Print ISSN 0253-8040
Online ISSN 0974-8164

Indian Journal of Weed Science

Volume - 49 | Number - 1
January - March 2017

Available Online @ www.indianjournals.com

Indian Society of Weed Science

Directorate of Weed Science Research
Jabalpur - 482 004
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Indian Journal of
Weed Science

Volume 49 | Number 1 | January - March, 2017

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Indian Journal of Weed Science **49**(1): 1–4, 2017
DOI: 10.5958/0974-8164.2017.00001.6

Penoxsulam evaluation for weed control efficacy and increased rice yield

T. Saranraj*, P. Devasenapathy and Subbalakshmi lokanadhan
Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003

Received: 7 January 2017; Revised: 28 February 2017

ABSTRACT

Field experiments were conducted for two years at wetland farm, Tamil Nadu Agricultural University, during *Kharif* seasons of 2014 and 2015 (June to October) to evaluate the penoxsulam (21.7% SC) for weed control in rice. Based on two years data, it was found that pre-emergence application of penoxsulam 22.5 g/ha resulted in significantly lower total weed density, weed dry weight and higher weed control efficiency at all the intervals. Application of penoxsulam could keep the weed density and dry weight below the economic threshold level and increase grain yield of 5.21 and 5.04 t/ha was obtained in 2014 and 2015, respectively. Unweeded control accounted for lower grain yield and higher weed index of 48.7 and 60.8%, respectively.

Key words: Rice, Soluble concentrate, Weed density, Weed dry weight, Weed control efficiency

Rice (*Oryza sativa* L.) is the staple food for about 50% of the world's population. In India, rice is cultivated in an area of about 44.10 million hectares (Mha) with a production of 105.31 million tones (MT) and in Tamil Nadu, the area is 2.01 Mha with production of 4.58 Mt (FAO 2012). Geometric growth of population and arithmetic increase in food grain production leave a vast gap in food supply. This gap is further widened due to urbanization and industrialization of fertile lands. The global requirement of rice by 2025 AD is expected 800 million tonnes, which is 26% higher than the present level of production. Rice crop suffers from various biotic and abiotic production constraints. Weed competition is one of the prime yield-limiting biotic constrains in rice. Weeds compete with crops for water, light, nutrients and space. Weeds are the most competitive in their early growth stages than at later stages grain yield (Jocob and Syriac 2005). The reduction in rice yield due to weed competition ranged from 9 -51% (Mani *et al.* 1986).

Among different rice establishment methods, the transplanted rice play vital role in terms of rice production in country. But, the transplanted rice is infested with wide range of weed species *viz.*, grasses, sedges and broad-leaved weeds. *Echinochloa cruss-galli* and *Cyperus difformis* are the most predominant and highly competetive with rice crop right from the planting till harvesting stage, whereas sedge weed *Cyperus difformis* competes with the crop during the early phase because of its shorter life cycle. Barua *et al.* (2008) reported 30 to 60 days after transplanting as critical period of crop weed competition. Reduction in grain yield due to unchecked weed infestation in transplanted rice varied between 29 to 63% (Bhuvaneswari *et al*. 2009). Therefore, evaluation of new herbicides for broad spectrum control of weed flora is imperative. Recent trend of herbicide use is to find out an effective weed control measure by using low dose high efficiency herbicides, which will not only reduce the total volume of herbicide use but also increase grain production (Kathiresan 2001). Therefore, the present study was undertaken to evaluate the performance of penoxsulam in transplanted *Kharif* rice and associated weeds.

***Corresponding author:** tsaranrajagronomy@gmail.com

MATERIALS AND METHODS

Experiment were laid out during *Kharif* season (June to October) of 2014 and 2015 at the wetland farm of Tamil Nadu Agricultural University, Coimbatore. The geographical location of the experiment site was 11^0 N latitude and $77\ ^0$E longitude with an altitude of 426.7 m above the MSL and the farm receives the total rainfall of 696 mm in 42 rainy days. The soil of the experimental site was well drained clay loam (44.5% clay, 10.2% silt and 45.7% sand), low in available nitrogen, medium in available phosphorus and high in available potassium. The soil analyzed 234, 15.8 and 467 kg/ha of $KMno_4$-N, olsen P and NH_4OAc-K, respectively with EC of 0.29 ds/m, pH of 8.58 and organic carbon of 0.58%. The experiment was laid out in randomized complete block design (RBD) with nine treatments replicated thrice. The gross plot and net plot size were 20 m^2 (5.0 x 4.0 m). Short duration rice variety '*ADT 43*' maturing in 100-110 days was used for the study. Treatments consisted of pre-emergence application of penoxsulam at 20, 22.5, 25 and 50 g/ha, butachlor (50% EC 1.0 kg/ha) and pretilachlor (50% EC) 750 g/ha as standard check, hand weeding and unweeded check. The herbicides as pre-emergence were applied at third day after transplanting followed by a hand weeding on 30 DAT. Hand operated knapsack sprayer fitted with a flat fan type nozzle (WFN 40) was used for spraying the herbicide adopting a spray volume of 500 L/ha. The recommended dose of 130:40:40 kg NPK/ha in the form of urea, single super phosphate and muriate of potash were applied to all plots uniformly in lines and fifty per cent of nitrogen was applied as basal while, the remaining dose was top dressed in tillering and panicle initiation in equal splits. Data were recorded on predominant weed flora, weed density and dry weight of weeds. The weed related observations were recorded as per the standard procedure and the data were statistically analyzed by following the procedure as given by Gomez and Gomez (2010).

RESULTS AND DISCUSSION

Effect on weeds

The weed flora of the experimental field consisted of grasses, sedges and broad-leaved weeds which were observed from the unweeded check plot at flowering stage of rice. The pre-dominant grassy weeds were *Echinochloa crus-galli* (L.) and *Echinochloa colona* (L) and the dominant sedge was *Cyperus difformis* (L). Among the broad-leaved weeds, *Ammania baccifera* (L.), *Eclipta alba* (L) and *Marsilea quadrifoliata* (L) were the dominant species.

Weed density

Pre-emergence application of penoxsulam at 20, 22.5, 25, 27.5 and 50 g followed by one hand weeding on 30 DAT resulted in effective control of grass weeds, broad-leaved weeds and to some extent sedges due to its broad spectrum action (**Table 1**). Pre emergence application of penoxsulam at low dose of 22.5 g/ha followed by standard check pretilachlor 50% EC 750 g/ha gave more impressive control of grass weeds like *Echinochloa crus-galli* and *Echinochloa colona*. This might be because of penoxsulam has both residual and burn down activity, therefore it could controlled susceptible weeds emerged at the time of application or which germinated soon after application (Willingham *et al.*, 2008). Similar to this result, Ottis *et al.* (2003) also reported that application of penoxsulam provided 99 and 97% control of *Echinochloa crus-galli* and *Brachiaria platyphylla* at 21 DAT.

This was due to the fact that herbicides followed by hand weeding or hand-hoeing is much effective compared with application of herbicides alone in rice because of weed emerging later in the season that can be effectively controlled with physical methods without crop injury (Farooq 2011).

Weed dry weight and weed control efficiency

Weed dry weight is the important parameter to assess the weed competitiveness for the crop growth and productivity. Sparse weed with high biomass might be more competitive for crops than dense weeds with lesser dry matter. Considerable reduction in weed dry weight was recorded with application of penoxsulam at 22.5 g/ha at all the stages of observation and it was followed by standard check of pretilachlor (**Table 2**).

Table 1. Effect of different weed management practices on total weed density in rice

Treatment	Weed density (no./m^2)					
	Kharif 2014			*Kharif* 2015		
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT
Penoxsulam 20 g/ha + HW 30 DAT	6.16 (38)	8.28 (67)	8.96 (79)	6.16 (36)	10.03 (99)	8.17 (65)
Penoxsulam 22.5 g/ha + HW 30 DAT	3.23 (9)	4.61 (19)	4.70 (20)	3.00 (7)	3.87 (13)	3.46 (10)
Penoxsulam 25 g/ha + HW 30 DAT	5.88 (35)	7.92 (61)	8.66 (74)	2.99 (7)	4.35 (17)	3.99 (14)
Penoxsulam 27.5 g/ha + HW 30 DAT	5.52 (30)	7.42 (54)	8.20 (65)	5.83 (32)	9.74 (93)	7.93 (61)
Penoxsulam 50 g/ha + HW 30 DAT	5.23 (26)	7.08 (48)	7.95 (62)	3.60 (11)	5.38 (27)	5.38 (27)
Std. check butachlor 1000 g/ha + HW 30 DAT	4.11 (15)	5.65 (30)	5.68 (30)	3.60 (11)	5.74 (31)	5.74 (31)
Std. check pretilachlor 750 g/ha + HW 30 DAT	3.70 (12)	5.12 (25)	5.16 (25)	3.60 (11)	6.07 (35)	6.07 (35)
Hand weeding	12.53 (157)	6.12 (36)	6.21 (37)	11.59 (133)	7.19 (50)	7.12 (49)
Unweeded control	13.09 (173)	14.73 (221)	12.69 (163)	12.91 (165)	18.34 (335)	15.54 (240)
LSD (p=0.05)	1.01	1.75	1.54	0.73	0.83	0.72

Figures in parentheses are original, transformed to values $\sqrt{x+2}$

Table 2. Total weed dry weight and weed control efficiency as influenced by different weed management practices in rice (*Kharif* 2014)

Treatment	Weed dry weight (g/m^2)			Weed control efficiency (%)		
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT
Penoxsulam 20 g/ha + HW 30 DAT	4.19 (16.34)	5.59 (29.33)	6.04 (34.63)	77.0	68.8	51.5
Penoxsulam 22.5 g/ha + HW 30 DAT	2.39 (3.80)	3.24 (8.52)	3.24 (8.92)	94.7	90.9	87.5
Penoxsulam 25 g/ha + HW 30 DAT	4.04 (15.24)	5.36 (26.95)	5.84 (32.37)	78.6	71.3	54.7
Penoxsulam 27.5 g/ha + HW 30 DAT	3.80 (12.87)	5.03 (23.51)	5.54 (28.72)	81.9	75.0	59.8
Penoxsulam 50 g/ha + HW 30 DAT	3.58 (11.09)	4.81 (21.26)	5.38 (27.08)	84.4	77.4	62.1
Std. check butachlor 1000 g/ha + HW 30 DAT	2.89 (6.54)	3.89 (13.19)	3.91 (13.35)	90.8	86.0	81.3
Std. check pretilachlor 750 g/ha + HW 30 DAT	2.66 (5.17)	3.56 (10.82)	3.54 (11.12)	92.7	88.5	84.4
Hand weeding	8.23 (65.96)	4.20 (15.67)	4.29 (16.46)	7.2	83.3	77.0
Unweeded control	8.47 (71.08)	9.61 (93.92)	8.33 (71.40)	0.0	0.0	0.0
LSD (p=0.05)	0.66	1.14	1.19	-	-	-

Figures in parentheses are original, transformed to values $\sqrt{x+2}$

Table 3. Total weed dry weight and weed control efficiency as influenced by different weed management practices in rice (*Kharif* 2014 and 2015)

Treatment	Weed dry weight (g/m^2)			Weed control efficiency (%)		
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT
Penoxsulam 20 g/ha + HW 30 DAT	4.48(18.11)	6.83(44.8)	6.39(39.00)	78.24	69.3	67.64
Penoxsulam 22.5 g/ha + HW 30 DAT	2.53(3.54)	2.53(4.40)	2.65(5.05)	95.75	97.0	95.81
Penoxsulam 25 g/ha + HW 30 DAT	2.36(3.62)	2.82(6.00)	2.98(6.89)	95.65	95.9	94.28
Penoxsulam 27.5 g/ha + HW 30 DAT	4.26(16.24)	6.63(42.00)	6.21(36.60)	80.48	71.2	69.63
Penoxsulam 50 g/ha + HW 30 DAT	2.75(5.56)	3.46(10.00)	3.93(13.62)	93.31	93.2	88.70
Std. check butachlor 1000 g/ha + HW 30 DAT	2.75(5.54)	3.69(11.60)	4.18(15.70)	93.34	92.1	86.97
Std. check pretilachlor 750 g/ha + HW 30 DAT	2.74(5.51)	3.89(13.20)	4.42(17.85)	93.38	91.0	85.19
Hand weeding	8.27(67.02)	4.68(20.00)	5.13(24.66)	19.47	86.3	79.54
Unweeded control	9.21(83.23)	12.15(146.00)	11.01(120.53)	0.00	0.0	0.00
LSD (p=0.05)	0.63	0.53	0.80	-	-	-

Figures in parentheses are original, transformed to values $\sqrt{x+2}$

Weed control efficiency was highly influenced by different weed control treatment. The application of penoxsulam 22.5 g resulted in the minimum weed count, weed dry matter production and the maximum weed control efficiency at 45 DAT in 2014 (**Table 2**) and pooled data of 2014 and 2015 (**Table 3**).

Phytotoxicity effect on rice

Phytotoxic effect of herbicides on rice was evaluated by observing for wilting, necrosis, epinasty, hyponasty and chlorosis of leaf tips/surface at 7, 14, 21 and 28 days after application (DAA). The observation on the level of phytotoxicity through visual assessment of crop response was rated in the scale of 1-10.

The mean phyto-toxicity scoring on rice at 7, 14, 21 and 28 days after application herbicides revealed that application of penoxsulam 21.7% SC at applied doses did not produce any phytotoxic symptoms such as chlorosis or epinasty or leaf tip burning on rice crop and herbicide was found completely safe for use in transplanted rice. The findings were in close conformity with the findings of Mubeen *et al.* (2014) *Mishra et al.* (2004), Bond *et al.* 2007 and Pal *et al.* (2009).

Effect on rice crop

Pre-emergence application of penoxsulam 22.5 g/ha recorded higher grain yield of 5.21 and 5.04 t/ha in 2014 and 2015, respectively and it was at par with pre-emergence application of pretilachlor 50% EC 750 g/ha (5.11 and 5.00 t/ha) due to better control of weeds at critical stages thus providing favourable environment for better growth and development leading to enhanced grain yield (**Table 4**). Hand weeding has recorded grain yield of 4.96 t/ha.

Among the weed control methods, higher weed index of 48.71 and 60.82% was recorded in unweeded control, which might be due to greater competition stress with prolific weed growth and higher nutrient removal by weeds. Based on the result of present investigation, it could be concluded that the pre-emergence application of penoxsulam at 22.5 g/ha can keep the weed density and dry weight

Table 4. Effect of weed management treatments on yield and weed index of rice

Treatment	*Kharif, 2014*			*Kharif, 2015*		
	Grain yield (t/ha)	Straw yield (t/ha)	Weed index (%)	Grain yield (t/ha)	Straw yield (t/ha)	Weed index (%)
Penoxsulam 20 g/ha + HW 30 DAT	3.89	7.40	25.02	2.76	5.28	45.18
Penoxsulam 22.5 g/ha + HW 30 DAT	5.21	10.16	00.00	5.04	10.89	0.00
Penoxsulam 25 g/ha + HW 30 DAT	3.90	7.69	25.04	4.32	8.92	14.35
Penoxsulam 27.5 g/ha + HW 30 DAT	3.95	7.79	24.12	3.20	6.00	36.55
Penoxsulam 50 g/ha + HW 30 DAT	4.00	8.00	23.16	3.98	8.19	21.15
Std. check butachlor 1000 g/ha + HW 30 DAT	5.05	10.01	2.99	3.92	7.92	22.28
Std. check pretilachlor 750 g/ha + HW 30 DAT	5.11	10.05	1.84	5.00	10.50	0.87
Hand weeding	4.96	9.54	4.72	4.06	8.92	19.58
Unweeded control	2.67	6.05	48.71	1.97	4.50	60.82
LSD (p=0.05)	0.52	0.64	-	0.55	1.18	-

reasonably at lower level and enhance the productivity of transplanted rice resulting in higher economic returns.

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Indian Journal of Weed Science **49**(1): 5–9, 2017
DOI: 10.5958/0974-8164.2017.00002.8

Rice productivity under different weed management and establishment methods

Arunima Paliwal*, V. Pratap Singh, Jai Prakash Bhimwal[1], Neeshu Joshi, S.P. Singh, Tej Pratap, S.K. Guru and A. Kumar
G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145

Received: 9 January 2017; Revised: 24 February 2017

ABSTRACT

Field experiment was conducted to find out alternative tillage practices with appropriate weed management opportunities to increase the yield potential of rice crop. Major associated weeds were *Echinochloa colona, E. crus-galli, Leptochloa chinensis* among grasses, *Caesulia axillaris, Alternanthera sessilis, Ammania baccifera* among broad-leaved weeds and *Cyperus rotundus, C. iria, C. difformis* and *Fimbristylis miliaceae* among sedges at 60 DAS. Adoption of conventional transplanted rice (TPR) with *Sesbania* inclusion as green manure along with integrated approaches of weed management using bispyribac-sodium 20 g/ha supplemented with one hand weeding at 45 DAS was found effective and profitable alternative than conventional transplanted rice and hand weeding to attain higher productivity of rice crop. However, the benefit cost ratio was higher when the crop was grown under zero-till situation (ZTR) along with retention of crop (wheat) residues followed by *Sesbania* as brown manure due to less cost involved under zero-till situation.

Key words: Bispyribac-sodium, Conventional tillage, Establishment method, Rice producivity, *Sesbania*, Zero tillage

Rice (*Oryza sativa*) is the most important cereal crop of the world, forming staple diet of 70% of world's population (Sahu *et al.* 2014). It is the widely cultivated crop in the India, with production of 104.80 million tonnes (Anonymous 2015). India ranks second in production and consumption of rice in the world. India need to produce about 130 million tonnes of rice by 2025 to feed the ever growing population (Hugar *et al.* 2009), which is a challenging task.

Traditionally, rice is grown by transplanting in puddled situation which has weakened the natural resource base, which also hampers the crop yield. It is associated with various constraints like labour availability, weeds, water, insects *etc*. Among the several production constraints, weeds are most important with great genetic diversity (Singh *et al.* 2003). More than one third of the total loss (33%) is caused by weeds alone (Mukherjee 2006). Crop losses due to weed competition throughout the world as a whole, are greater than those resulting from combined effect of insect pests and diseases (Hassan *et al.* 2005). Weeds reduce the crop yield, deteriorate quality and reduce market value of grains. Further, the question arises with the conventional cultivation of rice due to ever increasing energy prices for pumping water and running tractors, required for puddling and other operations, limited water and labour availability for the transplanting, sequential use of herbicides for weed control *etc*. Weed management also increases the cost of cultivation and thus farmers need technologies that can reduce their costs of cultivation and improve their returns. Conventional method of weed control is weather dependent, laborious, and expensive.

So, there is need to find an alternative production system, which could reduce cost of production, conserve natural resources, save time and labour, effectively control weeds, enhance productivity and ensure environmental safety. But, current production system can hardly compensate the food demand of increasing population with a fatigue natural resource base (Saharawat *et al.* 2010). Therefore, to sustain and improving the production system of rice, it is essential to adopt resource conserving technologies like direct seeding, zero-till with residue retention. Crop residue retention is a good option which increases the yield and profitability, while decreasing weed pressure. Manuring of the crop with *Sesbania* has dual advantage of adding biomass to soil, acting as mulch and smothering the weeds. Singh *et al.* (2009) reported that application of wheat residue mulch at 4 t/ha and *Sesbania* intercropping for 30 days were equally effective in controlling weeds in dry-seeded

***Corresponding author:** arunima.28@rediffmail.com
[1]Department of Agronomy, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan 313 001

rice. Therefore, present work was undertaken to find out alternative tillage practices with appropriate weed management opportunities to increase the yield potential of rice crop.

MATERIALS AND METHODS

A field experiment was conducted at NEB Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand, India) during *Kharif* 2015 and 2016. The soil of the experimental plot was high in organic carbon (0.76%), low in available nitrogen (212.6 kg/ha), medium in available phosphorus (17.2 kg/ha) and available potassium (203.1 kg/ha) with slightly alkaline pH (7.86). The experiment was laid out in strip plot design with 15 treatments, comprising 5 establishment methods of rice in vertical strip, *viz.* conventional transplanted rice (TPR-CT), TPR-CT followed by *Sesbania* as green manure, direct-seeded rice (DSR) *fb Sesbania* incorporation, zero-till direct-seeded rice (ZT-DSR) *fb Sesbania* as brown manure and ZT-DSR with retention of residues of previous wheat crop along with *Sesbania* as brown manure and 3 weed control measures in horizontal strip *viz.*, unweeded control, recommended herbicide *i.e.* bispyribac-sodium 20 g/ha as post-emergence and integrated weed management *i.e.* herbicide application *fb* one hand weeding at 45 DAS/DAT, replicated thrice in clay loam soil. Under ZT-DSR condition, the *Sesbania* was knocked down by the application of 2,4-D at 30 days after sowing and used as brown manure.

Variety '*Pant dhan-18*' was sown with recommended fertilizer dose (150:60:40 kg N:P:K/ha) through urea (46% N) and NPK mixture (12:32:16% N, P and K). Zinc at 25 kg/ha was applied only in rice as $ZnSO_4$ (23.5% zinc). Full dose of phosphorus, potassium and zinc and half of nitrogen fertilizer was applied as basal while remaining nitrogen was top dressed in two split doses at the time of tillering and panicle initiation stage. Plant protection measures and irrigations were provided as and when required. After sowing of the crop, residue of the previous crop (wheat residue in rice) was applied manually in the plots according to the treatments. Bispyribac-sodium 20 g/ha was applied after 25 days of sowing by using 500 litre volume of water/ha with knapsack sprayer fitted with flat fan boom nozzle. Data of density of complex weed flora (no./m^2) were collected from each individual plot from one side of the plot, leaving the two border rows with the help of a quadrate. For weed biomass (g/m^2), weeds were removed from the sampling rows above the ground with the sickle, sun dried then kept in hot air oven at 60±10 °C till constant dry weight is obtained. Different yield attributes parameters and yield were recorded at crop harvest. Economics was calculated on the basis of prevailing market prices of input used and output obtained. Weed population data were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis, adapted in statistical package CPCS-1, designed and developed by Punjab Agricultural University, Ludhiana (Cheema and Singh 1991).

