14.11	2.35	160	32.17
EP 104	5.67	27.93	162	17.26	2.51	173	26.63
EC 11	5.89	27.47	131	9.14	2.06	142	38.40
EC 12	6.11	32.12	134	16.20	2.32	139	36.30
EC 21	6.00	24.97	186	8.34	2.56	103	30.87
EC 33	3.22	23.88	126	13.42	3.09	79	24.09
EC 34	6.67	31.87	148	8.73	2.37	218	28.88
EP 120	7.11	27.85	145	15.76	3.03	195	24.52
EP 124	7.22	49.06	136	11.91	2.23	137	25.73
EP 127	4.78	28.36	141	11.13	3.02	275	26.93
EP 138	5.56	35.19	217	16.76	3.29	338	24.15
EP 117	7.00	31.86	176	14.59	4.05	310	22.24
EP 115	7.22	41.88	170	17.78	2.07	331	20.39
EP 114	7.56	42.84	190	16.20	3.71	392	21.52
EP 107	5.67	27.88	113	12.24	3.16	96	18.32
EP 106	4.78	28.29	105	10.36	3.78	120	30.34
EP 78	8.22	40.76	170	14.71	3.58	341	26.65
EP 68	7.89	40.56	165	14.67	3.56	305	26.75
EP 65	8.33	38.31	186	15.71	3.76	323	27.29
EP 64	7.00	38.82	183	14.41	3.74	260	25.66
EP 59	7.33	40.16	167	14.62	3.51	248	27.09
EP 84	7.89	32.64	153	13.70	2.89	242	18.02
EP 82	7.56	46.40	185	13.24	3.64	291	31.81
EP 81	7.88	45.18	192	10.83	3.43	357	28.72
EP 80	7.44	49.84	178	14.47	3.83	348	28.11
EP 52	8.67	39.20	156	13.47	3.10	274	37.39
EP 46	7.67	33.02	159	12.33	3.51	324	27.92
EP 57	7.67	39.64	163	15.46	2.89	330	28.92
EP 54	8.78	33.60	154	16.67	2.55	233	32.75
EP 55	8.78	28.27	161	15.80	3.84	296	26.84
EP 42	8.11	28.44	150	14.82	3.14	300	26.54
EP 24	6.67	32.29	164	17.53	2.89	226	28.42
EP 37	5.78	33.93	178	15.92	3.77	291	18.81
EP 41	6.78	30.67	189	18.29	2.40	221	26.87
EP 45	5.56	25.99	175	15.09	3.05	437	7.38
EP 1	6.22	33.29	153	12.39	2.77	293	19.26
EP 11	6.89	35.21	160	11.32	3.98	301	22.76
EP 12	7.00	36.91	147	11.14	2.87	205	22.07
EP 13	8.44	40.82	167	11.62	3.78	461	19.43
EP 9	7.67	37.42	160	11.32	3.14	336	18.23
EP 16	7.89	37.89	169	9.35	3.55	274	27.54
EP 17	7.89	33.31	171	13.32	3.44	243	24.86
EP 22	8.11	31.82	161	11.24	3.59	267	27.33
EP 14	9.00	32.98	174	10.67	3.51	383	21.32
LSD (P=0.05)	1.64	8.14	20	2.44	1.86	83	7.06

Table 3. Interaction effect of herbicides x germplasm on grain yield (g/m^2) of *Rabi* sorghum