RESULTS AND DISCUSSION

Weed flora

Major weed flora in the experimental fields was grouped into grasses, broad-leaved and sedges. Different weed spectrum observed during *Kharif* 2015 and 2016 were *E. colona, E. crus-galli, L. chinensis* among grasses; *C. axillaris, A. sessilis, A. baccifera* among broad- leaved weeds (BLW) and *C. rotundus, C. iria, C. difformis* and *F. miliaceae* among sedges at 60 DAS. The composition of grassy, BLWs and sedges in weedy plot under TPR-CT was 48.6, 31.1 and 20.3% during *Kharif* 2015 and 57.4, 18 and 24.6% during *Kharif* 2016; followed by *Sesbania* as green manure, which was 45.9, 17.3 and 36.7% and 66.1, 2.6 and 31.3%, respectively during *Kharif* 2015 and 2016; however it was found to be 15.5, 29.0 and 58.6% during *Kharif* 2015 and 21.0, 11.7 and 67.3% during *Kharif* 2016 under DSR *fb Sesbania* incorporation; under ZT-DSR *fb Sesbania* as brown manure, it was recorded as 16.1, 68.9 and 15.0% and 14.1, 39.3 and 46.0%, respectively during *Kharif* 2015 and 2016; while ZT-DSR with retention of residues of previous wheat crop along *fb Sesbania* as brown manure, recorded grassy weeds composition with 60.1 and 67.4%, respectively during *Kharif* 2015 and 2016, while BLWs and sedges was 22.1 and 17.8%, respectively during *Kharif* 2015 and 20.9 and 11.6%, respectively during *Kharif* 2016 (**Figure 1**).

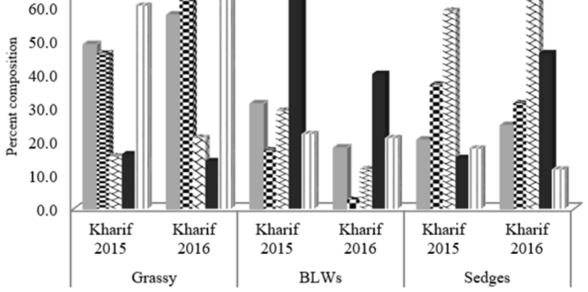

Figure 1. Composition of grassy, BLWs and sedges in weedy plot under differenet establishment methods of rice during *Kharif* 2015 and 2016

Effect on weeds population

Establishment methods significantly reduced the density and biomass of weeds in rice during both the years of study (**Table 1**). Among establishment methods, the lowest density of grassy weeds and biomass was recorded under zero-till direct-seeded rice without residue retention *fb Sesbania* as brown manure,which was at par with conventional direct-seeded rice followed by *Sesbania* incorporation in *Kharif* 2015, while during *Kharif* 2016, conventional DSR *fb Sesbania* incorporation recorded lowest grassy weed biomass being significantly at par with zero-till direct-seeded rice without residue retention *fb Sesbania* as brown manure in reducing the grassy weed density. The density of grassy weeds was low under zero-till direct- seeded rice without residue retention *fb Sesbania* as brown manure due to compaction of the soil surface which suppresses the emergence of grassy weeds which have narrow sized seeds. However, conventional transplanted rice with *Sesbania* as green manure significantly reduced the density and biomass of BLWs during both the years of experimentation, might be due to weed suppression by manuring of *Sesbania.* The density and biomass of sedges was recorded lowest under zero-till direct seeded rice with residue retention and *Sesbania* as brown manure during both the years of *Kharif* 2015 and *Kharif* 2016, which was at par with conventional transplanting TPR (CT), due to the residue retention, which act as mulch and control the sedges density. Sapre *et al.* 2015 also reported weed control by retention of residues under zero-till condition. Different weed management practices significantly influenced weed density and biomass of grassy, BLWs and sedges, recording lowest density including biomass under integrated approaches (bispyribac-sodium 20 g/ha *fb* one hand weeding at 45 DAS/DAT) followed by sole herbicidal application over the unweeded situation (**Table 1**). This might be due to adoption of integrated approaches of weed management, *viz.* herbicidal application supplemented with one hand weeding then other weed control treatments. The highest weed density and biomass was recorded under weedy situation.

Effect on crop yield

The yield and yield attributing characters of rice was significantly influenced by establishment system during *Kharif* 2015 and *Kharif* 2016 (**Table 2**). The number of panicles/m^2 was significantly highest under conventional system of rice TPR (CT) during both the years, being at par with conventional transplanted rice *fb Sesbania* inclusion as green manure during *Kharif* 2015. Similar results were noticed with number of grains/panicle. Conventional transplanted rice *fb Sesbania* inclusion as green

Table 1. Effect of establishment methods and weed management on weed density and biomass of weeds at 60 DAS of rice during *Kharif* 2015 and 2016

Treatment	Weed density (no./m^2)						Weed biomass (g/m^2)					
	Grassy		BLWs		Sedges		Grassy		BLWs		Sedges	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Establishment system												
TPR (conventional tillage)	6.3	6.2	4.4	3.7	2.8	3.6	8.8	8.4	3.6	3.1	2.9	3.9
	(40.7)	(41.4)	(20.2)	(13.8)	(9.8)	(15.1)	(81.9)	(76.5)	(13.2)	(9.9)	(10.5)	(16.8)
TPR (conventional tillage)- *Sesbania* (zero tillage)	6.0	5.6	3.3	2.0	4.2	4.3	8.4	7.7	2.7	1.7	4.3	4.5
	(36.9)	(34.3)	(11.3)	(4.0)	(21.3)	(19.4)	(77.5)	(62.4)	(7.4)	(2.4)	(22.7)	(21.3)
DSR (conventional tillage)- *Sesbania* (zero tillage)	3.2	3.8	4.9	3.8	5.4	4.7	4.5	5.2	4.0	3.3	5.4	4.8
	(11.4)	(18.1)	(27.1)	(15.4)	(44.9)	(48.0)	(23.5)	(34.3)	(18.8)	(11.7)	(44.7)	(50.4)
DSR (zero tillage)- *Sesbania* (zero tillage)	2.9	4.1	6.6	5.6	3.3	4.2	3.8	5.8	5.6	4.7	3.4	4.4
	(9.3)	(16.1)	(46.3)	(32.0)	(10.7)	(23.2)	(15.2)	(33.3)	(33.1)	(23.1)	(11.8)	(26.1)
DSR (zero tillage) + residue - *Sesbania* (zero tillage)	6.0	6.0	4.1	3.2	2.7	2.9	9.3	8.0	3.5	2.6	2.9	2.9
	(43.8)	(47.1)	(20.9)	(13.8)	(10.4)	(9.8)	(117.4)	(82.9)	(14.8)	(8.7)	(11.7)	(10.2)
LSD (p=0.05)	0.3	0.5	0.2	0.4	0.2	0.4	0.7	0.2	0.3	0.2	0.3	0.1
Weed management												
Recommended herbicide (bispyribac- Na 20 g/ha)	4.6	4.4	4.4	3.9	3.0	3.2	6.1	6.2	3.6	3.2	3.2	3.2
	(22.7)	(19.3)	(19.7)	(16.3)	(8.5)	(10.7)	(39.9)	(39.0)	(13.2)	(10.6)	(9.7)	(11.2)
IWM (recommended herbicide *fb* one hand weeding)	3.0	3.2	2.6	2.0	1.5	1.6	4.2	4.6	2.2	1.7	1.5	1.7
	(9.7)	(10.0)	(7.3)	(4.3)	(1.3)	(2.1)	(19.6)	(22.0)	(5.0)	(2.5)	(1.4)	(2.5)
Unweeded	7.1	7.8	6.9	5.0	6.6	7.1	9.5	10.3	5.8	4.4	6.7	7.4
	(52.9)	(64.9)	(48.5)	(26.9)	(48.4)	(56.5)	(129.8)	(112.6)	(34.2)	(20.4)	(49.7)	(61.1)
LSD (p=0.05)	0.3	0.5	0.04	0.5	0.2	0.4	1.0	0.2	0.4	0.1	0.2	0.1

Original data is indicated in parentheses; Data transformed to square root transformation; TPR- Transplanted rice; DSR- Direct seeded rice; IWM- Integrated weed management

Table 2. Effect of establishment methods and weed management on yield and yield attributes of rice during *Kharif* 2015 and 2016

Treatment	Panicles (no./m^2)		No. of grains/ panicle		1000- grain weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Establishment system										
TPR (conventional tillage)	222.8	244.9	127.1	123.0	26.9	26.4	5.1	4.6	7.4	9.2
TPR (conventional tillage)- *Sesbania* (zero tillage)	204.8	209.9	124.5	121.5	27.5	26.7	5.2	5.4	7.5	10.3
DSR (conventional tillage)- *Sesbania* (zero tillage)	171.7	144.6	107.4	82.3	26.0	17.9	3.7	3.0	5.4	6.6
DSR (zero tillage)- *Sesbania* (zero tillage)	124.4	100.6	96.4	71.7	26.3	18.1	2.9	2.3	4.2	6.0
DSR (zero tillage) + residue - *Sesbania* (zero tillage)	143.9	138.4	104.2	93.4	25.8	21.8	3.7	3.4	5.4	7.3
LSD (p=0.05)	23.2	4.2	16.6	4.4	0.9	1.7	0.4	0.7	0.5	1.6
Weed management										
Recommended herbicide (bispyribac- Na 20 g/ha)	197.7	191.3	125.2	114.6	26.6	26.2	4.8	4.5	7.1	9.8
IWM (recommended herbicide *fb* one hand weeding)	225.0	231.9	128.3	123.8	26.9	26.8	5.4	4.8	7.5	9.9
Unweeded	97.8	79.9	82.3	56.7	26.0	13.5	2.1	2.0	3.3	4.0
LSD (p=0.05)	12.3	5.7	11.6	5.0	0.4	1.5	0.3	1.1	0.3	2.2

Table 3. Effect of establishment methods and weed management on economics of rice during *Kharif* 2015 and 2016

Treatment	Cost of cultivation (x10^3 `/ha)		Gross return (x10^3 `/ha)		Net return (x10^3 `/ha)		B:C	
	2015	2016	2015	2016	2015	2016	2015	2016
Establishment system								
TPR (conventional tillage)	35.64	36.64	101.64	104.13	66.00	67.48	1.8	1.8
TPR (conventional tillage)-*Sesbania* (zero tillage)	35.64	36.64	103.05	119.87	74.59	79.33	1.9	2.3
DSR (conventional tillage)- *Sesbania* (zero tillage)	25.94	26.44	73.90	70.31	47.96	43.88	1.7	1.5
DSR (zero tillage)- *Sesbania* (zero tillage)	21.27	21.77	57.44	58.13	36.17	36.36	1.6	1.6
DSR (zero tillage) + residue - *Sesbania* (zero tillage)	20.94	21.44	73.52	78.69	52.59	57.25	2.4	2.5
Weed management								
Recommended herbicide (bispyribac- Na 20 g/ha)	27.84	28.54	96.47	104.32	68.62	75.77	2.6	2.8
IWM (recommended herbicide *fb* one hand weeding)	30.39	31.09	105.81	109.21	75.42	78.11	2.6	2.6
Unweeded	25.42	26.12	43.45	45.14	18.03	19.02	0.5	0.3

manure recorded highest 1000-grain weight, grain and straw yield followed by conventional TPR (CT) during both the years. Different weed management practices significantly influenced yield and yield attributing characters of rice recording highest grain yield (5.4 and 4.8 t/ha) and yield attributes under integrated approaches (bispyribac-sodium 20 g/ha *fb* one hand weeding at 45 DAS/DAT) followed by sole herbicidal application (bispyribac-sodium 20 g/ha) over the unweeded situation during both the years of study (**Table 2**). Similar results were also reported by Gaire *et al.* 2013. Number of grains/panicle was found at par with sole application of recommended herbicide (125.2) during *Kharif* 2015. However, during *Kharif* 2015 and *Kharif* 2016, 1000-grain weight was also at par with sole herbicidal application being superior over the unweeded situation. While, grain and straw yield was at par with sole herbicidal application (bispyribac-sodium 20 g/ha) only during *Kharif* 2016. This might be due to effective control of weeds with herbicidal application of bispyribac-sodium, which offers broad spectrum weed control (Parthipan *et al.* 2013) and integrated approach, thereby increasing the yield attributes and yield. The lowest grain and straw yield was recorded in unweeded situation due to severe weed competition evident from higher weed density and dry biomass (**Table 1**).

Economics

Among different establishment system, highest net return of ` 74591.00 and ` 79335.00, was recorded in the plots where rice was planted in the conventional transplanted rice with *Sesbania* as green manure, during *Kharif* 2015 and *Kharif* 2016, respectively, while zero-till direct seeded rice with residue retention followed by *Sesbania* (ZT) as brown manure attained highest benefit cost ratio as 2.4 and 2.5, during *Kharif* 2015 and *Kharif* 2016, respectively (**Table 3**). This result was attained due to less cost of cultivation under zero tilled direct seeded rice with residue retention along with *Sesbania* used as brown manure. Within weed management practices, IWM (bispyribac-sodium 20 g/ha *fb* 1 hand weeding at 45 DAS/DAT) practice recorded the highest net return (` 75417.00 and ` 78114.00), during *Kharif* 2015 and *Kharif* 2016, respectively, while benefit cost ratio was highest with integrated approach (2.6) of weed control during *Kharif* 2015 and with sole herbicidal application (2.8) followed by integrated approach (2.6) of weed control during *Kharif* 2016. This resulted due to less difference attained in net returns compared to the cost of cultivation among the two treatments.

It was concluded that adoption of conventional transplanted rice *fb Sesbania* inclusion as green manure along with integrated approaches of weed management (bispyribac-sodium 20 g/ha supplemented with one hand weeding at 45 DAS) was found effective and profitable alternative with respect to conventional tillage practices and hand weeding to attain higher productivity of rice crop under rice-wheat cropping system. However, the benefit cost ratio was higher with zero-till direct seeded rice along the retention of residues followed by *Sesbania* used as brown manure due to less cost of cultivation involved under zero-till situation.

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Indian Journal of Weed Science **49**(1): 10–14, 2017
DOI: 10.5958/0974-8164.2017.00003.X

Integrated weed management in direct-seeded rice

Pratik Sanodiya* and Manoj Kumar Singh
Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh 221 005

Received: 22 January 2017; Revised: 27 February 2017

ABSTRACT

A field investigation was conducted during *Kharif* season of 2014 and 2015 at Varanasi, Uttar Pradesh, to study the effect of integrated weed management on weed flora, yield and economics of direct seeded rice (*Oryza sativa* L.). Penoxsulam 35 g/ha at 10 DAS *fb* 1 hand weeding at 35 DAS reduced weed density of various weed flora, *viz. Echinocloa colona* (7.27%), *Echinocloa crus-galli* (6.58%), *Cynodon dactylon* (7.57%) among grasses; *Cyperus iria* (8.01%), *Cyperus difformis* (8.26%) and *Fimbristylis miliacea* (8.67%) among sedges and *Ammannia baccifera* (10.12%) and *Caesulia axillaris* (10.10%) among broad-leaved weeds besides other weeds (11.72%) in comparison to penoxsulam 35 g/ha at 20 DAS *fb* 1 hand weeding at 35 DAS. Penoxsulam 35 g/ha at 10 DAS *fb* 1 hand weeding at 35 DAS markedly improved growth attributes, *viz.* plant height, number of tillers/m^2, dry matter accumulation, leaf area index and chlorophyll content at 60 DAS and yield attributes, *viz.* panicle length, panicle weight, number of panicles/m^2, number of grains/panicle and test weight. Penoxsulam 35 g/ha at 10 DAS *fb* 1 hand weeding at 35 DAS statistically influenced the grain and straw yields and harvest index over all other treatments except hand weeding at 15 and 35 DAS. Highest net return (43790.76) and benefit: cost ratio (2.15) was also observed under penoxsulam 35 g/ha at 10 DAS *fb*1 HW at 35 DAS.

Key words: Bispyribac-Na, Chlorimuron-ethyl, Direct-seeded rice, Economics, Integrated weed management

Weed infestation in direct-seeded rice (DSR) fields remains the single largest constraint limiting their productivity. An effective early weed management tactic is imperative for any DSR production technology aiming at achieving higher productivity and profitability (Jaya Suria *et al.* 2011). Aerobic edaphic conditions under non-flooded conditions in DSR stimulate germination of diverse weed species. Weeds in DSR compete for moisture, nutrients, light and space and reduce the grain yield by 50 to 91% (Rao *et al.* 2007). Weed problem in direct-seeded rice can be managed by implementing integrated weed management. Chemical control proved to be a viable strategy with higher economic returns (Khaliq *et al.* 2012). Ehsanullah *et al.* (2012) observed that the post-emergence application of bispyribac-sodium was the most effective in reducing the total density and dry weight over weedy, followed by penoxsulam. However, weeds in direct-seeded rice cannot be controlled by herbicide alone because of various flushes of weeds during life cycle of crop. Therefore, it was imperative to identify effective integrated chemical and manual practices with their economics. Integrated weed management systems have the potential to reduce herbicide use and to provide more robust weed management over the long term (Swanton and Weise 1991). The present study was taken up to assess the suitable integration of different herbicides along with manual weeding on weed flora, yield and economics in direct-seeded rice.

***Corresponding author:** prsanodiya10@gmail.com

MATERIALS AND METHODS

A field experiment was conducted during *Kharif* season of 2014 and 2015 at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. The soil was sandy clay loam, with pH 7.40, low in available organic carbon (0.41%), available nitrogen (207.47 kg/ha) and medium in available phosphorous (23.85 kg/ha) and potassium (219.60 kg/ha). The experiment was laid out in a randomized block design, comprising 10 treatments replicated thrice. Rice variety *'MTU-7029'* was sown by zero till drill during the last week of June in both the years using the seed rate of 30 kg/ha and 20 cm row-row spacing. A recommended dose of fertilizer (150 kg N, 60 kg P_2O_5 and 60 kg K_2O) was applied through urea, single super phosphate and muriate of potash. Full dose of phosphorus and potassium were applied as basal application while nitrogen was applied half as basal and remaining half in two equal splits at tillering and panicle initiation stages of rice. Application of alone and tank mixed post-emergence herbicides was done according to the treatments using knap-sack sprayer fitted with even-fan nozzle using with 300 L/ha.

The crop was raised under irrigated condition recommended package of practices. Species-wise weed density and their biomass were measured at 60 DAS by placing a quadrate of 0.50 m^2 randomly at 2 places in each plot. Data on weed density and biomass were subjected to square root transformation before analysis. At 60 DAS, weed control efficiency (Tripathi and Mishra1971) and weed index (Gill and Kumar 1969) was calculated using weed biomass and grain yield, respectively. Biometric characters, *viz.* growth attributes (leaf area index was recorded by portable leaf canopy analyzer whereas, chlorophyll content was measured with SPAD), yield attributes and yields (grain and straw) of crop were recorded at 60 DAS and at harvest. Nutrient (N, P, K and Zn) uptake by weeds and crop was calculated multiplying weed biomass and crop dry matter, respectively with their nutrient contents at 60 DAS. Prevailing price of inputs in the market during 2014 and 2015 were used to calculate the economics of integrated weed management treatments. The net return and benefit: cost ratio (BCR) was worked out on the basis of gross returns (`/ha) and cost of cultivation (`/ha). Duncan multiple range test (DMRT) was used for comparing treatment means (Gomez and Gomez 1984). The biometric data on weed growth and yield averaged for two years for statistical analysis.

RESULTS AND DISCUSSION

Effect on weeds

The major weed flora observed in experimental field included *Echinocloa colona* (L.) Link. (13.74%), *Echinocloa crus-galli* (L.) Beauv (13.74%), *Cynodon dactylon* L. Pers. (10.19%) among grasses; *Cyperus iria* L. (10.62%), *Cyperus difformis* L. (10.09%) and *Fimbristylis miliacea* (L.) Vahl. (10.93%) among sedges and *Ammannia baccifera* L. (10.14%) and *Caesulia axillaris* Roxb. (10.17%) among broad-leaved weeds besides other weeds (10.26%).

Density of weed species and their biomass varied statistically at 60 DAS irrespective of integrated weed management treatments (**Table 1** and **2**). Penoxsulam 35 g/ha at 10 DAS *fb* one HW at 35 DAS recorded lower weed density of all weed species in comparison to penoxsulam 35 g/ha at 20 DAS *fb* one HW at 35 DAS and both treatments were statistically at par to each other except *Fimbristylis miliacea* during both the years. Penoxsulam 35 g/ha at 10 DAS *fb* one HW at 35 DAS reduced weed density of *Echinocloa colona* (7.27%), *Echinocloa crus-galli* (6.58%), *Cynodon dactylon* (7.57%) among grasses; *Cyperus iria* (8.01%), *Cyperus difformis* (8.26%) and *Fimbristylis miliacea* (8.67%) among sedges and *Ammannia baccifera* (10.12%) and *Caesulia axillaris* (10.10%) among broad-leaved weeds besides other weeds (11.72%) in comparison to weedy treatment. This could be attributed to alone application of penoxsulam 35 g/ha, which had effective control of both narrow and broad-leaved weeds at early crop stages while later on one manual weeding controlled weeds comprehensively. This result was in conformity with Dalamas *et al.* (2006). However, bispyribac-Na 25 g/ha at 10 DAS *fb* 1 HW at 35 DAS had lower weed density of all weed species as compared to bispyribac-Na 25 g/ha at 20 DAS *fb* 1 HW at 35 DAS and both treatments were statistically similar to each other (**Table 1**). Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS recorded lower weed biomass of all weed species in comparison to penoxsulam 35 g/ha at 20 DAS *fb* one HW at 35 DAS and both treatments were statistically at par to each other during both the years. However, bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 10 DAS *fb* one HW at 35 DAS had lesser weed biomass of all weed species as compared to bispyribac-Na 12.5g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 20 DAS *fb* one HW at 35 DAS and both treatments were statistically similar to each other except *Cynodon dactylon* (**Table 2**). These findings were in conformity with Khare *et al.* (2014) in direct-seeded rice.

At 60 DAS, penoxsulam 35 g/ha at 10 DAS *fb* one HW at 35 DAS resulted in higher weed control efficiency as compared to penoxsulam 35 g/ha at 20 DAS *fb* 1 HW at 35 DAS, bispyribac Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 10 DAS *fb* 1 HW at 35 DAS, bispyribac Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 20 DAS *fb* 1 HW at 35 DAS, bispyribac Na 12.5 g/ha + azimsulfuron 15 g/ha at 10 DAS *fb* 1 HW at 35 DAS, bispyribac-Na 12.5g/ha + azimsulfuron 15 g/ha at 20 DAS *fb* 1 HW at 35 DAS, bispyribac Na 25 g/ha at 10 DAS *fb* 1 HW at 35 DAS, bispyribac-Na 25 g/ha at 20 DAS *fb* 1 HW at 35 DAS and weedy (**Table 2**).

Nutrient depletion by weeds at 60 DAS

Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS recorded significantly lesser nutrient (NPK and Zn) depletion by weeds as compared to penoxsulam 35 g/ha at 20 DAS *fb* 1 HW at 35 DAS, bispyribac Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 10 DAS *fb* 1 HW at 35 DAS, bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 20 DAS *fb* 1 HW at 35 DAS, bispyribac-Na 12.5 g/ha + azimsulfuron 15 g/ha at 10 DAS *fb* 1 HW at 35 DAS, bispyribac-Na 12.5 g/ha + azimsulfuron 15 g/ha at 20 DAS *fb* 1 HW at 35

DAS, bispyribac-Na 25 g/ha at 10 DAS *fb* 1 HW at 35 DAS and bispyribac-Na 25 g/ha at 20 DAS *fb* 1 HW at 35 DAS in direct-seeded rice (**Table 3**). Nutrient removal by weeds depends on weed dry matter accumulation in respective treatments. Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS had lesser weed dry weight in comparison to rest of the treatment except hand weeding. Our results are also supported by Brar and Bhullar (2013).

Effect on crop

At 60 DAS, penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS resulted higher plant height, number of tillers/m^2, dry matter accumulation (g/running m), leaf area index and chlorophyll content in comparison to penoxsulam 35 g/ha at 20 DAS *fb*1 HW at 35 DAS and both treatments were statistically similar to each other except chlorophyll content. However, bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 10 DAS *fb* 1 HW at 35 DAS had higher plant height, number of tillers/m^2, dry matter accumulation (g/running m), leaf area index and chlorophyll content as compared to bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 20 DAS *fb* 1 HW at 35 DAS and bispyribac-Na 12.5g/ha + azimsulfuron 15 g/ha at 10 DAS *fb* 1 HW at 35 DAS and all these treatments were statistically similar to each other (**Table 3**). Penoxsulam 35 g/ha at 10 DAS *fb*1 HW at 35 DAS had better performance of growth attributes due to marked reduction in competition for growth resources due to reduction in weed density and weed dry weight (**Table 1** and **2**).

Integrated weed management treatments had significant variation in yield attributes and yield (**Table 4**). Amongst the integrated weed management treatments, penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS resulted higher panicle length, panicle weight (g/panicle), number of panicle/m^2, number of grains/panicle and test weight in comparison to penoxsulam 35 g/ha at 20 DAS *fb* 1 HW at 35 DAS and both treatments were statistically similar to each other. Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS recorded lowest weed index except hand weeding at 15 and 35 DAS. Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS had highest grain yield over rest of the treatments except hand weeding at 15 and 35 DAS. Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS and penoxsulam 35 g/ha at 20 DAS *fb*1 HW at 35 DAS recorded 114.8 and 103.8% increase in grain yield over weedy.

Nutrient uptake by crop at 60 DAS

At 60 DAS, hand weeding at 15 and 35 DAS resulted in the highest nutrient (NPK and Zn) uptake by crop followed by penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS, which had significantly higher nutrient(NPK and Zn) uptake in comparison to rest of

Table 1. Effect of integrated weed management on weed density (no./m^2) at 60 days after sowing in direct-seeded rice

Treatment	*E. colona*	*E. crus-galli*	*C. dactylon*	*C. iria*	*C. difformis*	*F. miliacea*	*A. baccifera*	*C. axillaris*	Other species
T_1 Bispyribac-Na 25 g/ha at 10 DAS *fb* 1 HW at 35 DAS	1.45^{efg} (1.60)	1.36^{ef} (1.35)	1.30^{fg} (1.18)	1.33^{de} (1.28)	1.32^{de} (1.25)	1.43^{ef} (1.55)	1.39^{de} (1.43)	1.43^{def} (1.53)	1.47^{de} (1.67)
T_2 Bispyribac Na 25 g/ha at 20 DAS *fb* 1 HW at 35 DAS	1.52^{def} (1.80)	1.41^{ef} (1.48)	1.40^{ef} (1.47)	1.43^{cd} (1.57)	1.39^{d} (1.43)	1.54^{fg} (1.87)	1.48^{cd} (1.70)	1.48^{de} (1.68)	1.51^{de} (1.78)
T_3 Bispyribac-Na 12.5 g/ha + azimsulfuron 15 g/ha at 10 DAS *fb* 1 HW at 35 DAS	1.58^{de} (2.00)	1.47^{de} (1.65)	1.51^{de} (1.78)	1.51^{bc} (1.80)	1.55^{c} (1.90)	1.62^{de} (2.12)	1.59^{c} (2.02)	1.54^{cd} (1.88)	1.56^{cde} (1.93)
T_4 Bispyribac-Na 12.5 g/ha + azimsulfuron 15 g/ha at 20 DAS *fb* 1 HW at 35 DAS	1.70^{cd} (2.38)	1.58^{cd} (2.00)	1.63^{cd} (2.17)	1.58^{bc} (1.98)	1.58^{c} (2.00)	1.69^{cd} (2.35)	1.61^{c} (2.10)	1.66^{bc} (2.27)	1.65^{bcd} (2.22)
T_5 Bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 10 DAS *fb* 1 HW at 35 DAS	1.86^{bc} (2.97)	1.65^{bc} (2.22)	1.67^{bc} (2.30)	1.62^{b} (2.12)	1.67^{bc} (2.30)	1.77^{b} (2.63)	1.79^{b} (2.72)	1.69^{bc} (2.35)	1.73^{bc} (2.50)
T_6 Bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron methyl) 2 g/ha at 20 DAS *fb* 1 HW at 35 DAS	1.91^{b} (3.17)	1.76^{b} (2.60)	1.80^{b} (2.73)	1.66^{b} (2.25)	1.72^{b} (2.47)	1.81^{b} (2.78)	1.85^{b} (2.93)	1.74^{b} (2.53)	1.79^{b} (2.70)
T_7 Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS	1.28^{g} (1.15)	1.24^{f} (1.03)	1.17^{g} (0.88)	1.21^{e} (0.97)	1.20^{e} (0.95)	1.26^{h} (1.08)	1.29^{e} (1.17)	1.29^{ef} (1.17)	1.37^{e} (1.37)
T_8 Penoxsulam 35 g/ha at 20 DAS *fb* 1 HW at 35 DAS	1.35^{fg} (1.33)	1.29^{f} (1.17)	1.23^{g} (1.02)	1.26^{e} (1.10)	1.24^{e} (1.05)	1.32^{fg} (1.25)	1.32^{de} (1.25)	1.33^{f} (1.28)	1.41^{e} (1.50)
T_9 Weed free	0.71^{h} (0.00)	0.71^{g} (0.00)	0.71^{h} (0.00)	0.71^{f} (0.00)	0.71^{f} (0.00)	0.71^{h} (0.00)	0.71^{f} (0.00)	0.71^{g} (0.00)	0.71^{f} (0.00)
T_{10} Weedy	4.04^{a} (15.80)	4.02^{a} (15.65)	3.48^{a} (11.62)	3.55^{a} (12.10)	3.46^{a} (11.50)	3.60^{a} (12.45)	3.47^{a} (11.55)	3.47^{a} (11.58)	3.49^{a} (11.68)
LSD (p=0.05)	6.06	5.85	4.54	5.73	4.03	4.65	5.73	5.98	6.18

Data were subjected to square root ($\sqrt{X+0.5}$) transformation; figures in parentheses are original values the integrated weed management treatments (**Table 3**). Bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 10 DAS *fb* 1 HW at 35 DAS had higher nutrients (NPK and Zn) uptake by crop as compared to bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 20 DAS *fb* 1 HW at 35 DAS and both the treatments were statistically similar to each other. This might be due to the lower weed density, dry weight and higher weed control efficiency and higher grain yield in penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS. These results were in close conformity with those reported by Khare *et al.* (2014).

Table 2. Effect of integrated weed management on weed biomass (g/m^2) and weed control efficiency (%) at 60 days after sowing in direct-seeded rice

Treatment	*E. colona*	*E. crusgalli*	*C. dactylon*	*C. iria*	*C. difformis*	*F. miliacea*	*A. baccifera*	*C. axillaris*	Other species	WCE (%)
T$_1$ Bispyribac-Na 25 g/ha at 10 DAS *fb* 1 HW at 35 DAS	1.23^{ef} (1.03)	1.16^{ef} (0.84)	0.88^{fg} (0.27)	1.19^{de} (0.91)	1.18^{de} (0.89)	1.26^{ef} (1.10)	0.78^{b} (0.11)	1.28^{def} (1.15)	1.32^{de} (1.25)	85.41
T$_2$ Bispyribac Na 25 g/ha at 20 DAS *fb* 1 HW at 35 DAS	1.33^{de} (1.27)	1.19^{ef} (0.92)	0.91^{ef} (0.34)	1.27^{cd} (1.11)	1.23^{d} (1.02)	1.35^{de} (1.33)	0.78^{b} (0.11)	1.33^{de} (1.26)	1.35^{de} (1.34)	84.10
T$_3$ Bispyribac-Na 12.5 g/ha + azimsulfuron 15 g/ha at 10 DAS *fb* 1 HW at 35 DAS	1.39^{cd} (1.44)	1.23^{de} (1.02)	0.95^{de} (0.41)	1.33^{bc} (1.28)	1.36^{c} (1.35)	1.41^{cd} (1.50)	0.78^{b} (0.11)	1.38^{cd} (1.41)	1.40^{cde} (1.45)	86.73
T$_4$ Bispyribac-Na 12.5 g/ha + azimsulfuron 15 g/ha at 20 DAS *fb* 1 HW at 35 DAS	1.48^{c} (1.68)	1.32^{cd} (1.24)	1.00^{cd} (0.50)	1.38^{bc} (1.41)	1.39^{c} (1.42)	1.47^{bc} (1.67)	0.78^{b} (0.11)	1.48^{bc} (1.70)	1.47^{bcd} (1.66)	86.27
T$_5$ Bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron-methyl) 2 g/ha at 10 DAS *fb* 1 HW at 35 DAS	1.62^{b} (2.14)	1.37^{bc} (1.37)	1.01^{c} (0.53)	1.41^{b} (1.50)	1.46^{bc} (1.63)	1.54^{b} (1.87)	0.79^{b} (0.12)	1.50^{bc} (1.76)	1.54^{bc} (1.88)	87.58
T$_6$ Bispyribac-Na 12.5 g/ha + (chlorimuron-ethyl + metsulfuron methyl) 2 g/ha at 20 DAS *fb* 1 HW at 35 DAS	1.65^{b} (2.23)	1.45^{b} (1.61)	1.06^{b} (0.63)	1.45^{b} (1.60)	1.50^{b} (1.75)	1.57^{b} (1.98)	0.79^{b} (0.12)	1.55^{b} (1.90)	1.59^{b} (2.03)	85.97
T$_7$ Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS	1.10^{g} (0.71)	1.07^{f} (0.64)	0.84^{g} (0.20)	1.09^{e} (0.69)	1.08^{e} (0.67)	1.13^{g} (0.77)	0.78^{b} (0.10)	1.17^{f} (0.88)	1.23^{e} (1.03)	92.53
T$_8$ Penoxsulam 35 g/ha at 20 DAS *fb* 1 HW at 35 DAS	1.16^{fg} (0.84)	1.11^{f} (0.72)	0.86^{g} (0.23)	1.13^{e} (0.78)	1.12^{e} (0.75)	1.18^{fg} (0.89)	0.78^{b} (0.11)	1.21^{ef} (0.96)	1.27^{e} (1.13)	91.59
T$_9$ Weed free	0.71^{h} (0.00)	0.71^{g} (0.00)	0.71^{h} (0.00)	0.71^{f} (0.00)	0.71^{f} (0.00)	0.71^{h} (0.00)	0.71^{c} (0.00)	0.71^{g} (0.00)	0.71^{f} (0.00)	100.00
T$_{10}$ Weedy	3.27^{a} (10.22)	3.19^{a} (9.70)	1.78^{a} (2.67)	3.01^{a} (8.59)	2.94^{a} (8.17)	3.06^{a} (8.84)	2.51^{a} (5.81)	3.03^{a} (8.69)	3.04^{a} (8.76)	0.00
LSD (p=0.05)	4.39	5.02	2.51	5.13	3.59	4.14	2.71	5.46	5.65	-

Data were subjected to square root ($\sqrt{x + 0.5}$) transformation; figures in parentheses are original values; Letters in common are not significantly different

Table 3. Effect of integrated weed management on plant height, number of tillers, dry matter accumulation, LAI and chlorophyll content and N, P, K (kg/ha) and Zn (g/ha) uptake by weeds and crop at 60 DAS in direct-seeded rice

Treatment	Plant height (cm)	No. of tillers/m^2	Dry matter accumulation (g/running m)	Leaf area index	Chloro-phyll content	Nutrient uptake by weeds at 60 DAS				Nutrient uptake by crop at 60 DAS			
						N (kg/ha)	P (kg/ha)	K (kg/ha)	Zn (g/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Zn (g/ha)
T$_1$	53.11^{b}	157.00^{cd}	32.86^{bc}	2.82^{a}	42.81^{cd}	131.^{d}	75^{d}	142^{d}	4118^{d}	13.24^{e}	2.09^{g}	16.28^{ef}	560.35^{f}
T$_2$	52.47^{bc}	156.50^{de}	32.31^{bc}	2.81^{a}	42.51^{de}	143^{b}	82^{b}	154^{b}	4488^{b}	12.64^{f}	1.84^{h}	15.65^{f}	535.99^{g}
T$_3$	52.09^{bcd}	156.00^{ef}	32.13^{bc}	2.80^{a}	42.38^{ef}	119^{f}	68^{f}	128^{f}	3743^{f}	13.74^{de}	2.46^{e}	16.79^{cde}	577.59^{def}
T$_4$	51.70^{cd}	155.50^{fg}	31.86^{cd}	2.79^{a}	42.06^{fg}	137^{c}	78^{c}	148^{c}	4306^{c}	13.47^{de}	2.21^{f}	16.49^{de}	564.69^{ef}
T$_5$	51.29^{cd}	155.00^{gh}	31.70^{cd}	2.78^{a}	41.78^{g}	111^{g}	63^{g}	120^{g}	3501^{g}	14.38^{bc}	2.71^{d}	17.50^{bc}	599.41^{bcd}
T$_6$	50.81^{d}	154.67^{h}	30.64^{d}	2.77^{a}	41.68^{g}	126^{e}	72^{e}	135^{e}	3957^{e}	13.98^{cd}	2.67^{d}	17.05^{cd}	585.40^{cde}
T$_7$	53.44^{b}	157.67^{b}	33.47^{b}	2.84^{a}	43.66^{b}	67^{i}	39^{i}	3^{i}	2110^{i}	14.92^{b}	3.12^{b}	18.16^{b}	618.30^{b}
T$_8$	53.19^{b}	157.33^{bc}	33.12^{bc}	2.83^{a}	43.06^{c}	75^{h}	43.3^{h}	82^{h}	2372^{h}	14.60^{b}	2.98^{c}	17.80^{b}	607.52^{bc}
T$_9$	55.68^{a}	161.00^{a}	38.33^{a}	2.95^{a}	45.18^{a}	0^{j}	0^{j}	0^{j}	0^{j}	17.25^{a}	4.12^{a}	21.24^{a}	742.58^{a}
T$_{10}$	38.60^{e}	129.83^{i}	18.32^{e}	1.41^{b}	37.48^{h}	1038^{a}	433^{a}	887^{a}	27225^{a}	7.40^{g}	1.01^{i}	9.19^{g}	287.37^{h}
LSD (p=0.05)	1.47	0.22	2.38	4.82	0.54	0.15	0.19	0.19	0.12	2.21	2.62	2.35	2.10

Letters in common are not significantly different

Table 4. Effect of integrated weed management on yield attributes yields, weed index, harvest index and economics in direct-seeded rice

Treatment	Panicle length (cm)	Panicle weight (g/ panicle)	No. of panicle (/m²)	No. of grains/ panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Weed index (%)	Harvest index (%)	Variable cost (x10³ `/ha)	Additional cost of weed control (x10³ `/ha)	Gross return (x10³ `/ha)	Net return (x10³ `/ha)	Benefit: Cost ratio (`/ha)
T_1	21.90^{b}	2.52^{b}	241.3^{c}	104.0^{d}	18.8^{b}	4.52^{cd}	6.07^{a}	12.8	42.7^{cd}	39.31	8.02	74.04^{cd}	34.72^{d}	1.88^{de}
T_2	21.88^{b}	2.52^{b}	240.8^{cd}	103.0^{e}	18.8^{b}	4.49^{d}	6.06^{a}	13.4	42.5^{cd}	38.73	7.43	73.59^{d}	34.86^{d}	1.90^{cde}
T_3	21.87^{b}	2.51^{b}	240.5^{de}	102.0^{f}	18.8^{b}	4.62^{bcd}	6.08^{a}	10.9	43.1^{bcd}	38.62	7.32	75.53^{cd}	36.91^{bcd}	1.96^{bcde}
T_4	21.85^{b}	2.50^{b}	240.1^{ef}	101.1^{g}	18.8^{b}	4.57^{bcd}	6.07^{a}	11.8	42.97^{bcd}	39.20	7.91	74.80^{cd}	35.60^{cd}	1.91^{cde}
T_5	21.84^{b}	2.48^{b}	239.6^{f}	100.3^{h}	18.8^{b}	4.73^{bc}	5.87^{a}	8.7	44.64^{abc}	37.00	5.70	76.92^{cd}	39.92^{b}	2.08^{ab}
T_6	21.82^{b}	2.48^{b}	239.0^{g}	100.0^{h}	18.79^{b}	4.68^{bcd}	6.07^{a}	9.8	43.51^{bcd}	37.59	6.29	76.31^{cd}	38.72^{bcd}	2.03^{abc}
T_7	21.92^{b}	2.55^{b}	242.5^{b}	106.0^{b}	18.8^{b}	5.05^{b}	6.17^{a}	2.5	45.02^{ab}	38.22	6.92	82.01^{ab}	43.79^{a}	2.15^{a}
T_8	21.91^{b}	2.54^{b}	242.0^{b}	105.0^{c}	18.8^{b}	4.79^{c}	6.20^{a}	7.5	43.61^{bcd}	38.81	7.51	78.23^{bc}	39.42^{bc}	2.02^{bcd}
T_9	23.39^{a}	2.92^{a}	250.5^{a}	111.6^{a}	20.7^{a}	5.19^{a}	6.12^{a}	0.0	45.88^{a}	46.00	14.70	83.90^{a}	37.91^{bcd}	1.82^{e}
T_{10}	16.68^{c}	1.69^{c}	213.3^{h}	71.6^{i}	15.9^{c}	2.35^{e}	3.37^{b}	54.6	41.66^{d}	31.30		38.79^{e}	7.49^{e}	1.24^{f}
LSD (p=0.05)	3.71	2.59	0.15	0.47	4.39	2.80	5.64	-	2.50			3.05	6.42	3.72

Letters in common are not significantly different

Economics

The gross return obtained by yield of crop varied significantly due to different treatments, which ultimately influenced the net returns and benefit: cost ratio. Penoxsulam 35 g/ha at 10 DAS *fb* 1 HW at 35 DAS had higher gross return as compared to penoxsulam 35 g/ha at 20 DAS *fb* 1 HW at 35 and both treatments were statistically similar to each other. Early post-emergence application of penoxsulam resulted in better control of weeds and variable cost of manual weeding was reduced at 35 DAS (**Table 4**). Consequently, the highest net return and benefit: cost ratio was observed under penoxsulam 35 g/ha at 10 DAS *fb*1 HW at 35 DAS. This could be attributed to higher grain yield of rice along with less labour and time required for manual weeding reducing cost of cultivation. Sairamesh *et al.* (2015) also supported these findings in direct-seeded rice.

Based on above findings it may be concluded that penoxsulam 35 g/ha at 10 DAS *fb*1 HW at 35 DAS should be applied for effective control of weeds, to obtain higher yield and net return in direct seeded rice.