Genotypes	Herbicide				% change (-/+) over control	
	Control	Metsulfuron-methyl 4 g/ha	Carfentrazone-ethyl 20 g/ha	Mean	Metsulfuron-methyl	Carfentrazone-ethyl
DSV 6	58.0	20.0	47.2	41.73	-65.52	-18.62
M 35-1	93.6	40.4	64.4	66.13	-56.84	-31.20
CSV 216R	77.2	36.28	32.0	48.67	-53.01	-58.55
Phule Chitra	114.0	96.0	112.4	107.47	-15.79	-1.40
P. Maulee	51.6	54.8	66.0	57.47	**+6.20**	**+27.91**
PEC 26	48.0	32.4	46.73	42.38	-32.50	-2.65
PEC 22	78.4	105.6	78.4	87.47	+34.69	0.00
EP 95	96.0	47.2	61.7	68.30	-50.83	-35.73
EP 94	45.63	42.0	62.4	50.01	-7.96	+36.75
EP 93	172.0	113.0	163.0	149.33	-34.30	-5.23
EP 92	55.6	8.8	64.4	42.93	-84.17	+15.83
EP 91	98.4	64.8	114.4	92.53	-34.15	+16.26
SEVS 3	157.2	61.2	110.8	109.73	-61.07	29.52
SEVS 2	83.2	17.6	117.2	72.67	-78.85	+40.87
EA 11	82.8	35.6	63.2	60.53	-57.00	-23.67
EA 10	67.6	63.6	99.6	76.93	-5.92	+47.34
SEVS 20	101.6	41.2	118.4	87.07	-59.45	+16.54
PEC 2	47.6	70.6	78.13	65.44	**+48.32**	**+64.14**
PEC 5	90.2	122.0	106.0	106.07	**+35.25**	**+17.52**
PEC 7	164.0	129.8	154.0	149.27	-20.85	-6.10
PEC 15	131.3	135.6	125.2	130.70	+3.27	-4.65
EP 97	64.8	72.4	95.6	77.60	**+11.73**	**+47.53**
EP 102	113.2	81.2	91.1	95.17	-28.27	-19.52
EP 105	58.8	81.2	82.4	74.13	**+38.10**	**+40.14**
EP 103	114.8	5.6	107.2	75.87	-95.12	-6.62
EP 104	80.8	44.8	62.8	62.80	-44.55	-22.28
EC 11	101.2	29.2	135.2	88.53	-71.15	+33.60
EC 12	88.4	41.6	107.6	79.20	-52.94	+21.72
EC 21	63.2	30.4	44.4	46.00	-51.90	-29.75
EC 33	49.6	4.4	21.2	25.07	-91.13	-57.26
EC 34	66.0	94.0	105.6	88.53	**+42.42**	**+60.00**
EP 120	80.4	54.0	55.6	63.33	-32.84	-30.85
EP 124	60.4	32.8	49.2	47.47	-45.70	-18.54
EP 127	128.0	60.8	115.2	101.33	-52.50	-10.00
EP 138	150.4	97.2	75.2	107.60	-35.37	-50.00
EP 117	81.6	94.8	89.6	88.67	**+16.18**	**+9.80**
EP 115	86.4	72.7	95.2	84.77	-15.86	+10.19
EP 114	111.6	81.6	129.3	107.50	-26.88	+15.86
EP 107	28.2	15.6	20.8	21.53	-44.68	-26.24
EP 106	78.0	45.2	33.6	52.27	-42.05	-56.92
EP 78	111.2	150.8	109.6	123.87	+35.61	-1.44
EP 68	157.2	98.0	78.87	111.36	-37.66	-49.83
EP 65	141.2	96.8	125.6	121.20	-31.44	-11.05
EP 64	91.6	88.0	89.6	89.73	-3.93	-2.18
EP 59	83.6	90.8	102.0	92.13	**+8.61**	**+22.01**
EP 84	49.2	18.0	92.4	53.20	-63.41	+87.80
EP 82	63.4	171.6	172.2	135.73	**+5.02**	**+5.39**
EP 81	176.0	83.2	172.4	143.87	-52.73	-2.05
EP 80	179.0	125.6	103.6	136.07	-29.83	-42.12
EP 52	160.0	154.0	176.8	163.60	-3.75	+10.50
EP 46	146.8	122.4	107.2	125.47	-16.62	-26.98
EP 57	111.2	117.2	174.4	134.27	**+5.40**	**+56.83**
EP 54	132.4	75.2	132.8	113.47	-43.20	+0.30
EP 55	130.4	84.27	111.2	108.62	-35.38	-14.72
EP 42	100.8	89.2	135.2	108.40	-11.51	+34.13
EP 24	126.0	49.2	94.0	89.73	-60.95	-25.40
EP 37	82.4	36.4	83.4	67.40	-55.83	+1.21
EP 41	93.6	46.8	103.2	81.20	-50.00	+10.26
EP 45	44.4	14.4	45.6	34.80	-67.57	+2.70
EP 1	107.0	42.4	60.27	69.89	-60.37	-43.67
EP 11	104.4	76.0	85.6	88.67	-27.20	-18.01
EP 12	104.0	19.8	50.4	58.07	-80.96	-51.54
EP 13	87.6	60.0	186.0	111.20	-31.51	+112.33
EP 9	73.2	36.67	114.8	74.89	-49.90	+56.83
EP 16	137.7	70.8	104.0	104.16	-48.57	-24.46
EP 17	82.0	73.6	85.6	80.40	-10.24	+4.39
EP 22	140.8	68.0	92.4	100.40	-51.70	-34.38
EP 14	164.8	42.8	103.7	103.77	-74.03	-37.08
Mean	100.2	67.36	95.51			
	Germplasm (G)	Herbicide (H)	G x H			
LSD (P=0.05)	22.44	9.67	35.67			