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Indian Journal of Weed Science **49**(1): 15–19, 2017
DOI: 10.5958/0974-8164.2017.00004.1

Post-emergence herbicides for the control of resistant littleseed canarygrass in wheat

S.S. Punia*, Dharam Bir Yadav, Maninder Kaur and V.K. Sindhu
Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana 125 004

Received: 17 December 2016; Revised: 23 January 2017

ABSTRACT

Farmers' participatory field trials were conducted at village Kheri Raiwali in Kaithal district of Haryana during winter seasons of 2011-12 and 2012-13 to evaluate the bio-efficacy of post-emergence herbicides, their mixtures and sequential application for the control of the resistant littleseed canarygrass (*Phalaris minor*) and other weeds in wheat. Application of clodinafop 60 g/ha, fenoxaprop 120 g/ha and sulfosulfuron 25 g/ha at 35 days after sowing (DAS) did not provide satisfactory control of *P. minor*; however, mesosulfuron + iodosulfuron 14.4 g/ha provided better control (85-90%). Pinoxaden 50 g/ha resulted in 80% control of *P. minor* during first year but it provided only 55% control during second year. Ready-mix combination of metribuzin with fenoxaprop and clodinafop significantly improved the control of *P. minor* and broad-leaf weeds as compared to alone application of fenoxaprop and clodinafop. Maximum weed control efficiency (WCE) and highest grain yield (5.2 t/ha) was recorded with the application of sulfosulfuron + metsulfuron 32 g/ha during 2011-12, which was statistically at par with mesosulfuron + iodosulfuron and clodinafop + metribuzin; whereas during the second year, sulfosulfuron + metsulfuron 40 g/ha resulted in highest grain yield. Sequential application of sulfosulfuron + metsulfuron 32 g/ha at 25 DAS before irrigation *fb* sulfosulfuron + metsulfuron 32 g/ha at 40 DAS (after first irrigation) registered 97% WCE but its continuous adoption may lead to rapid development of resistance. The study indicates the need of new post-emergence herbicide with different mechanism of action (MOA), which can be integrated with non-chemical weed control strategies.

Key words: Herbicide mixture, Herbicide resistance, Metribuzin, *Phalaris minor*, Wheat

Wheat (*Triticum* a*estivum* L.) is the second most important grain crop of India after rice and thus crucial for the food security of the country. Being the main winter season crop, it occupies an area of 31.0 million ha with production of 86.5 million tons and average productivity of 2.79 t/ha. Wheat competes with several grassy and broad-leaf weeds during its growth period depending upon the adopted agronomic practices, soil types, underground water quality, weed control techniques and cropping system followed. For realizing potential crop yield, proper weed management is essential. *Phalaris minor* has become the most dominant weed of wheat in the rice-wheat cropping system (RWCS) in the north-western Indo-Gangetic Plains of India due to congenial agro-ecological conditions. PS II inhibitor herbicides were adopted on large scale for effective control of *P. minor* and other weeds during eighties, but continuous use of isoproturon resulted in the evolution of resistance in *P. minor* biotypes in north-western India (Malik and Singh 1995, Singh *et al.* 1997). This was the most serious case of herbicide resistance in the world, resulting in total crop failure from heavy weed infestations (2000-3000 plants/m^2). Alternate herbicides *viz.* clodinafop, sulfosulfuron and fenoxaprop were recommended to control isoproturon resistant population of *P. minor* during 1997. These herbicides provided effective control of this weed up to 2007 (Chhokar and Sharma 2008) and played a crucial role in restoring the productivity of wheat under RWCS in the country. Over the years, loss of efficacy to these herbicides has made the task of managing herbicide resistant *P. minor* biotypes more daunting (Dhawan *et al.* 2009). Presently, its control has become even more difficult after it evolved multiple herbicide resistance to recommended herbicides: diclofop-methyl, fenoxaprop-p-ethyl, clodinafop-propargyl, pinoxaden (ACCase); sulfosulfuron and premix of mesosulfuron + iodosulfuron (ALS inhibitors); mediated by enhanced metabolism and target site mutations (Punia *et al.* 2010, Dhawan *et al.* 2012). Multiple herbicide resistant populations of *P. minor* in wheat in RWCS is again threatening wheat productivity and profitability as it did in the early 1990s when resistance to isoproturon first occurred. Based on the observations recorded from farmers' interviews and previous field experiments, it was assumed that *P. minor* is not

***Corresponding author:** puniasatbir@gmail.com

being effectively controlled by the available herbicides (Punia *et al.* 2012). The use of multiple herbicide mechanism of action (MOAs) either as herbicide mixtures or sequential application can be investigated to work out a realistic strategy for the management of resistant *P. minor*. Metribuzin has been observed to cause phytotoxicity at high doses; however, its use in mixture at lower doses may be advantageous in management of multiple herbicide resistant *P. minor* (Singh 2015b, Yadav *et al.* 2016). So, the present experiment was planned to evaluate the bio-efficacy of herbicides, their mixtures and sequential use for management of the resistant *P. minor* at farmers' field.

MATERIALS AND METHODS

To study the bio-efficacy of different herbicides against *P. minor* and other broad-leaf weeds, a field experiment was laid out during winter seasons of 2011-12 and 2012-13 at village- Kheri Raiwali in district Kaithal, Haryana. The soil of the experimental field was clay loam in texture, low in available N, medium in phosphorus, high in potassium and slightly alkaline in reaction (pH 8.3). The treatments included pinoxaden 50 g/ha, clodinafop 60 g/ha, fenoxaprop 120 g/ha, sulfosulfuron 25 g/ha, mesosulfuron + iodosulfuron (ready-mix, RM) 14.4 g/ha, fenoxaprop + metribuzin (RM) 100+175 g/ha, clodinafop + metribuzin (RM) 60+210 g/ha, sulfosulfuron + metsulfuron (RM) 32 g/ha during *Rabi* 2011-12 whereas four new treatments of pinoxaden 60 g/ha, clodinafop 120 g/ha, sulfosulfuron + metsulfuron (RM) 40 g/ha and sulfosulfuron + metsulfuron (RM) 32 g/ha before irrigation (25 DAS) *fb* sulfosulfuron + metsulfuron (RM) 32 g/ha after irrigation (40 DAS) were added to the above treatments during 2012-13. The treatment of two sequential applications of sulfosulfuron + metsulfuron was the farmers' practice being followed in that area to combat the herbicide resistance problem. The experiment was laid out in randomized complete block design with three replications with a plot size of 20 x 8 m. There were small untreated plots during both the years in which herbicides were not sprayed. During 2011-12, wheat cultivar '*PBW 550*' was sown on 10 November, 2011 whereas wheat cultivar '*HD 2967*' was sown on 12 November 2012 during 2012-13. Seeding rate was 100 kg/ha at 20 cm row spacing. All the herbicides were sprayed with battery operated knapsack sprayer fitted with flat fan nozzle using spray volume of 375 l/ha at 40 psi pressure. Phyto-toxicity in terms of chlorosis, stunting, leaf burning, scorching, hyponasty and epinasty was visually observed at 15 days after treatment (DAT) and 45 DAT using rating scale of 0 – 100 scale, where 0 = no effect on plant and 100 = complete death of plant. Control of *P. minor* and broad-leaf weeds was also visually estimated by using a scale of 0 (no control) to 100 (complete control) at 75 days after sowing. The data on weed density were recorded with two 0.5 m x 0.5 m quadrants per plot at harvest and were subjected to square root transformation before statistical analysis. The weed control efficiency was computed for *P. minor*, broad-leaf weeds and total weeds control as a per cent reduction in weed population at harvest under different herbicidal treatments in comparison to weedy check. Biometric observations were recorded on effective tillers per meter row length, ear length and crop yield. Crop was harvested on 18 April, 2012 and 21 April, 2013 during 2011-12 and 2012-13, respectively. Grain yield of wheat was recorded by harvesting two samples from an area of 4.0 x 4.0 m in each plot. Data on visual per cent weed control were subjected to angular transformation before statistical analysis to improve the homogeneity of the variance. Year wise data were subjected to ANOVA separately and means were compared using Fisher's protected LSD test at 5% level of significance using the 'OPSTAT' software of CCS Haryana Agricultural University, Hisar.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with natural weed flora of the wheat crop and it was mainly dominated by *Phalaris minor*¸ which alone constituted 77-81% of the total weed flora. The other weed flora consisted of *Rumex dentatus*, *Chenopodium album*, *Coronopus didymus*, *Anagallis arvensis*, *Medicago denticulata* and *Melilotus indica*. Per cent control of *P. minor* and broad-leaf weeds was significantly affected by herbicides treatments as compared to weedy check at 75 days after sowing (**Table 1**). During both the years, clodinafop 60 g/ha, fenoxaprop 120 g/ha and sulfosulfuron 25 g/ha did not provide satisfactory control of *P. minor* in wheat (30%, 25-28% and 60-70%, respectively); however, mesosulfuron + iodosulfuron 14.4 g/ha provided better control (85-90%) of *P. minor*. Pinoxaden 50 g/ha resulted in 80% control of *P. minor* during first year but it provided only 55% control of *P. minor* during second year. Increasing the dose of clodinafop from 60 to 120 g/ha and pinoxaden from 50 to 60 g/ha significantly improved *P. minor* control (30 to 45 and 55 to 88%, respectively) at 75 DAS during 2012-13. Clodinafop, fenoxaprop and pinoxaden did not provide any control of broadleaf weeds and sulfosulfuron provided only 65-80% control; however, mesosulfuron + iodosulfuron effectively controlled (90%) broad-leaf weeds during both the years. Ready-mix combination of metribuzin with fenoxaprop and clodinafop significantly improved the control of *P. minor* (70-75%) and broad-leaf weeds (90-92%) as compared to alone application of fenoxaprop and clodinafop. The resistant populations of *P. minor* were also found susceptible to triazine (metribuzin and terbutryn) and dinitroaniline (pendimethalin) herbicides as reported by Chhokar and Sharma (2008) and Singh (2015b). Sulfosulfuron + metsulfuron 32 g/ha gave 85-92% control of *P. minor* along with 85-90% broad-leaf weeds during both the years. Increase in dose of sulfosulfuron + metsulfuron from 32 to 40 g/ha significantly enhanced the control of *P. minor* and broad-leaf weeds during 2012-13. The sequential application of sulfosulfuron + metsulfuron 32 g/ha at 25 DAS *fb* sulfosulfuron + metsulfuron 32 g/ha at 40 DAS resulted in significantly higher control of *P. minor* (98%) and broad-leaf weeds (98%) as compared to all other herbicidal treatments.

All the treatments except fenoxaprop 120 g/ha, were significantly superior to weedy check in reducing the population of *P. minor* at harvest during both the years (**Table 1**). Ready-mix herbicides at their normal dose significantly reduced the *P. minor* population as compared to clodinafop 60 and 120 g/ha; fenoxaprop 120 g/ha and pinoxaden 50 g/ha but

Table 1. Per cent control of weeds at 75 DAS and weed population at harvest as influenced by different herbicidal treatments in wheat at farmers' fields

Treatment	Dose (g/ha)	Visual weed control (%)*				Weed population (no./m^2)**			
		P. minor		BLW		*P. minor*		BLW	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden	50	64.0 (80.7)	48.1 (55.3)	0.0 (0.0)	0.0 (0.0)	5.2 (26.7)	8.4 (69.3)	6.4 (41.3)	6.3 (38.7)
Pinoxaden	60	-	63.7 (80.3)	-	0.0 (0.0)	-	5.7 (32.0)	-	6.0 (36.0)
Clodinafop	60	33.2 (30.0)	32.9 (29.7)	0.0 (0.0)	0.0 (0.0)	9.9 (97.3)	10.2 (104)	6.3 (38.7)	6.5 (41.3)
Clodinafop	120	-	41.9 (44.7)	-	0.0 (0.0)	-	8.8 (77.3)	-	6.3 (38.7)
Fenoxaprop	120	32.1 (28.3)	30.0 (25.0)	0.0 (0.0)	0.0 (0.0)	10.4 (107)	11.5 (132)	6.6 (42.7)	6.4 (40.0)
Sulfosulfuron	25	50.7 (60.0)	56.8 (70.0)	64.7 (81.7)	53.7 (65.0)	7.5 (56.0)	6.0 (36.0)	3.7 (13.3)	3.9 (14.7)
Mesosulfuron + iodosulfuron	14.4	71.5 (90.0)	67.2 (85.0)	71.5 (90.0)	71.9 (90.0)	3.2 (12.0)	4.8 (22.7)	2.9 (8.0)	2.3 (5.3)
Fenoxaprop + metribuzin	100+175	56.8 (70.0)	57.0 (70.0)	73.4 (91.7)	71.5 (90.0)	6.8 (45.3)	7.1 (50.7)	3.2 (9.3)	2.5 (5.3)
Clodinafop + metribuzin	60+210	59.8 (74.7)	59.9 (74.7)	72.0 (90.3)	71.5 (90.0)	6.0 (34.7)	6.2 (37.3)	3.2 (9.3)	2.2 (4.0)
Sulfosulfuron + metsulfuron	32	76.2 (91.7)	67.2 (85.0)	71.5 (90.0)	67.4 (85.0)	2.9 (9.3)	5.0 (24.0)	2.7 (8.0)	3.1 (9.3)
Sulfosulfuron + metsulfuron	40	-	73.4 (91.7)	-	73.4 (91.7)	-	4.1 (16.0)	-	2.7 (6.7)
Sulfosulfuron + metsulfuron *fb* sulfosulfuron + metsulfuron	32 & 32	-	85.7 (98.3)	-	85.7 (98.3)	-	1.9 (4.0)	-	1.4 (1.3)
Weedy check	-	0.0 (0.0)	0.0 (0.0)	(0.0)	0.0 (0.0)	11.8 (139)	12.3 (152)	6.6 (42.7)	6.1 (37.3)
LSD (P=0.05)	-	7.5	5.1	2.7	5.2	1.4	1.3	1.1	0.8

*Original figures in parentheses were subjected to angular transformation before statistical analysis; **Original figures in parentheses were subjected to square root transformation before statistical analysis

Table 2. Crop injury, yield and yield attributes of wheat as influenced by different herbicidal treatments at farmers' fields

Treatment	Dose (g/ha)	Crop injury (%) 15 DAT		Crop injury (%) 45 DAT		Plant height (cm)		Effective tillers/m row length		Ear length (cm)		Grain yield (t/ha)	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden	50	0	0	0	0	78.5	88.6	81	86	10.4	10.6	4.40	4.40
Pinoxaden	60	-	0	-	0	-	91.4	-	90		11	-	4.60
Clodinafop	60	0	0	0	0	77.4	87.4	72	74	10.5	10.2	3.96	3.95
Clodinafop	120	-	0	-	0	-	88.0	-	82		10.5	-	4.20
Fenoxaprop	120	0	0	0	0	75.6	85.3	66	68	9.4	9.8	3.80	3.95
Sulfosulfuron	25	0	0	0	0	74.9	92.3	83	93	11	10.9	4.50	4.50
Mesosulfuron+iodosulfuron	14.4	5	5	0	0	77.1	90.9	97	102	11.9	12.4	5.00	4.85
Fenoxaprop+ metribuzin	100+175	15	15	10	10	73.0	89.6	85	93	10.9	11.2	4.60	4.60
Clodinafop+metribuzin	60+210	0	15	0	10	79.2	90.0	96	94	11.6	11	4.96	4.60
Sulfosulfuron+metsulfuron	32	0	0	0	0	75.5	90.4	99	97	11.8	11.5	5.20	4.76
Sulfosulfuron+metsulfuron	40		0	-	0	-	90.2	-	103		12.5	-	4.90
Sulfosulfuron+metsulfuron *fb* sulfosulfuron+metsulfuron	32 & 32	-	5	-	0	-	92.7	-	105		12.4	-	4.85
Weedy check						72.7	82.6	57	59	9.1	8.7	3.30	3.15
LSD (P=0.05)	-		-		-	NS	6.1	6	7	1.1	1.4	0.37	0.24

remained at par with sulfosulfuron 25 g/ha and pinoxaden 60 g/ha during 2012-13. Minimum population of *P. minor* and broad-leaf weeds was recorded with the sequential application of sulfosulfuron + metsulfuron *fb* sulfosulfuron + metsulfuron, indicating that the sequential application of herbicides can improve weed control when single application even at increased rates have poor efficacy. Among the herbicidal treatments, highest weed control efficiency (97%) was recorded with sequential application of sulfosulfuron + metsulfuron *fb* sulfosulfuron + metsulfuron during 2012-13; followed by sulfosulfuron + metsulfuron 32 g/ha and mesosulfuron + iodosulfuron, which registered 90 and 89% WCE, respectively during 2011-12 (**Figure 1** and **2**). However, lower weed control efficiency was recorded with clodinafop, fenoxaprop and pinoxaden as these herbicides showed no efficacy against broad-leaf weeds and provided unsatisfactory control of *P. minor*. Ready-mix combination of metribuzin with fenoxaprop and clodinafop resulted in higher WCE due to better control of *P. minor* and broad-leaf weeds. The data on visual mortality indicated that *P. minor* has developed a high level of resistance against ACCase inhibitor herbicides (clodinafop, fenoxaprop) and medium level of resistance against ALS inhibitor herbicides (sulfosulfuron) at village- Kheri Raiwali in district Kaithal, Haryana. Poor efficacy of these herbicides during second year inferred that level of resistance increased over the years. The earlier literature also reported the varying levels of herbicide resistance in *P. minor* populations in Haryana (Dhawan *et al.* 2012, Chhokar *et al.* 2015, Singh 2015b).

Effect on crop

Ready-mix combinations of fenoxaprop + metribuzin showed 15% phyto-toxicity on the wheat (Var. *PBW 550* and *HD 2967*) at 15 DAT, however crop recovered with time (**Table 2**). Wheat crop also recovered from the initial suppression caused by the application of clodinafop + metribuzin and mesosulfuron + iodosulfuron. Differential varietal sensitivity to metribuzin has been reported earlier as well (Yadav *et al.* 2012). Among the herbicidal treatments, lowest yield and yield attributes of wheat were recorded with fenoxaprop 120 g/ha (3.80 and 3.95 t/ha) and clodinafop 60 g/ha (3.95 and 3.96 t/ha), though these treatments were significantly better than the weedy check (3.30 and 3.15 t/ha) during both the years (**Table 2**). During 2012-13, increasing the dose of clodinafop from 60 to 120 g/ha and pinoxaden from 50 to 60 g/ha resulted in increased grain yield of wheat, but the differences were not significant. However, combination of metribuzin with clodinafop and fenoxaprop significantly improved grain yield as compared to their alone application. Highest grain yield (5.2 t/ha) was recorded with the application of sulfosulfuron + metsulfuron, which was statistically at par with mesosulfuron + iodosulfuron and clodinafop + metribuzin during 2011-12, which might be attributed to the increased number of tillers and ear length of wheat under these treatments. During the second year, application of sulfosulfuron + metsulfuron 40 g/ha resulted in highest grain yield (4.90 t/ha), which remained at par with the sequential application of sulfosulfuron + metsulfuron (4.85 t/ha), mesosulfuron + iodosulfuron (4.85 t/ha) and sulfosulfuron + metsulfuron 32 g/ha (4.76 t/ha).

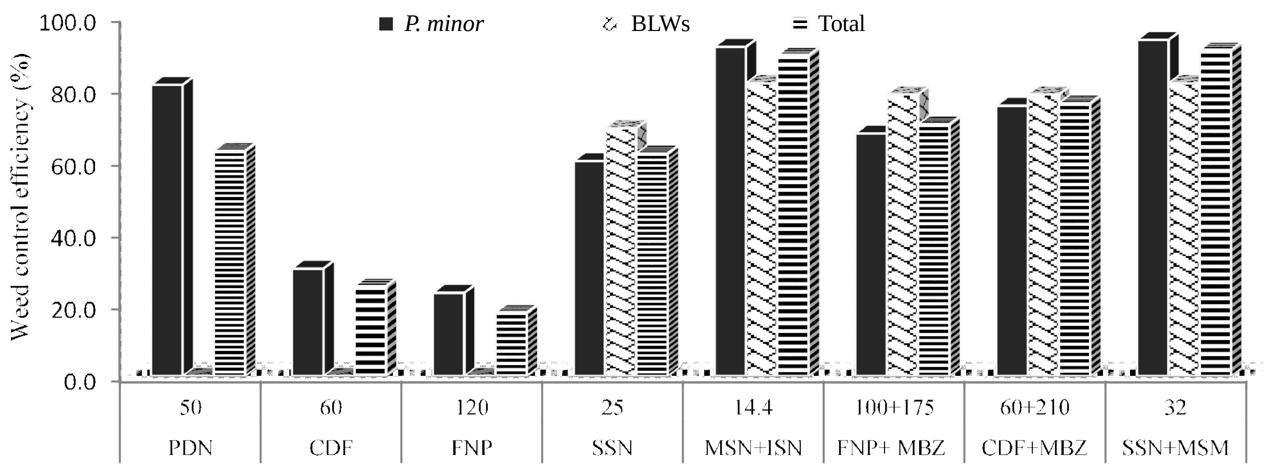

Figure 1. Weed control efficiency of different herbicides for *P. minor*, broad-leaf weeds (BLWs) and total weeds in wheat during 2011-12. The herbicide doses are in g/ha. PDN, pinoxaden; CDF, clodinafop; FNP, fenoxaprop; SSN, sulfosulfuron; MSN, mesosulfuron; ISN, iodosulfuron; MBZ, metribuzin; MSM, metsulfuron

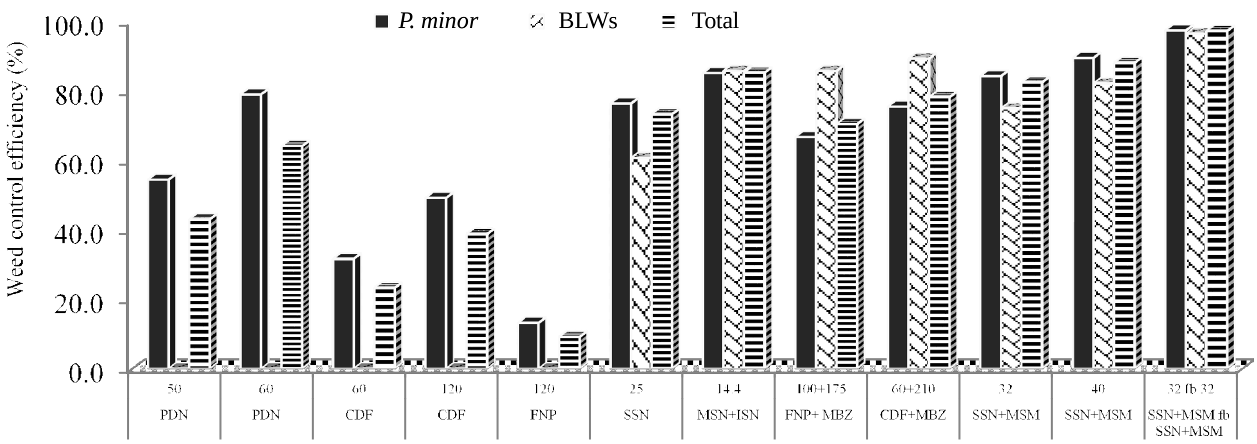

Fig. 2. Weed control efficiency of different herbicides for *P. minor*, broad-leaf weeds (BLWs) and total weeds in wheat during 2012-13. The herbicide doses are in g/ha. PDN, pinoxaden; CDF, clodinafop; FNP, fenoxaprop; SSN, sulfosulfuron; MSN, mesosulfuron; ISN, iodosulfuron; MBZ, metribuzin; MSM, metsulfuron; *fb*, followed by.

So, application of herbicide mixtures such as mesosulfuron + iodosulfuron, fenoxaprop + metribuzin, clodinafop + metribuzin provided some relief from resistant *P. minor* and could be exploited as alternative options but it is not an enduring solution. Use of metribuzin in long run may not remain effective because of higher propensity of *P. minor* for enhanced metabolism of PSII inhibitors (Singh 2015a). Similarly, application of sulfosulfuron + metsulfuron at higher dose or its sequential use before and after irrigation, provided effective control of all the weeds but it will again lead to rapid development of resistance. The resistance in weeds as such needs to be addressed with integrated weed management approaches, including crop and herbicide rotations, herbicide combinations with cultural and mechanical methods.

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Indian Journal of Weed Science **49**(1): 20–22, 2017
DOI: 10.5958/0974-8164.2017.00005.3

Tillage and weed management on yield and nutrient uptake of wheat under maize-wheat cropping system in Western Himalayas

Lobzang Stanzen*, Anil Kumar, R. Puniya, Neetu Sharma, Amit Mahajan and Ashu Sharma
Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Main Campus Chatha, Jammu, Division of Agronomy, 180 009

Received: 24 December 2016; Revised: 21 January 2017

ABSTRACT

A field experiment was conducted during *Rabi* season of 2013-14 and 2014-15 at SKUAST-Jammu to study the effect of tillage and weed management on yield and nutrient uptake of wheat under maize-wheat cropping system in sub-tropical irrigated conditions. The results revealed that different tillage systems recorded non-significant grain yield of wheat. However, ZT in wheat either preceded by conventional tillage (CT) or zero tillage (ZT) in maize was more beneficial as it recorded higher net returns and benefit: cost ratio than CT in wheat. Among the weed management, post-emergence application of metribuzin at 200 g/ha resulted in lowest total weed density and biomass of weeds, which was statistically at par with two hand weedings and significantly lower than weedy check. The post-emergence application of metribuzin at 200 g/ha also recorded highest weed control efficiency (WCE), net returns and B:C ratio during both the years of experimentation followed by two hand weedings.

Key words: Cropping system, Nutrient uptake, Tillage, Weed management, Wheat, Yield

Wheat is the most important cereal crop and an integral component of food security at global level. At present, the soil resources are under stress owing to intensive cropping with a raising of more than two crops in a year without replenishing this resource as is desirable. Repeated conventional tillage coupled with other faulty land utilization practices have caused large scale degradation of our soils over the past 50-60 years and most of the soils have lost up to one-half of their native organic matter content and fauna (Malik *et al.* 2006). Traditional tillage practices also contribute to the energy and labour cost in crop production systems resulting in lower economic returns (Saharawat *et al.* 2010 and Kumar *et al.* 2013).

Furthermore, intensive ploughing results in decrease in soil organic matter due to acceleration of the oxidation and breakdown of organic matter and ultimately led to degradation of soil properties (Gathala *et al.* 2011). Zero tillage practice in wheat crop is beneficial to farmers because it saves preparation time which often delays the wheat sowing.

Lower productivity of wheat by and large can also be attributed to several other limiting factors and all but most important among these has been the poor weed management, which poses a major threat to crop productivity. Wheat crop is badly infested with grass as well as broad-leaf weeds. Crop losses due to weed competition throughout the world as a whole, are greater than those resulting from combined effects of insect-pests and diseases (Hassan *et al.* 2005). Therefore, timely weeding is most important to minimize the losses in crop yields especially during the critical crop-weed competition periods. Management of weeds through the use of herbicides has been found to be very effective and economical compared to that realized with manual or mechanical methods in various crops including wheat. Hence keeping the above facts in forefront there is greater need to evaluate tillage and weed control for wheat in irrigated maize-wheat cropping system.

***Corresponding author:** stanzen2015@gmail.com

MATERIALS AND METHODS

Experiment was carried out during *Rabi* season of 2013-14 and 2014-15. The experimental soil was sandy clay loam in texture with slightly alkaline in reaction (pH 7.87), medium in organic carbon (0.52 %), available phosphorus (12.32 kg/ha) and potassium (148.4 kg/ha) and low in available nitrogen (247.60 kg/ha). The experiment was conducted in split-plot design with three replications. The main plot comprised of four tillage treatments, *viz.* zero tillage in wheat preceded by zero tillage in maize (ZT pb ZT), conventional tillage in wheat preceded by zero tillage in maize (CT pb ZT), zero tillage in wheat preceded by conventional tillage in maize (ZT pb CT) and conventional tillage in wheat preceded by conventional tillage in maize (CT pb CT), whereas, sub-plot comprised of three weed management practices, *viz.* hand weedings (two), metribuzin at 200 g/ha and weedy check. Wheat variety '*RSP 561'* was sown on 15 November, 2013 and 18 November, 2014 with 100 kg seed/ha at row to row spacing of 20 cm. The crop was fertilized with 100 kg N, 50 kg P and 25 kg/ha K through urea, DAP and MOP, respectively. Full dose of P and K along with 1/3rd of N were applied as basal dose at the time of sowing and remaining N was applied in two equal splits at tillering stage and booting stage. Post-emergence application of herbicide was sprayed by knapsack sprayer fitted with flat fan nozzle using a spray volume of 500 l/ha. Weedy check plots remained infested with native population of weeds till harvest. Data on weed density and biomass were taken by quadrate method. The weed density and biomass were subjected to square root transformation $(\sqrt{x+1})$ to normalize their distribution. WCE was calculated by using the formulae suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed density, weed dry matter and WCE

The experimental field was infested with *Medicago denticulata, Anagallis arvensis, Cirsium arvensis, Chenopodium album* among broad-leaf weeds whereas, *Phalaris minor* and *Poa annua* among grasses. Tillage treatments failed to show any significant impact on total weed density and biomass (**Table 1**). The highest weed-control efficiency was recorded under CT pb CT which might be due to minimum biomass of weeds under conventional tillage over zero tillage which in turn increase weed control efficiency. These results corroborated with the findings of Jain *et al.* (2007). Different weed management treatments had significant effect on density and biomass of weeds in wheat. Among weed management treatments, lowest density and biomass of total weed at 90 DAS and at harvest were recorded with the post-emergence application of metribuzin at 200 g/ha which was found to be statistically at par with two hand weedings. Highest weed control efficiency was also recorded with application of metribuzin at 200 g/ha (**Table 1**). Chauhan *et al.* (2000) and Pandey *et al.* (2006) also recorded the best efficacy of metribuzin with respect of total density and biomass of both grass and non-grass weeds in wheat.

Nutrient uptake of crop

Tillage treatments failed to show any significant impact on N, P and K uptake of wheat. However, CT in wheat either preceded by CT or ZT recorded higher uptake of N, P and K of wheat crop during both the years of cropping than ZT in wheat (**Table 2**). There was a significant increase in nutrient (N, P and K) uptake of wheat due to different weed management treatments as compare to weedy check. Among weed management treatment, highest N, P and K uptake were recorded by metribuzin at 200 g/ha which was statistically at par with two hand weedings. Similar findings were noticed by Pandey *et al.* (2007) and Jat *et al.* (2004).

Yield and economics

Grain yield of wheat was statistically similar with respect to tillage treatments during both the years of cropping (**Table 2**). However, CT in wheat either preceded by CT or ZT recorded higher grain yield of wheat crop during both the years of cropping than ZT in wheat. Amongst the weed management treatments, application of metribuzin at 200 g/ha, recorded highest grain yield of wheat which was statistically at par with two hand weedings (**Table 2**). The highest grain yield might have been achieved due

Table 1. Effect of tillage and weed management practices on total weed density and biomass in wheat

Treatment	Total weed density (number/m^2)				Total weed biomass (g/m^2)				WCE at 90 DAS (%)
	90 DAS		At harvest		90 DAS		At harvest		
	2013	2014	2013	2014	2013	2014	2013	2014	Mean
Tillage									
ZT pb ZT	9.41(95)	9.31(94)	8.46(79)	8.37(77)	12.19(157)	12.00(153)	10.86(129)	10.69(127)	72.4
CT pb ZT	9.21(93)	9.06(91)	8.25(76)	8.13(76)	12.00(152)	11.83(149)	10.70(125)	10.58(124)	72.3
ZT pb CT	9.42(96)	9.26(94)	8.39(77)	8.29(77)	12.12(155)	11.94(152)	10.80(126)	10.69(125)	70.9
CT pb CT	9.18(92)	8.98(90)	8.23(76)	8.09(75)	11.87(149)	11.67(147)	10.45(121)	10.39(121)	74.6
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	-
Weed management									
Hand weeding (two)	7.38(54)	7.16(51)	6.38(40)	6.20(38)	10.14(102)	9.82(96)	8.51(72)	8.29(67)	71.1
Metribuzin at 200 g/ha	7.19(51)	6.87(47)	6.17(37)	5.88(34)	9.78(95)	9.36(87)	8.09(65)	7.84(61)	74.0
Weedy check	13.34(177)	13.41(179)	12.45(154)	12.57(157)	16.22(262)	16.40(268)	15.50(239)	15.63(243)	-
LSD (P=0.05)	0.21	0.29	0.21	0.33	0.51	0.60	0.43	0.45	-

Original data are given in parentheses; pd - Preceded by

Table 2. Effect of tillage and weed management practices on nutrient uptake by crop (grain + straw) yield and economics of wheat

Treatment	Nutrient uptake by crop (kg/ha) N		P		K		Grain yield (t/ha)		Net returns (x10³ `/ha)		B:C ratio	
	2013	2014	2013	2014	2013	2014	2013-14	2014-15	2013	2014	2013	2014
Tillage												
ZT pb ZT	80.9	84.8	18.3	19.2	105.1	115.6	3.14	3.16	45.5	50.6	2.25	2.45
CT pb ZT	86.8	90.9	19.8	20.4	110.7	122.4	3.32	3.35	44.8	50.3	1.84	2.02
ZT pb CT	81.9	85.7	18.6	19.2	106.3	116.9	3.15	3.18	45.7	50.9	2.26	2.46
CT pb CT	87.6	92.6	20.0	20.8	111.7	123.0	3.33	3.37	45.0	50.6	1.85	2.04
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	-
Weed management												
Hand weeding (two)	99.0	104.2	22.8	23.1	123.5	136.2	3.85	3.90	51.3	57.5	1.87	2.04
Metribuzin at 200 g/ha	104.6	109.8	24.1	24.2	127.5	140.6	3.95	4.00	60.7	67.4	3.04	3.31
Weedy check	49.3	51.5	12.3	12.3	74.3	81.6	1.91	1.90	23.8	26.9	1.25	1.38
LSD (p=0.05)	6.4	7.1	1.9	2.4	8.2	9.8	2.04	2.20	-	-	-	-

pd - Preceded by

to better weed control, *i.e*. lowest weed density and weed biomass resulted in higher grain yield of wheat These results were in close conformity to those of Ashrafi *et al.* (2009).

Among the tillage treatments, ZT pb CT recorded highest net returns and benefit: cost ratio followed by ZT pb ZT during both the years of cropping (**Table 2**). This might have happened due to reduction in cost of cultivation under zero tillage treatments while producing similar grain yield as that obtained under conventional tillage. These results were in close conformity with the findings of Shekhar *et al.* (2014). Among weed management treatments, highest net returns and B:C ratio were obtained with application of metribuzin at 200 g/ha in wheat crop, which was closely followed by two hand weeding (**Table 2**). This might have happened due to the fact that all treatments associated with weed control increased the grain yield of wheat than weedy check with regard to net monetary returns. Similar findings have been reported by Shekhar *et al.* (2014). On the basis of two year study, it was concluded that ZT in wheat either preceded by CT or ZT in maize was more beneficial as it recorded higher net returns and benefit: cost ratio than CT in wheat. Among the weed management treatments, post emergence application of metribuzin at 200 g/ha in wheat was found to be most economical for weed management.

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Indian Journal of Weed Science **49**(1): 23–28, 2017
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Adoption and impact assessment of weed management technologies in wheat and greengram under conservation agriculture system in central India

P.K. Singh*, Shobha Sondhia, R.P. Dubey, Sushilkumar, Bhumesh Kumar, Yogita Gharde and V.K. Choudhary
ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482 004

Received: 12 March 2017; Revised: 27 March 2017

ABSTRACT

Rice-wheat is the major cropping system in the Indo-Gangetic plains and is also practiced on considerable area in Madhya Pradesh. Rice-wheat production system under conventional practices involves tedious and time-consuming methods of field preparation and weed management; increases cost of production, deteriorates soil fertility, and do not offer desired benefits for increasing the grain yields. In conventional agriculture, burning of crop leftover residue has become a major challenge that leads to loss of precious plant nutrients and deteriorates environmental quality. In order to mitigate these problems, technically-feasible, economically-viable and ecologically-permissible technologies need to be essentially adopted. A technology is required to facilitate timely sowing in standing stubbles, minimize weed infestation, lower cost of production, improve fertilizer/water-use efficiency and improve soil health. To reap the benefits of conservation agriculture (CA), studies were conducted at farmers' fields in rice-wheat-greengram cropping system in black-cotton soils in Madhya Pradesh for consecutive five years. Sowing was done with Happy Seeder. Emergence of weeds from upper soil surface was effectively controlled by herbicides. Results showed that the benefits of CA can well be harnessed in black-cotton soils with rice-wheat-greengram cropping system. Retention of crop residues on soil surface provided an effective mulch cover for nutrient and moisture conservation, temperature moderation and weed control.

Key words: Adoption, Conservation Agriculture, Greengram, Herbicides, Wheat

Keeping in view the multiplicity of problems threatening present day farming in India, conservation of resources has become significant to sustain farming. Consequently there has been positive shift towards promotion of conservation agriculture (CA) throughout the world (Mertens and Jensen 2002, Melander *et al.* 2005, Sharma and Singh 2014, Bajwa 2014). The CA aims at increasing productivity and improving soil health (Fowler and Rockstrom 2001, Hobbs 2007, Giller *et al.* 2009). This practice promises better soil health than conventional tillage based agriculture (Erenstein 2003, Gowing and Palmer 2008). However, presence of weeds often down plays numerous advantages of CA (Buhler *et al.* 1994) and poses a great challenge to its wider adoption. Absence of tillage leads to presence of weed seeds on the upper soil layer which offers severe competition to the crop. Weed management in CA requires special attention with integration of several technologies such as tillage, crop establishment methods, agronomic practices, machinery *etc*. (Lafond *et al.* 2009).

***Corresponding author:** drsinghpk@gmail.com

Rice-wheat is the major cropping system in the Indo-Gangetic plains (Chauhan *et al.* 2012). It is also followed in central and eastern parts of the Madhya Pradesh (MP), which is the second largest state of India having 15.1 m ha of net sown area. Crop cultivation practices in MP comprise intensive ploughing of land, removal or burning of crop residues and stubbles, fixed crop rotations, less use of organic manures, moderate use of chemical fertilizers and other pesticides including herbicides. With increasing use of combines for harvesting of rice and wheat to save time and combat problem of labour scarcity, the management of left over crop residues has become a serious problem in rice-wheat cropping system. Burning of crop residues to facilitate sowing of succeeding crop not only pollutes the environment with hazardous gases but also results in loss of precious plant nutrients from soils. Conventional rice-wheat production system involves sowing of wheat seeds in fine seedbed prepared by 4-5 tillage operations, which take 10-15 days time and incur ` 3000-4000/ha for land preparation. Such tillage operations increase the production cost with little benefit on crop yield and thus reduce the profit margin. Thus reduction in soil fertility, scarcity of farm labour, declining water table and high cost of production of conventional agriculture require some alternative methods of wheat cultivation (Edwards and Smith 2005). The issues such as delay in sowing, severe weed infestation, crop residue management, declining factor productivity, increasing cultivation cost require urgent attention. In order to combat such problems, the technologies should be technically-feasible, economically-viable and ecologically-permissible, and should ameliorate late sowing, minimize weed infestation, minimize production cost, improve fertilizer/water-use efficiency and improve soil fertility. Resource conservation technologies have been reported to reduce cost, improve soil health and protect the environment (Chauhan *et al.* 2012). Therefore, a study was undertaken in rice-wheat-greengram cropping system to see the effect of CA technology on yield increase at farmers' field and its impact and adoption among farmers.

MATERIALS AND METHODS

This study was undertaken to manage weeds in wheat and greengram under rice-wheat-greengram cropping system under conservation agriculture in black-cotton soils of Madhya Pradesh for consecutive five years from 2012-13 to 2015-16 at farmers' fields in five localities covering 30 villages in central part of the state. These On-Farm Research (OFR) cum Demonstration trials were conducted by the ICAR-Directorate of Weed Research, Jabalpur.

In the first year (2012-13), trials were conducted in wheat in the Panagar block of Jabalpur on farmers' fields at 6 locations. Wheat was sown with Happy Seeder without tilling (maintaining rice stubbles in the field) along with use of glyphosate and clodinafop + metsulfuron at 60 + 4 g/ha herbicides for weed control. After the successful demonstration of the technology at farmer's fields of Jabalpur region, both wheat (10 sites) and greengram (5 sites) were sown with Happy Seeder in the same locality during 2013-14 at farmer's fields of 0.4 ha plot size. In 2015, OFR cum demonstration trial on CA based technology was extended to 5 villages and 7-8 farmers in each district in Mandla, Seoni, Narsinghpur and Katni districts of MP.

In 2015-16, about 100 more trials were laid out at 30 villages. Resource conservation technologies such as direct-seeding of rice, brown manuring with *Sesbania*, zero-till sowing of crops with Happy Seeder, residue retention on soil surface, growing of summer greengram or *Sesbania* in the crop rotation and integrated weed management technologies were demonstrated under diversified cropping systems. Wheat and greengram were grown during *Rabi* and summer with three treatments, CA with recommended fertilizers dose (RFD) and herbicide, CA with RFD and without herbicide, and farmer's practice (FP). Farmers of the locality were following conventional tillage (CT), high seed rate, imbalance fertilizer without proper weed management, the amount of which varied with the farmers/places.

Data on weed emergence and growth such as weed density/m^2 and dry weight (g/m^2) were recorded at 40 and 60 days after sowing (DAS) and grain yields were recorded at crop maturity and benefit-cost ratio of each treatment was worked out as per standard protocols.

RESULTS AND DISCUSSION

Performance of conservation agriculture technologies adopted in wheat and greengram at different localities in five districts is described below:

Jabalpur district

The OFR trials were conducted on CA and weed management during *Rabi* 2013-16 at 6 fields in wheat and 20 fields in greengram at Jabalpur district.

Effect on wheat: The ready mix of clodinafop + metsulfuron at 60 + 4 g/ha was used to control weeds in the crop in the OFR. Seed germination and establishment of wheat crop under conservation agriculture was good. The major weed flora observed was *Lathyrus sativus*, *Vicia sativa, Chenopodium album*, *Medicago denticulata* and *Melilotus alba* among broad-leaf and *Avena* sp. (wild oat) and *Phalaris minor* among grasses.

Application of RFD (120:60:40 kg N, P_2O_5, K_2O/ha) along with herbicide (clodinafop + metsulfuron at 60 + 4 g/ha) at 30 DAS under conservation agriculture resulted in the lowest weed density and biomass and higher grain yield (4.93 t/ha), higher net income (` 54,462/ha) with higher B:C ratio (3.8) compared to farmer's practice of conventional tillage, use of higher seed rate, unbalanced fertilizer and without proper weed management (**Figure 1 and Table 1**).

Effect on summer greengram: The OFR trials were undertaken on greengram under conservation agriculture during summer 2014-2016 at twenty farmer's fields of Jabalpur district. Sowing of greengram was done with Happy Seeder just after harvesting of wheat crop without removal or burning the standing crop stubbles.

CA + post-emergence application of imazethapyr 100 g/ha effectively controlled broad spectrum of weeds and resulted in seed yield of 1.25 t/ha as compared to 0.72 t/ha under FP (CT + no weeding), and provided an additional net return of ` 13,000/ha with higher B: C ratio over FP. Use of Happy seeder saved time, favoured early sowing on residual soil moisture (visualized) and saved field preparation cost. Unlike ZT seed drill, Happy Seeder facilitated the use of wheat crop residue as mulch in the field and thereby helped in managing weeds and conserving moisture (**Figure 2** and **Table 2**).