'*PEC 2*', '*PEC 5*', '*PEC 15*', '*EP 97*', '*EP 105*', '*EC 34*', '*EP 117*', '*EP 78*', '*EP 59*', '*EP 82*', and '*EP 57*' showed tolerance to metsulfuron-methyl (3.27 - 48.32% increase in grain yield over control). Maximum increase in grain yield (48.32%) was recorded with '*PEC 2*' followed by '*EC 34*' (42.42%), '*EP 105*' (38.10%) and '*PEC 5*' (35.25%). Carfentrazone-ethyl, however, showed initial leaf phytotoxicity after its spraying but recovered later within 15 days. The promising genotypes tolerant to carfentrazone were '*EP 13*', *'EP 84', 'EP 9' 'PEC 2', 'EC 34', 'EP 57', 'EP 105', 'EP 97', 'EA 10'* (40-112% increase in grain yield over control). Some of the promising genotypes showed tolerance to both metsulfuron and carfentrazone were *'PEC 2', 'PEC 5', 'EP 97', 'EP 105'* and '*EC 34*'.

It may be concluded that *Rabi* sorghum germplasm *PEC 2, PEC 5, EP 97, EP 105* and *EC 34* may be included in breeding programme for developing sorghum cultivars tolerant to metsulfuron-methyl and carfentrazone-ethyl.

SUMMARY

Field experiment was conducted during *Rabi* 2010-11 at the Indian Institute of Millets Research, Hyderabad (Telangana) to screen the *Rabi* sorghum germplasm and varieties tolerant to quizalofop-ethyl, metsulfuron-methyl and carfentrazone-ethyl herbicides. The crop was infested mainly with *Parthenium hysterophorus* (43.36%), *Cyperus rotundus* (19.91%), *Celosia argentea* (20.38%), *Euphorbia geniculata* (12.42%) and others (*E. hirta* and *Digitaria sanguinalis*) (3.93%). Of the 68 genotypes evaluated for herbicide tolerance, none was tolerant to quizalofop-ethyl. '*Phule Maulee*', *'PEC 22', 'PEC 2', 'PEC 5', 'PEC 15', 'EP 97', 'EP 105', 'EC 34', 'EP 117', 'EP 78', 'EP 59', 'EP 82',* and *'EP 57'* showed tolerance to metsulfuron-methyl (3.27 - 48.32% increase in grain yield over control) with very good control of all broad-leaved weeds. The promising genotypes showed tolerance to both metsulfuron and carfentrazone were *'PEC 2', 'PEC 5', 'EP 97', 'EP 105'* and *'EC 34'*. Carfentrazone-ethyl, however, showed initial leaf phytotoxicity but crop recovered within 15 days of herbicide application.

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Short communication

Quantitative estimation of total phenols in *Calyptocarpus vialis* - An emerging weed in Karnataka

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Calyptocarpus vialis Less. (Asteraceae) commonly known as straggler daisy, has already become aggressive invasive species in Karnataka (Rao and Sagar 2012) in Mysuru, Bengaluru, Ballari, Dharwad, Hubballi, Vijayapura, Kalaburagi (South India). It is now spreading rapidly in other places in Karnataka. Due to its monoculture thickets, associated floras have been suppressed. This directly points towards its allelochemical released into the environment. Present study was carried out in order to quantify the total phenols which are responsible for the invasive and aggressive nature of *C. vialis*.