Katni district

The OFR trials were conducted on CA and weed management during *Rabi* 2013-16 at five farmers' fields in Chitwara, Bichiya, Ghughra, Banda and Lakhapateri villages. After wheat harvest, greengram was sown on these fields.

Effect on wheat: Mean results of five sites indicated that RFD + herbicides with CA significantly reduced the weed population by 63.5% and weed dry weight by 82.4% and increased grain yield by 47.3% compared to farmers' practice (3.49 t/ha). RFD + herbicides with CA resulted in higher B:C ratio (3.44) than farmers' practice (1.81) (**Figure 1** and **Table 1**).

Effect on summer greengram: Greengram sown with Happy Seeder after harvest of wheat and application of RFD and herbicide imazethapyr 100 g/ha resulted in appreciably good seed yield (1.26 t/ha) with B:C ratio of 3.90 (**Figure 2** and **Table 2**).

Mandla district

In Mandla district also, OFR trials were conducted on wheat at 8 farmers' fields and greengram at 6 farmers' fields in Bhawal, Bejegaon, Lalipur, Gujarsani and Harratikur villages during *Rabi* 2013-16.

Effect on wheat: Farmer's practice was compared with CA and RFD but without weed management and CA with RFD and weed management with herbicides. Mean of 8 trials revealed that CA with RFD and herbicide based weed managment significantly reduced the weed population and dry weight compared to farmers' practice and produced 20% higher grain yield (4.2 t/ha) than farmers' practice. The B:C ratio of with CA alongwith RFD and herbicide application was also higher (3.16) than that obtained from farmers' practice (**Figure 1** and **Table 1**).

Effect on summer greengram: Greengram sowing with Happy Seeder and weed control by application of imazethapyr 100 g/ha resulted seed yield of 1.35 t/ha with B:C ratio of 3.63 (**Figure 2** and **Table 2**).

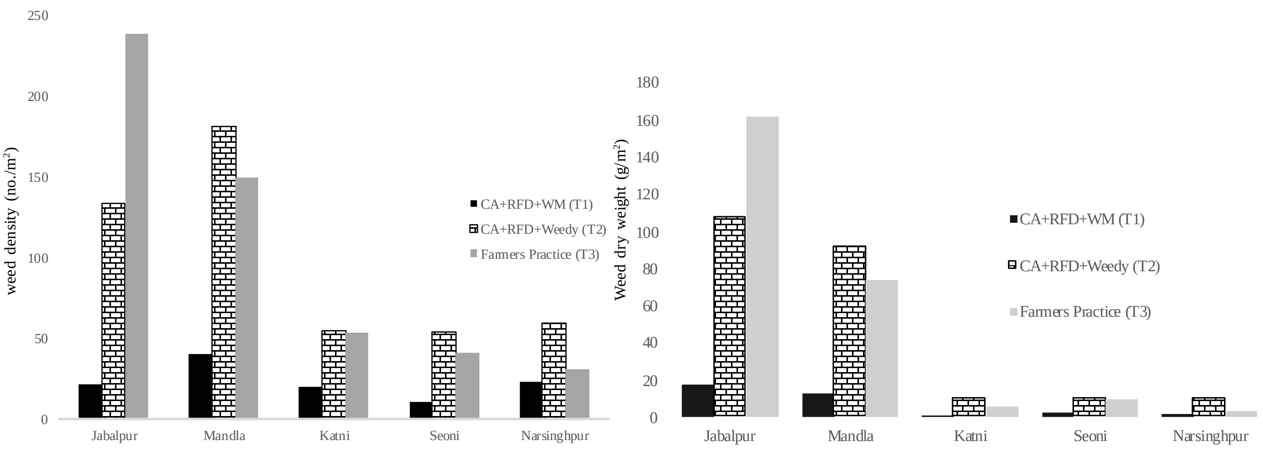

Figure 1. Effect of conservation agriculture on weed density and weed dry weight in wheat at different locations during *Rabi* 2013-16

Table 1. Productivity of wheat (t/ha) under conservation agriculture in OFR during *Rabi* 2013-16 (average of 29 farmer's fields)

Treatment	Jabalpur		Mandla		Katni		Seoni		Narsinghpur	
	Grain yield	B:C ratio	Grain yield	B:C ratio	Grain yield	B:C ratio	Grain yield	B:C ratio	Grain yield	B:C ratio
CA + RFD + WM	4.93	3.80	4.20	3.16	5.14	3.44	5.05	3.44	4.10	3.46
CA + RFD + weedy	3.51	2.90	3.30	2.87	4.34	3.15	2.91	2.15	2.76	2.68
Farmers practice	3.22	2.22	3.50	2.30	3.49	1.81	2.83	1.78	3.75	2.40

CA-Conservation agriculture; RFD- Recommended fertilizer dose; WM: weed management

Narsinghpur district

Effect on wheat: To discourage burning of crop residues of paddy after its harvest, wheat was sown with Happy Seeder in the standing crop residues without any tillage operation at 5 locations at farmers' fields during *Rabi* 2013-2016. Application of ready mix combination of clodinafop + metsulfuron at 60 + 4 g/ha at 25 DAS in wheat effectively controlled weeds and produced higher grain yield (4.10 t/ha) and B: C ratio (3.46) compared to farmers' practice which yielded 3.75 t/ha of grain with B:C ratio of 2.40 (**Figure 1 and Table 1**).

Seoni district

In Seoni district, OFR trials were conducted on wheat at 5 farmers' fields and greengram at 10 farmers' fields during *Rabi* 2013-16.

Effect on wheat: In Happy Seeder sown plots, application of RFD (120:60:40 N, P_2O_5, K_2O kg/ha) and post emergence (POE) herbicide (clodinafop + metsulfuron at 60 + 4 g/ha) resulted in higher mean grain yield (5.05 t/ha) and B:C ratio (3.44) over farmers' practice (2.83 t/ha and 1.78, respectively) (**Figure 1 and Table 1**).

Effect on summer greengram: Under CA with recommended fertilizer dose (20:60:40 kg N, P_2O_5 and K_2O/ha) and post-emergence application of herbicide (imazethapyr at 100 g/ha), greengram produced higher mean seed yield (1.70 t/ha) and B: C ratio (2.82) over farmers' practice (0.88 t/ha and 1.31, respectively) (**Figure 2 and Table 2**).

Better crop emergence, lesser number of weeds under CA, RFD and with or without herbicide based weed management resulted in higher yield (4.0-4.5 t/ha) than conventional practices (2.4-3.0 t/ha). The lower production costs and higher yields increased benefit cost ratio under CA system. Precision land leveling can reduce the labour requirement by 75 per cent in wheat in comparison to traditional leveled fields (Jat *et al.* 2009).

Yield loss models are generally used to estimate the effect of weeds on yield at an early growth stage of crop development before they have a distressing effect on crop. Data of weed density of all locations were used to fit a crop yield model to estimate the effect of weeds on wheat yield. A linear function as suggested by Dew (1972) was used to express the relationship between crop yields and weed density in wheat crop. It is given by

$$Y = a + bx$$

Where, y is the crop yield, x is the weed density, a is the intercept at $x = 0$, and b is the regression coefficient.

The model suggests reduction in grain yield with increase in weed density (**Figure 3**). With each unit (number) power of 10 increase in weed density/m^2, the wheat yield will decrease by 0.586 t/ha.

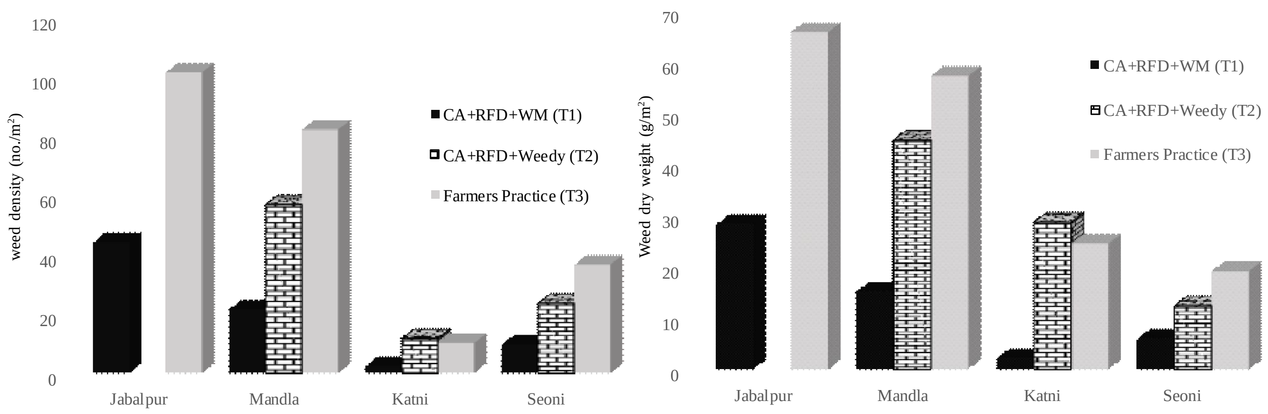

Figure 2. Effect of conservation agriculture on weed density and weed dry weight in summer greengram during 2013-16 (average of 41 farmer's field)

Table 2. Productivity of greengram (t/ha) under conservation agriculture during summer 2013-16 (mean of 41 locations)

Treatment	Jabalpur		Mandla		Katni		Seoni	
	Seed yield	B:C ratio	Seed yield	B:C ratio	Seed yield	B:C ratio	Seed yield	B:C ratio
CA + RFD + WM	1.25	2.94	1.35	3.63	1.26	3.90	1.70	2.82
CA + RFD + weedy	-	-	1.03	3.09	0.95	3.32	1.35	2.44
Farmers practice	0.72	1.43	0.89	2.18	0.87	2.10	0.88	1.31

CA-Conservation agriculture; RFD- Recommended fertilizer dose; WM: weed management

Table 3. Cost of production (`/ha) and gross income (`/ha) in wheat and greengram

Treatment	Jabalpur				Mandla			
	Wheat		Greengram		Wheat		Greengram	
	Cost of production	Total income	Cost of production	Total income	Cost of production	Total income	Cost of production	Total income
CA + RFD + WM	19,563	74,025	19,850	58,395	20,500	65,286	21,550	78,150
CA + RFD + weedy	17,625	52,665	-*	-*	18,000	51,617	19,750	62,100
Farmers practice	22,875	48,405	23,400	33,631	24,375	56,102	24,650	53,640

CA: Conservation agriculture; RFD: Recommended fertilizer dose; WM: Weed management; *Related data not recorded

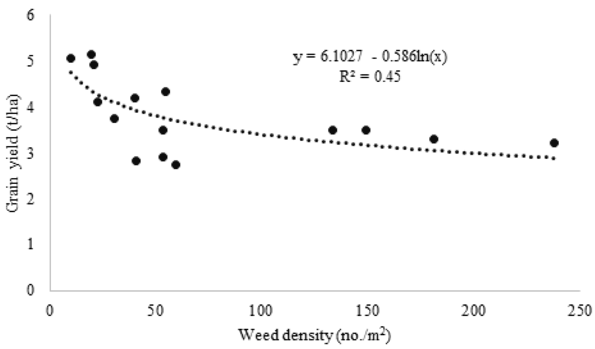

Figure 3. Fitting of linear model for estimating wheat crop yield as a function of weed density

Economic impact of CA

Production cost varied from ` 22,875 to ` 24,375 per ha in case of wheat and ` 23,400 to ` 24,650 per ha in case of greengram under farmers' practice (conventional tillage). Cost of production under CA based treatment varied from ` 19,563 to ` 20,500 per ha for wheat crop and ` 19,850 to ` 21,550 per ha for greengram. Higher benefit cost ratio obtained in CA based weed management than farmers' practice in wheat and greengram indicated effectiveness of CA based technology for effective weed management and yield enhancement (**Table 3**).

Impact of CA technologies on farming community

OFR-cum-demonstrations have been successful in convincing the farmers about the benefits of conservation agriculture. As a result the area under zero tillage has been rapidly increasing and previous practice of crop residue burning has been stopped to a greater extent. The CA based technology has made significant impact on farmers of the Jabalpur, Mandla, Narsighpur, Katni and Seoni districts and surrounding region and has now spread to more than 2000 ha of land in MP state within a span of 5 years. Farmers were impressed with the performance of the greengram in summer season also. They have realized the benefits of CA in terms of saving in cost of field preparation and labour, time and conservation of soil moisture.

Constraints towards adoption of CA technology

Conservation agriculture has the potential to break productivity barriers, sustain natural resources and offer better environmental health and, therefore has been widely accepted by farmers in developed countries (Bolliger *et al.* 2006, Triplett and Warren 2008). Despite several benefits, adoption of CA systems by farmers in central India is still in its infancy as they require a total paradigm shift from conventional agriculture with regard to crop management. CA technologies are essentially herbicide- (Lafond *et al.* 2009), machine- and knowledge-driven. Weed composition differs from farm to farm. Small-seeded weeds proliferate well under CA and have to be controlled by special measures (Chauhan *et al.* 2006, Sosnoskie *et al.* 2006). There is, thus need to explore these opportunities in a site-situation-specific manner for local adaptation.

Results of the present study comprising large number of OFR conducted at farmers' fields in various districts of Madhya Pradesh of central India, reveals that conservation agriculture retains crop residues in soil surface which act as mulch to improve nutrient availability and soil structure, and restrict the moisture loss from soil surface, retains nutrients in soil otherwise lost through burning of crop residues. Successful introduction of greengram as summer crop and use of CA technology offers additional income and improvement in soil fertility. With the availability of farm machinery for ease of sowing and better residue management and herbicides for efficient weed management, intensification of rice-wheat-greengram cropping system is feasible at lower environmental cost and enhanced income. These OFR trials will motivating the other farmers of the locality and nearby to adopt conservation agriculture in larger area. Increased number of demonstrations and training and capacity building of the stakeholder are required in other part of the state to boost the confidence level of the farmers and convince them to adopt conservation agriculture technology.

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Indian Journal of Weed Science **49**(1): 29–32, 2017
DOI: 10.5958/0974-8164.2017.00007.7

Control of mixed weed flora in wheat with sequential application of pre- and post-emergence herbicides

Simerjeet Kaur*, Tarundeep Kaur and Makhan S. Bhullar
Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141 004

Received: 19 February 2017; Revised: 12 March 2017

ABSTRACT

The field efficacy of pre- and post-emergence herbicides for control of mixed weed flora in wheat was evaluated in a field study conducted at Punjab Agricultural University, Ludhiana during *Rabi* seasons *of* 2014-15 and 2015-16. The season long growth of weeds reduced wheat yield upto 38.5%. Pendimethalin and metribuzin recorded 65-73 and 73-78% control of *Phalaris minor,* respectively and their tank-mix application enhanced *P. minor* control to 78-85%. Pendimethalin and metribuzin recorded 26-33 and 58-63% control of *Medicago denticulata,* respectively and their tank-mix application enhanced control to 77-92% of this weed. Pendimethalin and metribuzin provided control of *Rumex dentatus* to the extent of 98-100% and 68-92%, respectively, while provided 98-100 and 63-72%, respectively control of *C. album*. Sequential application of pendimethalin as pre-emergence followed by sulfosulfuron as post-emergence recorded the highest weed control efficiency (96%) and wheat grain yield (4.8 t/ha), and it was at par to pre-emergence pendimethalin + metribuzin, post-emergence pinoxaden + metsulfuron, mesosulfuron + iodosulfuron, sulfosulfuron + metsulfuron and two hand weeding.

Key words: Herbicides, Mixed weed flora, Pre-mix, Sequential application, Tank-mix, Weed control, Wheat

Wheat (*Triticum aestivum* L.) is infested with complex weed flora. The average yield losses due to weeds in wheat vary from 20 to 32% across different wheat growing regions in India (Chhokar *et al.* 2008). Herbicides are the key component of weed management program in wheat in India, particularly in North Western states. All types of weeds are not controlled by a single herbicide and the continuous use of a single herbicide results in weed shifts and evolution of herbicide resistance. The presence of mixed weed flora warrants integrated use of chemical control measures. The continuous use of isoproturon in wheat resulted in evolution of resistant in *Phalaris minor* against this herbicide (Malik and Singh 1995) and this weed now has evolved multiple resistance against fenoxaprop, clodinafop and sulfosulfuron (Chhokar and Sharma 2008, Singh *et al.* 2010) and recently to pinoxaden (Kaur *et al.* 2015). More recently, herbicide resistance has been reported in *Rumex dentatus* against metsulfuron-methyl (Chhokar *et al.* 2017) and in *Avena ludoviciana* against clodinafop (Singh 2016). This indicated the need for intervention of herbicides with different mode of action in the rotation or sequential application for control of complex weed flora in wheat. Metribuzin, a PS II inhibiting herbicide, as pre-emergence has been found effective against *P. minor* and other grasses and broad-leaf weeds (Malik *et al.* 2005), however, its variable effect on weed control and also on phytotoxicity in wheat under higher soil moisture or faulty application made it a limited choice herbicide among farmers. Tank-mix or pre-mix use of different herbicide chemistries or sequential application of pre- and post-emergence herbicides at different times showed effective weed control (Baghestani *et al.* 2008). Besides managing mixed weed flora, the integrated use of herbicides may help in managing herbicide resistance problems. In present study, the efficiency of combination of pre- and post-emergence herbicides used in sequence, as tank-mix or as pre-mix against weeds and growth and yield of wheat was evaluated.

***Corresponding author:** simer@pau.edu

MATERIALS AND METHODS

A field experiment was conducted at Punjab Agricultural University, Ludhiana during winter season of 2014 and 2015. The experimental site was situated in Trans-Gangetic Agro-Climatic zone, representing the Indo-Gangetic alluvial plains at 30°56' N latitude, 75°52' E longitude and at an altitude of 247 m above mean sea level. The experimental soil was loamy sand with neutral pH (7.43) and EC (0.22 dS/m) and it was low in organic carbon (0.42%) and available nitrogen (210 kg/ha) and very high in available phosphorus (77 kg/ha) and high in available potassium (352.5 kg/ha).The wheat cultivar '*HD 2967'* was sown in first week of November in 2014 and 2015. The experiment was laid out in a randomized complete block design with 4 replications. Twelve weed control treatments included were pendimethalin 0.75, 1.0 kg/ha as pre-emergence (PE), metribuzin 0.175 and 0.21 kg/ha as PE, tank-mix of pendimethalin + metribuzin 0.75 + 0.175, 1.0 + 0.175 kg/ha as PE, sulfosulfuron 0.025 kg/ha as post-emergence (PoE), clodinafop 0.06 kg/ha as PoE, sequential application of pendimethalin 0.75, 1.0 kg/ha as PE followed by (*fb*) sulfosulfuron 0.018 kg/ha as PoE, sulfosulfuron + metsulfuron 0.03+0.002 kg/ha (pre-mix) as PoE, tank-mix of pinoxaden + metsulfuron 0.06 + 0.004 kg/ha as PoE, mesosulfuron + iodosulfuron 0.012 + 0.0024 kg/ha (pre-mix) as PoE, clodinafop + metsulfuron 0.06 + 0.004 kg/ha (pre-mix) as PoE, two hand weedings at 20 and 40 days after sowing (DAS), and unweeded control. The plot size was 7.0 x 2.8 m. The pre-emergence herbicides were sprayed on the day of sowing using 500 litre water/ha and post-emergence were sprayed at 35 DAS with 375 litre water/ha, using knapsack sprayer fitted with flan-fan nozzle. The crop toxicity and visual weed control under different weed control treatments was recorded at 30 days after spray. The crop was manually harvested in third week of April. Final plant height was recorded up to base of spike from 10 randomly selected plants and average was reported. The data on yield attributes and grain yield was recorded at crop harvest. The prevailing market prices of inputs and outputs were used for calculating economic returns and benefit-cost ratio (B:C) under different weed control treatments. Weed data was squareroot transformed before statistical analysis. The data were analyzed by using standard statistical procedures and comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with *Phalaris minor* (36%), *Medicago denticulata* (34%), *Rumex dentatus* (20%), *Chenopodium album* (5%) and *Coronopus didymus* (5%) in both the years of study.

As 30 DAS, pre-emergence herbicides had significant effect on density of *M. denticulata, R. dentatus* and *C. album* at 30 DAS. Pendimethalin 0.75 and 1.0 kg/ha recorded 65-73%, and metribuzin 0.175 and 0.21 kg/ha recorded 73-78% control of *P. minor* (**Figure 1**); tank-mix application of metribuzin 0.175 kg/ha with pendimethalin 0.75 and 1.0 kg/ha enhanced *P. minor* control to 78-85%. Pendimethalin alone or as tank mix with metribuzin provided 98-100% control of *R. dentatus* and *C. album*. Metribuzin alone recorded 68-92% control of *R. dentatus* and 63-72% of *C. album.* Singh *et al.* (2011) also reported that metribuzin 150 g/ha failed to control *C. album* and *R. dentatus.* Pendimethalin and metribuzin used alone recorded poor control of 26-33% and 58-63%, respectively, of *Medicago denticulata;* their tank-mix application recorded effective control to the extent of 77-92% of this weed.