C. vialis whole plants were collected, washed to remove mud and other dust particles. The leaves, stem and roots were separated and dried under shade. The dried samples were crushed separately using blender and the powder thus obtained was stored in air tight container. Twenty gram of each dried sample was dissolved in 200 ml of methanol, chloroform, ethyl acetate in conical flask and kept on rotary shaker for 24 h then filtered and centrifuged at 5000 rpm for 15 min. Supernatant was collected and the solvent was evaporated in watch glass. The dried extract was collected in airtight vials and stored at 4 ^{o}C for further studies. Aqueous extract was prepared by boiling 20 g of plant powder in 200 ml distilled water on heating mantle for 30 minutes. The extract was filtered, evaporated, concentrated and preserved at 4 ^{o}C. Phytochemical analysis was done following standard methods (Sadasivam and Manickam 1996).

Molisch's test was performed for carbohydrate estimation. Two ml of extract, 3-4 drops of Molisch's reagent was added and mixed properly. To this, concentrated sulphuric acid was added along with walls of the test tube. Appearance of a purple or blue ring in between the two layers indicates the presence of carbohydrate.

Biuret test was performed for protein. Two ml of biuret reagent (mixture of 2 ml of 10% NaOH and 2-3 drops of 0.5% $CuSO_4$) was added to the crude extract and heated. Appearance of purple/blue color confirms the presence of proteins.

Mayer's test was done for alkaloid estimation. Crude extracts were evaporated to dryness and residues were heated with 2% Hydrochloric acid on a boiling water bath. The extract were cooled, filtered and treated with the Mayer's reagent. Presence of yellow precipitation or turbidity shows the presence of alkaloids.

Ferric chloride test was done for phenol. Two ml of plant extract, 2ml of distilled water followed by 10 % $FeCl_3$ solution was added. Bluish black colour indicates the presence of phenol and tannins.

Foam test was done for saponin estimation. Two ml of extract was taken in a test tube and 10 ml of distilled water was added and shaken vigorously. Formation of foams confirms the presence of saponin.

Gelatin test was done for tannins. Crude plant extracts were treated with 5 ml of 1% gelatin solution containing NaCl and observed for the occurrence of white precipitate.

Flavonoid were estimated by adding 2 ml of 50% methanol in 4 ml of extract. The solution was warmed and metal magnesium was added. This was followed by addition of 5 to 6 drops of concentrated hydrochloric acid. Red coloration confirms the presence of flavanoids.

For determination of glycosides, any one of tests given below was done. Libermann's test was done for glycosides. Two ml of chloroform and 2 ml of acetic acid was added. The solution was ice cooled followed by addition of concentrated H_2SO_4. Colour change from blue to green indicated the presence of glycosides; Salkowski's test was done crude extract was dissolved in 2 ml of chloroform. To this conc. H_2SO_4 was added and the mixture was shaken. Formation of reddish brown color indicates the presence of glycosides; Keller-kilani test to the crude extract was added 2 ml of acetic acid and few drops of 2% $FeCl_3$ solution. The entire mixture was then

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poured in a test tube containing 2 ml of conc. H_2SO_4. A brown ring at the junction indicates the presence of glycoside.

Sulphuric acid test was done for steroids. Two ml of chloroform, 2 ml of conc. H_2SO_4 was added by the sides of the test tube and observed for red color at the lower chloroform layer.

Sulphuric acid test was done for terpenoids. Crude plant extract was dissolved in 3 ml of chloroform. This was than evaporated to dryness and 2 ml of conc. H_2SO_4 was added and heated for about 3 minutes. A grayish colour indicated the presence of terpenoids.

Ethyl acetate, chloroform and aqueous plant extracts was determined following method of Singleton *et al.* (1999). The reaction mixture was prepared by mixing 0.5 ml of extract, 2.5 ml of 10% Folin-Ciocalteu's reagent dissolved in distilled water and 2.5 ml 20% Na_2CO_3. Simultaneously blank was prepared, containing 0.5 ml methanol, 2.5 ml 10% Folin-Ciocalteu's reagent dissolved in water and 2.5 ml of 20% Na_2CO_3. A standard curve was prepared using gallic acid. For this, 10 mg gallic acid was dissolved in 100% methanol. Several dilutions of Gallic acid methanol were prepared, *viz.* 2.5, 5, 10, 15 and 25 µg/ml. One ml aliquot of each dilution was taken in a test tube and diluted with 10 ml of distilled water and to this 2.5 ml Folin-Ciocalteu's reagent was added. This was followed by the addition of 2.5 ml of 7.5% $NaHCO_3$ in each test tube. The resulting mixture was left to stand for 30 minutes at room temperature. Absorbance of the standard was measured at 765 nm using UV spectrophotometer against blank. Quantification was done on the basis of a standard curve of gallic acid. Based on the measured absorbance, the concentration of phenolics was read (mg/ml) from the calibration line; then the content of phenolics in extracts was expressed in terms of gallic acid equivalent (mg of GA/g of extract). Gallic acid equivalent (GAE) T= C x V/M, where GAE is the gallic acid equivalence (mg/ml); V is the volume extract (ml) and M is the weight (g) of the pure plant extract.

The % yield extracts was calculated by using the following formula:

$$\% \text{ yield} = \frac{\text{Weight of extract obtained (g)}}{\text{Weight of plant material (g)}} \text{ X } 100$$

RESULTS AND DISCUSSION

Qualitative estimation of preliminary phytochemicals in *C. vialis*.: The percent yield of *C. vialis* extract has been given in Table 1. The result of qualitative phytochemical analysis is given in Table 2 and 3. Results showed positive results for phenols, tannins, saponins, glycosides, steroids, terpenoids, coumarins in various solvents extracts.

Table 1. Percentage yield of *C. vialis* extracts

Plant part	% yield in various solvent			
	Methanol	Water	Ethyl acetate	Chloroform
Leaves	7.6	3.26	0.5	1.9
Stem	1.89	6.07	NT	NT
Root	4.5	6	NT	NT

NT= Not Tested

Table 2. Phytocompounds in different solvents extracts of leaves of *C. vialis*

Phytocompound	Ethyl acetate extract	Methanol extract	Chloroform extract	Aqueous extract
Protein	-	-	-	-
Phenol	+	+	+	+
Saponin	-	-	+	+
Tannins	-		+	-
Glycosides	+	+	+	+
Steroids	-	+	+	+
Terpenoids	-	-	+	+
Phlobatannins	-	-	-	-
Coumarins	-	+	-	-
Leucoanthocyanins	-	-	-	-

Table 3. Phytocompounds in different solvents extracts of *C. vialis*

Phytocompound	Root		Stem	
	Aqueous extract	Methanol extract	Methanol extract	Aqueous extract
Proteins	+	+	+	+
Phenols	+	+	+	+
Saponin	-	-	-	-
Tannins	-	-	-	-
Glycosides	+	+	+	+
Steroids	+	+	+	+
Terpenoids	-	+	+	+
Phlobatannins	-	-	-	-
Coumarins	-	+	-	+

Phenolic content of the extracts

Different parts of *C. vialis* were extracted with methanol, aqueous, chloroform and ethyl acetate and were subjected for analysis of total phenolic content. The calibration curve showed linearity for gallic acid in the range of 0.25 – 2.5 ìg/ml, with a correlation coefficient (R2) of 0.999 (Fig. 1).

Total phenolic content was estimated by gallic acid (Fig. 2, 3, and 4) and expressed as milligrams of gallic acid equivalent (GAE). Different concentrations, *viz.* 2.5, 5, 7.5, 10 and 15 mg/ml of ethyl acetate, chloroform, methanol and aqueous extracts of leaves were prepared and subjected to quantitative estimations of total phenols. Phenolics in leaves

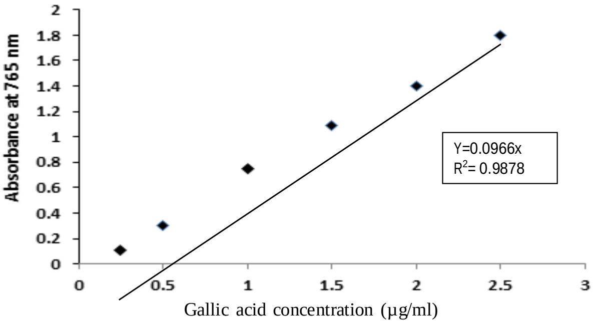

Fig. 1. Calibration plot for phenolic determination

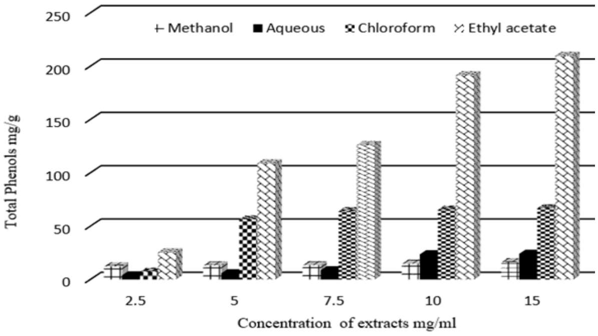

Fig. 2. Total phenols in leaves extracts

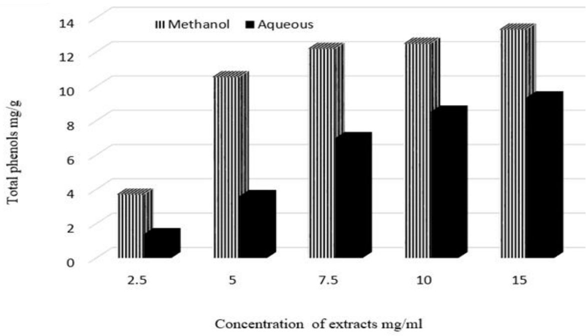

Fig. 3. Total phenols in stem extracts

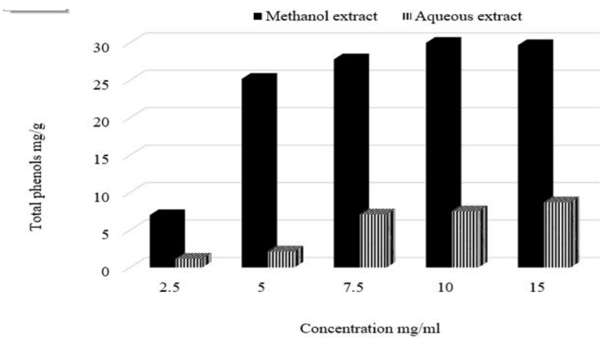

Fig. 4. Total phenols in root extracts

extracted with ethyl acetate were high (209.7 mg/g) followed by chloroform (66.70 mg/g), aqueous (24.06 mg/g) and methanol (16.2 mg/g) at 15 mg/ml concentration. In stem extracts, the phenolics extract in methanol were moderate depending upon the concentration. In root extracts, methanol extract showed high content than aqueous extract.

The presence of phenolics in the root, stem and leave of *C. vialis* indicate its allelopathic effect on its associated flora. Phenolic compounds are known to be responsible for antioxidant, anti-inflammatory, antimicrobial and several other biological properties. In the present study, considerable amount of phenolics were found in *C. vialis*. This has paved way to the agricultural scientists, pharmacologists, biochemists, biotechnologists, cytologists *etc*. to explore potential properties for sustainable use of *C. vialis*, which can be used for the human welfare and which will equally contribute to the protection of loss biodiversity. Further a question rises whether we can consider of designing agro-ecosystems incorporating this weed.

The present work established that *Calyptocrapus vialis* leaf contains most of the phytochemicals. The leaves, root and stem of *C. vialis* contain phenolic compounds, which reveal it's allelopathic nature.

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SUMMARY

Preliminary phytochemical analysis and quantitative estimation of total phenols in root, stem and leaves of *Calyptocarpus vialis* Less. (Asteraceae) were done using different solvents, *viz*. methanol, ethyl acetate, aqueous and chloroform. In all the solvent extracts of leaves, there was presence of phenols, glycosides, steroids, tannins and terpenoids. For quantitative estimations, different concentrations of various solvent extracts were prepared, *viz*. 2.5, 5, 7.5, 10 and 15 mg/ml. Quantitative estimation of total phenols showed that ethyl acetate extract in leaves contained high phenolic contents followed by chloroform, aqueous and methanol extracts. In stem and root, high phenolic content was found in methanol extracts at high concentrations of the plant sample. This seems to be the first report from India.

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