At 60 DAS, pendimethalin alone 0.75 and 1.0 kg/ha resulted in 54-74% weed control efficiency (WCE) and metribuzin of 53-69%; their tank-mix application recorded higher WCE (74-82%) compared to their alone application. The post-emergence tank-mix application of pinoxaden + metsulfuron, pre-mix of sulfosulfuron + metsulfuron, mesosulfuron + odosulfuron, clodinafop + metsulfuron provided effective control (87-100%) of broad-leaf weeds and significantly reduced the weed biomass than unweeded control (**Table 1**); pinoxaden + metsulfuron recorded the significant control of *P. minor* than all other post-emergence herbicides and pendimethalin 0.75 kg/ha, metribuzin 0.175 kg/ha, clodinafop, sulfosulfuron, clodinafop + metsulfuron, sulfosulfuron + metsulfuron recorded similar density of *P. minor to* unweeded control. Tank-mix application of pendimethalin + metribuzin at 1.0+0.175 kg/ha, sequential application of pendimethalin at 0.75 and 1.0 kg/ha as PE *fb* sulfosulfuron at 0.018 kg/ha as PoE, tank-mix of pinoxaden+metsulfuron as PoE recorded >80% WCE and provided effective control of both grasses and broad-leaf weeds, and significantly reduced the weed biomass. The synergistic response for weed control was observed when herbicides were applied in mixture (Baghestani *et al.* 2008). Sequential application of pendimethalin followed by pre-mix of mesosulfuron + iodosulfuron, tank mix of pinoxaden + metsulfuron, pre-mixes of sulfosulfuron + metsulfuron and fenoxaprop + metribuzin or two applications of PoE herbicides in rotation was effective for weed control in wheat (Singh *et al.* 2011). *Medicago denticulata* was the troublesome weed in pendimethalin and metribuzin alone treated plots. Clodinafop failed to control *P. minor* as experimental field was infested with confirmed resistant biotype against clodinafop and was ineffective on broad-leaf weeds. Sulfosulfuron was also poor on *P. minor* and *R. dentatus,* but recorded effective control of *M. denticulata*, *C. album* and *C. didymus*. Reports of evolution of resistance in *P. minor* populations to FOPS in Pakistan (Yasin *et al.* 2011), Iran (Gherekhloo *et al.* 2011) and *Avena* *ludoviciana* to diclofop, fenoxaprop, sethoxydim, clethodim and pinoxaden herbicides in Australia (Ahmad-Hamdani *et al.* 2012) signifies that all the selective herbicides being used in wheat have a limited shelf life and their judicious use will help in effective weed control and integrated approaches of chemical rotations or sequential use or pre-mix and tank-mix may help in this regard.

Effect on crop growth, yield and economics

All pre-emergence herbicides treatments recorded similar population of wheat plants at 30 DAS (**Figure 1**). No crop phyto-toxicity was observed during both the years. All weed control treatments resulted in more crop biomass than unweeded control except clodinafop 0.06 kg/ha. More crop biomass was due to effective weed control. All weed control treatments resulted in more number of effective tillers than unweeded control at harvest. Weed control treatments recorded significantly higher wheat grain yield and yield attributes than unweeded control. Application of pendimethalin 1.0 kg/ha or metribuzin 0.21 kg/ha or tank-mix of pendimethalin 0.75 and 1.0 kg/ha + metribuzin at 0.175 kg/ha or sequential application of pendimethalin 0.75 and1.0 kg *fb* sulfosulfuron at 0.018 kg or tank-mix of pinoxaden + metsulfuron 0.06+0.004 kg/ha or pre-mix of sulfosulfuron + metsulfuron at 0.03+0.002 kg/ha or pre-mix of mesosulfuron + iodosulfuron at 0.012 + 0.0024 kg/ha resulted in statistically similar wheat grain yield to two hand weeding. Clodinafop 60 g/ha recorded significantly higher grain yield and yield attributes than unweeded control but it was significantly low as compared to other herbicidal treatments (**Table 2**). The tank-mix of pinoxaden + metsulfuron recorded

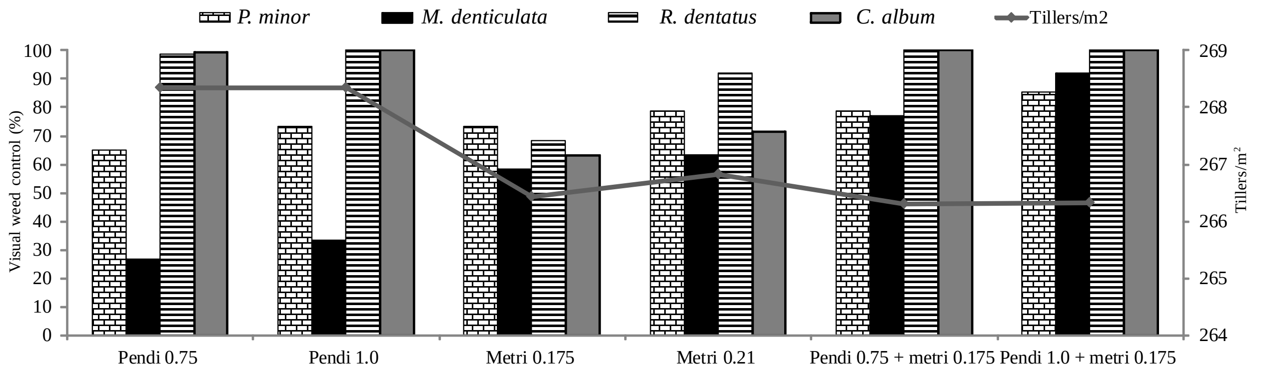

Figure 1. Visual weed control of different weeds at 30 DAS with pre-emergence herbicides. Visual weed control was taken with respect to unweeded control

Table 1. Effect of different weed control treatments on weeds in wheat (pooled data of 2014-15 and 2015-16)

Treatment	Weed density and biomass at 60 days after sowing							
	Density (no./m²)					Biomass (g/m²)		WCE (%)
	P. minor	*M. denticulata*	*R. dentatus*	*C. album*	*C. didymus*	Grasses	BLW	
Pendimethalin (PE) 0.75 kg/ha	4.0 (15)	4.9 (25)	1.3 (1)	1.3 (1)	1.9 (3)	4.9 (23)	3.0 (8)	54.4
Pendimethalin (PE) 1.0 kg/ha	2.8 (7)	4.8 (25)	1.1 (0)	1.0 (0)	1.3 (1)	3.6 (12)	2.6 (6)	73.5
Sulfosulfuron (PoE) 0.025 kg/ha	4.0 (15)	1.0 (0)	5.1 (25)	1.2 (1)	1.3 (1)	4.3 (18)	3.3 (10)	58.8
Metribuzin (PE) 0.175 kg/ha	3.6 (12)	4.6 (22)	3.2 (10)	1.9 (3)	1.0 (0)	4.6 (21)	3.4 (11)	52.9
Metribuzin (PE) 0.21 kg/ha	2.8 (7)	4.1 (17)	3.0 (9)	1.6 (2)	1.5 (1)	3.7 (13)	3.0 (8)	69.1
Clodinafop PoE 0.06 kg/ha	4.5 (20)	4.2 (18)	5.3 (27)	2.4 (5)	3.0 (8)	5.3 (28)	4.2 (17)	33.8
Pendimethalinc + metribuzin (tank-mix as PE) 0.75 + 0.175 kg/ha	3.3 (10)	4.3 (20)	1.3 (1)	1.0 (0)	1.8 (2)	3.7 (12)	2.6 (6)	73.5
Pendimethalin + metribuzin (tank-mix as PE) 1.0 + 0.175 kg/ha	2.6 (6)	4.0 (17)	1.1 (0)	1.0 (0)	1.4 (1)	3.0 (8)	2.2 (4)	82.4
Pendimethalin (PE) *fb* sulfosulfuron (PoE) 0.75 *fb* 0.018 kg/ha	2.5 (6)	1.2 (1)	1.0 (0)	1.0 (0)	1.0 (0)	2.3 (5)	1.2 (0)	92.6
Pendimethalin (PE) *fb* sulfosulfuron (PoE) 1.0 *fb* 0.018 kg/ha	2.1 (4)	1.1 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.9 (3)	1.1 (0)	95.6
Sulfosulfuron + metsulfuron (pre-mix as PoE) 0.03 + 0.002 kg/ha	4.2 (17)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	5.3 (28)	1.0 (0)	58.8
Pinoxaden + metsulfuron (pre-mix as PoE) 0.06 + 0.004 kg/ha	2.7 (8)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	3.3 (13)	1.0 (0)	80.9
Mesosulfuron + iodosulfuron (pre-mix as PoE) 0.012 + 0.0024 kg/ha	3.6 (13)	1.5 (2)	1.0 (0)	1.7 (2)	1.0 (0)	4.2 (18)	1.2 (1)	72.1
Clodinafop + metsulfuron (pre-mix as PoE) 0.06 + 0.004 kg/ha	4.5 (20)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	4.4 (19)	1.0 (0)	72.1
2 Hand weeding (20 and 40 DAS)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	100.0
Unweeded control	4.3 (18)	4.3 (18)	5.2 (27)	3.1 (9)	2.7 (6)	5.9 (34)	5.7 (34)	-
LSD (p=0.05)	0.4	0.3	0.2	0.3	0.3	0.6	0.3	-

PE: Pre-emergence; PoE: Post-emergence; *fb*-Followed by; Figures in parentheses are means of original values subjected to square root transformation

Table 2. Wheat grain yield and yield attributes and economics under different weed control treatments (pooled data of 2014-15 and 2015-16)

Treatment	Plant height at harvest (cm)	Effective tillers (no./m^2)	Spike length (cm)	Grain yield (t/ha)	Biological yield (t/ha)	B:C*
Pendimethalin (PE) 0.75 kg/ha	73.8	337	11.2	4.35	12.5	2.21
Pendimethalin (PE) 1.0 kg/ha	73.6	358	11.7	4.60	12.68	2.28
Sulfosulfuron (PoE) 0.025 kg/ha	87.9	330	11.5	4.52	12.42	2.26
Metribuzin (PE) 0.175 kg/ha	87.1	340	11.3	4.51	12.86	2.32
Metribuzin (PE) 0.21 kg/ha	90.0	345	11.6	4.61	12.72	2.34
Clodinafop PoE 0.06 kg/ha	88.8	297	11.3	3.45	11.26	1.74
Pendimethalinc + metribuzin (tank-mix as PE) 0.75 + 0.175 kg/ha	87.4	367	11.6	4.68	12.91	2.32
Pendimethalin + metribuzin (tank-mix as PE) 1.0 + 0.175 kg/ha	87.5	365	11.4	4.74	12.88	2.35
Pendimethalin (PE) *fb* sulfosulfuron (PoE) 0.75 *fb* 0.018 kg/ha	88.4	358	11.5	4.67	12.83	2.31
Pendimethalin (PE) *fb* sulfosulfuron (PoE) 1.0 *fb* 0.018 kg/ha	88.4	374	11.6	4.86	13.19	2.38
Sulfosulfuron + metsulfuron (pre-mix as PoE) 0.03 + 0.002 kg/ha	88.1	355	11.4	4.69	12.55	2.33
Pinoxaden + metsulfuron (pre-mix as PoE) 0.06 + 0.004 kg/ha	90.2	353	11.4	4.827	12.428	2.39
Mesosulfuron + iodosulfuron (pre-mix as PoE) 0.012 + 0.0024 kg/ha	88.6	352	11.3	4.724	12.116	2.33
Clodinafop + metsulfuron (pre-mix as PoE) 0.06 + 0.004 kg/ha	87.2	305	11.3	4.482	12.380	2.24
2 Hand weeding (20 and 40 DAS)	90.1	365	11.2	4.813	13.538	1.94
Unweeded control	85.9	254	10.9	2.959	10.911	1.55
LSD (p=0.05)	NS	29	NS	0.338	0.831	-

*B:C: Benefit-cost ratio, calculated by dividing gross returns with variable cost of cultivation

the highest returns and B:C, which was comparable to tank-mix of pendimethalin 1.0 kg + metribuzin 0.175 kg/ha, pendimethalin 1.0 kg *fb* sulfosulfuron 0.018 kg/ha and metribuzin 0.21 kg/ha. Baghestani *et al*. (2008) also reported that tank-mix use of herbicides resulted in higher grain yield of wheat.

It can be concluded that pre-emergence application of tank-mix of pendimethalin 0.75 and 1.0 kg/ha plus metribuzin 0.175 kg/ha or sequential application of pendimethalin 0.75-1.0 kg as pre-emergence and sulfosulfuron 0.018 kg as post-emergence or post-emergence application of tank-mix of pinoxaden + metsulfuron 0.06+0.004 kg/ha or pre-mix of sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha or pre-mix of mesosulfuron+iodosulfuron at 0.012 + 0.0024 kg/ha could be adopted for broad-spectrum weed control in wheat.

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DOI: 10.5958/0974-8164.2017.00008.9

Assessment of pre-mix broad spectrum herbicides for weed management in wheat

D.D. Chaudhari, V.J. Patel, H.K. Patel, Aakask Mishra, B.D. Patel* **and R.B. Patel**
B.A. College of Agriculture, Anand Agricultural University, Anand, Gujarat 388 110

Received: 24 January 2017; Revised: 27 February 2017

ABSTRACT

A field experiment was carried out during the *Rabi* season of 2014 and 2015 on sandy loam soil to test the bio-efficacy of pre-mix broad spectrum herbicides for weed management in wheat. Major dominant weed flora in the experimental plot were *Chenopodium murale* (54.1%), *Chenopodium album* (11.9%), *Phalaris minor* (10.4%) and *Melilotus alba* (9.6%). Application of pre-mix sulfosulfuron (75%) + metsulfuron-methyl (5%) 32 g/ha as post-emergence, clodinafop (15%) + metsulfuron-methyl (1.0%) 64 g/ha as post-emergenc (PoE), mesosulfuron (3%) + iodosulfuron-methyl sodium (0.6 %) 14.4 g/ha as PoE and hand weeding at 20 and 40 DAS remained at par with each other and significantly reduced the density and biomass of both monocot as well as dicot weeds and resulted in significantly more number of effective tillers and yield of grain and straw. However, mesosulfuron (3%) + iodosulfuron-methyl sodium (0.6 %) 14.4 g/ha PoE showed phytotoxic effect on plant.

Key words: Pre-mix herbicides, Weed dry weight, Weed flora, Wheat, Yield

Wheat is one of the most important food grain crop which is grown in approximately 225 million hectares worldwide and about half of which is in developing countries. India is the second largest producer of wheat in the world contributing about 80.6 million tons of grains with the productivity of 2.8 t/ha from the area of 28.4 million hectares (Anon, 2012). Weed infestation is one of the major barriers in realizing potential yield of wheat. Uncontrolled weeds are reported to cause up to 66% reduction in wheat grain yield (Angiras *et al.* 2008, Kumar *et al.* 2009 and Kumar *et al.* 2011) or even more depending upon the weed density, type of weed flora and duration of infestations. Chemical weed control is a preferred practice due to scarce and costly labour as well as lesser feasibility of mechanical or manual weeding. In order to optimize the weed control efficacy and minimize the application costs, use of pre-and post-emergence herbicides, as well as herbicide mixtures, has become the alternative. This strategy also represents an important tool to avoid problems related to herbicide resistance. Considering above fact, the present experiment was planned to assess the relative bio-efficacy of pre-mix herbicide molecule for broad spectrum weed control.

MATERIALS AND METHODS

The present experiment was conducted in two consecutive *Rabi s*eason of the year 2014 and 2015-16 in B.A. College of Agriculture, Anand Agricultural University, Anand (Gujarat). The soil was sandy loam in texture having low in total nitrogen (0.042 %) and medium in available phosphorus (69.10 kg/ha) and high in potassium (358 kg/ha). Ten weed management practices, *viz.* pendimethalin 500 g/ha as pre-emergence (PE), 2,4-D 750 g/ha as post-emergence (PoE), metsulfuron-methyl 4.0 g/ha as PoE, clodinafop-propargyl 60 g/ha as PoE, sulfosulfuron 25 g/ha as post-emergence, sulfosulfuron (75%) + metsulfuron-methyl (5%) (pre-mix) 32 g/ha as post-emergence, clodinafop (15%) + metsulfuron-methyl (1%) (pre-mix) 64 g/ha as post-emergence, mesosulfuron (3%) + iodosulfuron-methyl-sodium (0.6%) (pre-mix) 14.4 g/ha as post-emergence, hand weeding (HW) at 20 and 40 DAS and weedy check were studied in randomized block design with four replications. The wheat cv. '*GW-496*' was sown manually keeping the row distance of 22.5 cm with the seed rate of 120 kg/ha during 1st week of December during both the years. Entire quantity of phosphorous (40 kg/ha) and half dose of nitrogen (60 kg/ha) in the form of single super phosphate and urea, respectively were applied as basal. Remaining quantity of nitrogen was applied in two equal split. The herbicides were applied using knapsack sprayer fitted with flat fan nozzle with spray volume of 500 L/ha. The other package of practices was adopted to raise the crop as per the recommendations. After sowing, a light irrigation was given to the crop for uniform germination and next day the pre-emergence herbicides were applied. The crop was harvested on

***Corresponding author:** bdpatel62@yahoo.com

last week of March and first week of April during 2014-15 and 2015-16, respectively. The observations on number of weeds and dry matter of weeds were taken from randomly selected four spots by using 0.25 m^2 iron quadrate from net plot area. The weed data were subjected to square root transformation before analysis. Weed control efficiency was also calculated on the basis of dry matter production by weeds. Data on yield attributes and yield were determined at harvest. The data were statistically analyzed by using statistical procedures and comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

Weed flora

Major weed flora observed on weedy plot comprised of *Chenopodium murale*, *Chenopodium album*, *Phalaris minor*, *Melilotus alba*, *Avena fatua*, *Asphodelus tenuifolius* and *Setaria tomentosa*. In weedy plot, grassy weeds constituted about 21.3% while broad-leaf weeds accounted 78.7%, of the total weed population. Herbicide treatments showed differences in weed control during both the years of experimentation in wheat crop.

Effect on weeds

Among the different herbicidal treatments, complete control of monocot and dicot weeds were achieved under pre-mix broad spectrum application of sulfosulfuron (75%) + metsulfuron-methyl (5%) 32 g/ha as post-emergence, clodinafop (15%) + metsulfuron-methyl (1%) 64 g/ha as post-emergence and mesosulfuron (3%) + iodosulfuron (0.6%) 14.4 g/ha as post-emergence at harvest (**Table 1**). Malik *et al.* (2013) observed that clodinafop + metsulfuron-methyl proved very effective against complex weed flora and the control of grassy and broad-leaved weeds to the extent of 95%. Alone application of sulfosulfuron 25 g/ha as post-emergence also provides 100% control of both monocot and dicot weed during 2014-15. Further, post-emergence application of 2,4-D 750 g/ha and metsulfuron-methyl 4.0 g/ha alone effectively control all the dicot weeds. In general, pre-mixed herbicidal mixture was found effective in reducing both monocot and dicot weeds as compared to sole application of 2,4-D, metsulfuron- methyl, pendmethalin, clodinafop-propargyl and sulfosulfuron. Poor control of broad-leaf weeds with the application of clodinafop-propargyl in wheat was also observed by Kaur *et al.* (2015).

Effect on crop

Non-significant differences were observed in plant height recorded at harvest during 2014-15, while it was significant in 2015-16 due to different herbicidal treatments (**Table 2**). Significantly lowest plant height of 78.5 cm was recorded in mesosulfuron (3%) + iodosulfuron (0.6%) 14.4 g/ha

Table 1. Weed density and dry biomass recorded at harvest as influenced by weed management practices in wheat

Treatment	Monocot weed count (no./m^2)		Dicot weed count (no./m^2)		Monocot weed dry biomass (g/m^2)		Dicot weed dry biomass (g/m^2)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimethalin 500 g/ha as PE	4.12^{c} (16.0)	4.35^{d} (18.0)	1.0^{d} (0.0)	3.31^{c} (10.0)	19.9^{a} (395.1)	16.0^{b} (255.1)	1.0^{c} (0.0)	3.91^{e} (14.4)
2,4-D 750 g/ha as post-emergence	4.42^{bc} (18.7)	5.09^{c} (25.0)	1.0^{d} (0.0)	1.0^{d} (0.0)	19.3^{a} (371.5)	15.4^{b} (237.5)	1.0^{c} (0.0)	1.0^{f} (0.0)
Metsulfuron-methyl 4.0 g/ha as PoE	4.70^{b} (21.3)	5.80^{b} (32.7)	1.0^{d} (0.0)	1.0^{d} (0.0)	20.2^{a} (408.2)	15.7^{b} (247.2)	1.0^{c} (0.0)	1.0^{f} (0.0)
Clodinafop-propargyl 60 g/ha as PoE	1.00^{d} (0.0)	2.30^{f} (4.3)	8.26^{b} (67.3)	9.83^{a} (95.7)	1.00^{c} (0.0)	3.01^{d} (8.1)	6.42^{a} (40.3)	16.6^{a} (274)
Sulfosulfuron 25 g/ha as PoE	1.00^{d} (0.0)	2.64^{e} (6.0)	1.0^{d} (0.0)	3.55^{c} (11.7)	1.00^{c} (0.0)	2.32^{d} (4.4)	1.00^{c} (0.0)	5.24^{d} (26.0)
Sulfosulfuron (75%) + metsulfuron- methyl (5%) WG 32 g/ha as PoE	1.0^{d} (0.0)	1.0^{g} (0.0)	1.0^{d} (0.0)	1.0^{d} (0.0)	1.0^{c} (0.0)	1.0^{e} (0.0)	1.0^{c} (0.0)	1.0^{f} (0.0)
Clodinafop (15%) + metsulfuron- methyl (1%) WP 64 g/ha as PoE	1.0^{d} (0.0)	1.0^{g} (0.0)	1.00^{d} (0.0)	1.0^{d} (0.0)	1.0^{c} (0.0)	1.0^{e} (0.0)	1.0^{c} (0.0)	1.0^{f} (0.0)
Mesosulfuron (3%) + iodosulfuron (0.6%) WDG 14.4 g/ha as PoE	1.0^{d} (0.0)	1.0^{g} (0.0)	1.00^{d} (0.0)	1.0^{d} (0.0)	1.0^{c} (0.0)	1.0^{e} (0.0)	1.0^{c} (0.0)	1.0^{f} (0.0)
Hand weeding 20 and 40 DAS	4.12^{c} (16.0)	4.20^{d} (16.7)	2.37^{c} (4.7)	3.51^{c} (11.3)	3.31^{b} (10.0)	7.82^{c} (60.4)	2.82^{b} (7.0)	7.12^{c} (49.0)
Weedy check	5.38^{a} (28.0)	6.56^{a} (42.0)	9.05^{a} (81.0)	5.35^{b} (27.7)	19.4^{a} (376.2)	17.6^{a} (308.8)	6.52^{a} (41.6)	11.3^{b} (127)
LSD (p=0.05)	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.

Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values. Treatment means with the letters in common are not significant by Duncan's new multiple range test at 5% level of significance; PE: Pre-emergence; PoE - Post-emergence.

Table 2. Growth and yield attributes of wheat as influenced by different weed management practices

Treatment	Plant height (cm) at harvest		Effective tillers (no./m) at harvest		DMA (g/plant) at 60 DAS		Grain yield (t/ha)		Straw yield (t/ha)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimethalin 500 g/ha as PE	89.9	85.6[a]	50.4[b]	66.4[c]	9.46	9.95	2.42[b]	2.87[c]	4.20[b]	5.40[c]
2,4-D 750 g/ha as PoE	89.6	86.5[a]	48.0[b]	63.3[c]	8.89	10.8	2.69[b]	2.27[de]	4.87[b]	5.10[c]
Metsulfuron-methyl 4.0 g/ha as PoE	87.6	88.1[a]	43.3[b]	60.1[c]	9.90	10.5	2.36[b]	2.62[cd]	4.67[b]	5.21[c]
Clodinafop-propargyl 60 g/ha as PoE	91.4	88.5[a]	84.5[a]	58.7[c]	9.88	9.97	3.71[b]	2.24[e]	6.38[a]	4.35[d]
Sulfosulfuron 25 g/ha as PoE	90.3	85.8[a]	97.1[a]	84.6[ab]	9.87	10.3	3.76[a]	3.89[b]	6.64[a]	6.21[b]
Sulfosulfuron (75%) + metsulfuron methyl (5%) WG 32 g/ha as PoE	91.3	85.9[a]	99.5[a]	97.8[a]	9.88	10.5	4.27[a]	4.38[a]	6.89[a]	6.68[ab]
Clodinafop (15%) + metsulfuron-methyl (1%) WP 64 g/ha as PoE	91.0	87.9[a]	92.9[a]	98.1[a]	9.45	10.7	4.35[a]	4.55[a]	6.89[a]	6.88[a]
Mesosulfuron (3%) + iodosulfuron (0.6%) WDG 14.4 g/ha as PoE	89.9	78.5[b]	92.6[a]	81.3[b]	9.05	9.18	3.93[a]	3.95[b]	6.67[a]	6.23[ab]
Hand weeding at 20 40 DAS	92.8	85.3[a]	83.3[a]	88.0[ab]	9.99	10.5	3.95[a]	4.22[ab]	6.71[a]	6.51[ab]
Weedy check	94.7	86.5[a]	46.1[b]	38.1[d]	9.68	10.2	1.61[c]	1.48[f]	3.91[b]	3.50[e]
LSD (p=0.05)	NS	3.57	Sig.	Sig.	NS	NS	Sig.	Sig.	Sig.	Sig.

Letters in common are not significant by Duncan's new multiple range test at 5% level of significance

as post-emergence in 2015-16. The lowest plant height under mesosulfuron (3%) + iodosulfuron (0.6%) 14.4 g/ha was mainly due to their phototoxic effect on plant after their application. Number of effective tillers differed significantly due to different herbicidal treatment in both the years. All the pre-mixed herbicidal treatments and alone application of clodinafop-propargyl, sulfosulfuron as well as twice hand weeding treatment remained at par with each other but found significantly superior over rest of the treatments. The lowest number of tillers was recorded under weedy check treatment during both the years. Dry matter accumulation recorded at 60 DAS was found to be non-significant due to different weed management practices, though the marginally low dry matter accumulation/plant was recorded under pre-mix broad spectrum post-emergence application of mesosulfuron (3%) + iodosulfuron (0.6%) 14.4 g/ha due to their phytotoxic effect on plant at seven days after application.

Grain and straw yields were significantly affected by different herbicidal treatment wherein, all three pre-mixed herbicidal treatment, alone sulfosulfuron 25 g/ha as post-emergence and twice hand weeding treatment recorded significantly higher grain yield than pendimethalin 500 g/ha, 2,4-D 750 g/ ha, metsulfuron-methyl 4.0 g/ha, clodinafop-propargyl 60 g/ha and weedy check during 2014-15. While post-emergence application of clodinafop (15%) + metsulfuron-methyl (1%) 64 g/ha, sulfosulfuron (75%) + metsulfuron-methyl (5%) 32 g/ha and twice hand weeding treatment recorded significantly higher grain yield as compared to rest of the treatments in 2015-16 except twice hand weeding, which was at par with treatment of sulfosulfuron 25 g/ha as PoE applied alone.

The present investigation conclusively inferred that application of clodinafop plus metsulfuron-methyl 64 g/ha or sulfosulfuron plus metsulfuron-methyl 32 g/ha as post-emergence application (25-30 DAS) or hand weeding at 20 and 40 days after sowing provided excellent control of mixed weed flora with better yield of wheat.

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Indian Journal of Weed Science **49**(1): 36–40, 2017
DOI: 10.5958/0974-8164.2017.00009.0

Herbicide combinations for control of complex weed flora in wheat

Sheela Barla*, R.R. Upasani and A.N. Puran
Department of Agronomy, Birsa Agricultural University, Ranchi, Jharkhand 834 006

Received: 5 January 2017; Revised: 16 February 2017

ABSTRACT

A field experiment was conducted in 2014 and 2015 to find out the effect of herbicides on weed dynamics and productivity of wheat under Jharkhand situation. Two hand weeding performed in wheat crop at 30 and 60 DAS recorded significantly reduced weed density and weed dry matter of broad-leaf, grassy, sedges and total weeds at 30 and 60 DAS with WCE of 94.3 and 94.2%, respectively and was similar to post-emergence application of clodinafop 0.06 kg/ha and pre-emergence application of pendimethalin + metribuzin 1.0 kg/ha + 0.175 kg/ha. This resulted in maximum total and effective tillers, grain (3.08 t/ha) and straw (5.37 t/ha) yield and net return (` 32,019.00 and B:C ratio (1.33) compared to other herbicides application.

Key words: Chemical control, Herbicide combination. Relative yield loss, Weed control efficiency, Wheat

Weeds compete with crop species for water, nutrients and light and ultimately reduce crop yield (Cudney *et al.* 2001). The competition of weeds for nutrients may results in such obvious responses as dwarfing in plant size, nutrient starved conditions, wilting and actual dying out of plants (Andreasen *et al.* 1996). Therefore, effective weed management is imperative to produce optimum yields. Among different weed management practices, chemical weed control is preferred (Marwat *et al.* 2008) because of less labor involvement and no mechanical damage to the crop that happens during manual weeding. Moreover, the control is more effective as the weeds even within the rows are killed which invariably escape, because of morphological similarity to wheat. Combination of isoproturon and 2,4-D as tank mixture have been recommended against complex weed flora. This combination has been found promising in the situation where isoproturon was effective against *Phalaris minor*. But against complex weed flora dominated by other weeds, this combination was not so effective. Under such situations, a suitable combination of clodinafop with some broad-spectrum herbicides like sulfosulfuron and metribuzin was needed. Hence, the present investigation was carried out to evaluate the efficacy of pre- and post-emergence herbicides and their combination against mixed weed flora and productivity as well as profitability in wheat production.

MATERIALS AND METHODS

A field experiment was conducted in research farm of Birsa Agricultural University, Ranchi, during winter season of 2014 and 2015 to find out the effect of herbicides on weed dynamics and productivity of wheat under Jharkhand situation. The treatments comprised of pre-emergence application of pendimethalin 0.75 kg/ha, metribuzin 0.021 kg/ha, pendimethalin + metribuzin (1.0 + 0.175 kg/ha), pendimethalin 1.0 kg/ha *fb* sulfosulfuron 0.018 kg/ha, post- emergence application of sulfosulfuron 0.025 kg/ha, clodinafop 0.06 kg/ha, sulfosulfuron 75% + metsulfuron-methyl 20% (0.03 + 0.002 kg/ha), metsulfuron 0.004 kg/ha, mesosulfuron 3% + iodosulfuron0.6% (0.012 + 0.0024 kg/ha), clodinafop 15% + metsulfuron1% (0.06 + 0.004 kg/ha), along with 2 hand weeding at 30 and 60 DAS and weedy check. The experiment was laid out in a randomized block design with three replications. The experimental soil was low in nitrogen (130 kg/ha) and medium in phosphorus (18 kg/ha) and potash (230 kg/ha). Recommended dose of fertilizer 120:60:40 kg N, P_2O_5 and K_2O/ha, respectively, was applied through urea, di-ammonium phosphate and muriate of potash. Half of the nitrogen, full dose of phosphorus and potassium were applied before sowing. Remaining half of nitrogen was applied in two equal splits at crown root initiation and maximum tillering stages of crop. Crop was sown at spacing of 20 cm on 05th and 19th December, 2014-15 and 2015-16 and harvested on 12th and 24th April, 2015 and 2016, respectively. The yield attributing parameters and yield of the crop were recorded after physiological maturity. Weeds were counted species-wise and differentiated into categories of grass, and broad-leaf and sedges weed. Weed count was expressed as no./m^2. The mean data were subjected

***Corresponding author:** sheela.barla123@gmail.com

to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution. Relative percentage composition of weeds of individual weed species was calculated by the formula as suggested by Shetty and Rao (1979).

Relative composition of a species (%) =No. of individual species/ Total no. all weeds X 100.

The relative yield loss (YL) of the crop challenged by weed competition under field conditions was estimated using equation, YL (%) = 1- (YCW/YCM) X 100, where YCW and YCM are crop yields in competition with weeds and in weed-free conditions, respectively.

RESULTS AND DISCUSSION

Major weed flora in wheat crop were broad-leaved weeds like *Coronopus dydimus, Mililotus alba, Vicia sativa, Spergula arvensis, Alternanthera sessilis, Anagalis arvensis* with average relative composition 47.02, 27.63, 3.59, 2.69, 1.51 and 1.50%, respectively, while average relative composition of narrow-leaved weeds like *Sorghum halepense* and *Cynodon dactylon* were 8.21 and 4.90 percent, respectively and sedge *Cyperus rotundus* was 2.95%.

Weed density, dry matter and weed control efficiency

Two hand weeding performed in wheat crop at 30 and 60 DAS recorded significantly reduced weed density as well as weed dry matter of grassy, broad-leaf, sedges and total weeds (**Table 1)** and was similar to post-emergence application of clodinafop 0.06 kg/ha and pre-emergence application of pendimethalin + metribuzin (1.0 + 0.175 kg/ha) during 2014 and 2015 and also when data were pooled (**Table 2**). Kumar *et al.* (2013) also recorded reduced weed dry matter with clodinafop. In case of dry matter, mesosulfuron 3% + iodosulfuron 0.6% (0.012 + 0.0024 kg/ha) applied as post-emergence was also similar except at 60 DAS during 2015-16 (**Table 3**). Consequently two hand weeding recorded maximum weed control efficiency and was similar to post-emergence

Table 1. Effect of weed control methods on weed density (no./m²) in wheat

Treatment	Grassy						Broad-leaf weed						Sedges					
	30 DAS			60 DAS			30 DAS			60 DAS			30 DAS			60 DAS		
	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
Pendimethalin 0.75kg/ha	3.39 (12.0)	2.60 (7.15)	3.03 (9.57)	4.31 (20.1)	7.86 (64.9)	6.36 (42.5)	17.36 (325)	24.93 (641)	21.95 (483)	21.91 (525)	20.85 (469)	21.39 (497)	1.60 (3.67)	3.34 (10.7)	2.74 (7.17)	1.73 (4.58)	4.08 (16.8)	3.31 (10.7)
Sulfosulfuron 0.025kg/ha	5.47 (30.0)	1.56 (3.36)	4.14 (16.7)	6.93 (49.8)	7.98 (65.2)	7.53 (57.5)	22.14 (491)	24.41 (595)	23.30 (543)	27.72 (770)	24.15 (584)	26.01 (677)	3.07 (11)	5.25 (27.3)	4.40 (19.2)	3.97 (19.6)	6.37 (40.2)	5.47 (29.9)
Metribuzin 0.21kg/ha	4.33 (18.3)	2.79 (7.81)	3.67 (13.1)	5.43 (29.6)	7.05 (49.2)	6.30 (39.4)	20.12 (405)	22.18 (492)	21.18 (449)	25.18 (635)	15.07 (297)	21.43 (466)	2.50 (7.67)	1.10 (1.0)	1.99 (4.33)	2.98 (11.7)	4.08 (16.8)	3.81 (14.3)
Clodinafop 0.06kg/ha	2.54 (6.3)	3.7 (14.9)	3.21 (10.6)	3.17 (10.4)	3.91 (15.1)	3.57 (12.7)	10.24 (112)	11.24 (134)	10.75 (123)	12.66 (167)	7.97 (94)	10.90 (131)	1.18 (1.33)	1.18 (1.33)	1.18 (1.33)	1.25 (1.67)	0.71 (0)	1.05 (0.83)
Pendimethalin + metribuzin 1+ 0.175 kg/ha	2.35 (5.7)	3.00 (8.64)	2.71 (7.15)	2.99 (9.8)	4.84 (24.2)	4.10 (17.0)	13.07 (179)	15.00 (251)	14.28 (215)	16.11 (264)	9.37 (144)	13.75 (204)	1.25 (1.67)	1.25 (1.67)	1.25 (1.67)	1.34 (2.08)	0.71 (0)	1.11 (1.04)
Pendimethalin *fb* sulfosulfuron1+ 0.018 kg/ha	2.73 (7.0)	13.71 (190)	9.89 (98.8)	3.41 (11.5)	15.81 (256)	11.44 (133.6)	13.64 (208)	14.32 (212)	14.18 (210)	17.00 (324)	31.84 (1098)	26.03 (711)	1.90 (3.33)	4.88 (23.3)	3.71 (13.3)	2.28 (4.85)	6.79 (45.8)	5.07 (25.3)
Sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha	5.98 (40.0)	4.78 (22.5)	5.49 (31.3)	7.71 (69.5)	8.20 (76.4)	7.99 (72.9)	22.56 (523)	27.68 (793)	25.35 (658)	28.39 (839)	27.23 (771)	27.82 (805)	4.88 (23.3)	2.82 (7.67)	3.99 (15.5)	6.08 (36.5)	6.44 (40.9)	6.26 (38.7)
Metsulfuron 0.004 kg/ha	6.94 (48.0)	6.66 (50.6)	7.01 (49.3)	8.64 (74.1)	15.40 (241)	12.51 (157)	25.23 (667)	28.93 (895)	27.53 (781)	31.19 (991)	28.92 (970)	30.72 (980)	5.21 (27.3)	5.92 (34.7)	5.59 (31)	6.59 (45.1)	6.93 (48.0)	6.84 (46.5)
Mesosulfuron + iodosulfuron 0.012 +0.0024 kg/ha	3.04 (9.0)	7.63 (57.9)	5.82 (33.4)	3.74 (13.7)	6.10 (37.5)	5.06 (25.6)	12.76 (213)	19.18 (398)	16.57 (306)	15.78 (332)	16.23 (292)	16.16 (312)	1.73 (3)	1.73 (3)	1.73 (3)	2.02 (4.09)	3.92 (15.1)	3.17 (9.6)
Clodinafop + metsulfuron 0.06 + 0.004 kg/ha	12.32 (151)	6.06 (37.2)	9.73 (94.3)	15.47 (240)	6.11 (36.9)	11.76 (138)	26.09 (720)	13.98 (257)	22.03 (488)	33.10 (1194)	9.37 (144)	25.13 (669)	4.40 (30.7)	1.90 (3.33)	3.58 (17)	5.63 (54.9)	0.71 (0)	4.07 (27.4)
2 Hand weeding	1.50 (3.0)	3.33 (10.8)	2.66 (6.90)	1.61 (3.75)	2.39 (6.93)	2.09 (5.34)	8.26 (69)	9.06 (83)	8.67 (76)	10.23 (105)	7.97 (94)	9.71 (99)	1.10 (1)	1.87 (3.67)	1.56 (2.33)	1.16 (1.25)	0.71 (0)	0.99 (0.63)
Unweeded control	12.39 (15)	13.60 (184)	1302 (170)	15.65 (252)	16.38 (272)	16.19 (262)	29.10 (849)	32.18 (1044)	30.68 (946)	36.72 (1374)	34.97 (1295)	35.93 (1334)	5.92 (34.7)	5.55 (30.7)	5.74 (32.7)	7.41 (54.9)	7.36 (54)	7.40 (54.5)
LSD (p=0.05)	1.93	2.19	1.33	2.65	3.53	2.63	8.67	9.79	6.51	11.58	15.44	10.64	2.67	0.97	1.69	3.72	0.97	2.14

Figures in parentheses indicate original values subjected to square root transformation

Table 2. Effect of weed control methods on total weed density (no./m^2) in wheat

Treatment	30 DAS			60 DAS		
	2014	2015	Pool	2014	2015	Pool
Pendimethalin 0.75 kg/ha	17.82(341)	25.29(659)	22.33(500)	22.48(550)	22.78(551)	22.64(550)
Sulfosulfuron 0.025 kg/ha	23.06(532)	25.03(626)	24.06(579)	28.92(839)	26.25(689)	27.63(764)
Metribuzin 0.21 kg/ha	20.76(431)	22.38(501)	21.59(466)	25.99(676)	17.80(363)	22.66(520)
Clodinafop 0.06 kg/ha	10.66(120)	12.04(150)	11.37(135)	13.18(179)	9.64(109)	11.64(144)
Pendimethalin + metribuzin 1 + 0.175 kg/ha	13.36(186)	15.38(261)	14.60(224)	16.49(276)	11.67(169)	14.48(222)
Pendimethalin *fb* sulfosulfuron 1 + 0.018 kg/ha	14.06(218)	20.60(426)	17.88(322)	17.53(341)	36.38(1399)	28.93(870)
Sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha	23.96(586)	28.25(824)	26.30(705)	30.20(945)	29.27(889)	29.74(917)
Metsulfuron 0.004 kg/ha	26.71(742)	30.39(980)	28.98(861)	33.08(1111)	33.99(1259)	33.91(1185)
Mesosulfuron + iodosulfuron 0.012 + 0.0024 kg/ha	13.31(225)	20.83(459)	17.74(342)	16.47(350)	17.80(345)	17.30(347)
Clodinafop + metsulfuron 0.06 + 0.004 kg/ha	29.40(902)	15.95(298)	24.41(600)	37.26(1489)	12.20(181)	28.24(835)
2 Hand weeding	8.45(73)	9.81(97)	9.16(85)	10.44(110)	8.77(101)	9.97(105)
Unweeded control	32.16(1039)	35.37(1259)	33.81(1149)	40.59(1681)	39.66(1620)	40.15(1651)
LSD (p=0.05)	8.49	9.09	6.09	11.50	13.32	10.31

Figures in parentheses indicate original values subjected to square root transformation

Table 3. Effect of weed control methods on weed dry matter (g/m^2)

Treatment	Grassy						Broad-leaf weed						Sedges					
	30 DAS			60 DAS			30 DAS			60 DAS			30 DAS			60 DAS		
	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
Pendimethalin 0.75 kg/ha	2.40 (5.65)	4.24 (17.6)	3.46 (11.6)	2.79 (7.88)	8.17 (67.8)	6.13 (37.8)	11.79 (144)	18.89 (358)	15.78 (251)	13.85 (201)	23.16 (559)	19.30 (380)	1.25 (1.65)	2.37 (7.13)	1.99 (4.39)	1.35 (2.15)	6.10 (37.7)	4.47 (19.9)
Sulfosulfuron 0.025 kg/ha	3.87 (15.2)	6.23 (42.2)	5.19 (28.7)	4.51 (20.8)	7.54 (57.0)	6.25 (38.9)	15.31 (235)	19.82 (396)	17.71 (316)	17.88 (320)	9.37 (88.6)	14.29 (204)	2.28 (6.04)	4.62 (24.4)	3.68 (15.2)	2.63 (8.31)	5.42 (29.8)	4.30 (19.1)
Metribuzin 0.21 kg/ha	3.07 (9.2)	2.73 (11.6)	3.03 (10.4)	3.56 (12.5)	7.18 (51.3)	5.68 (31.9)	13.96 (197)	16.69 (314)	15.75 (256)	16.30 (268)	14.03 (226)	15.62 (247)	1.73 (3.08)	1.39 (2.34)	1.65 (2.71)	1.97 (4.3)	3.62 (12.6)	2.98 (8.46)
Clodinafop 0.06 kg/ha	1.81 (2.89)	1.98 (5.85)	2.00 (4.37)	2.08 (4.03)	5.64 (32.2)	4.25 (18.1)	7.17 (55)	8.61 (78)	7.97 (67)	8.33 (74.0)	9.30 (88.3)	8.98 (81.1)	0.98 (0.6)	1.05 (0.85)	1.02 (0.73)	1.03 (0.78)	0.71 (0)	0.90 (0.39)
Pendimethalin + metribuzin 1.0 + 0.175 kg/ha	1.74 (2.84)	2.15 (6.28)	2.09 (4.56)	1.99 (3.95)	4.11 (17.1)	3.25 (10.5)	8.97 (83)	8.62 (78)	8.80 (81)	10.45 (112)	14.03 (227)	12.67 (169)	1.02 (0.75)	1.11 (1.06)	1.07 (0.91)	1.09 (0.98)	0.71 (0)	0.94 (0.49)
Pendimethalin *fb* sulfosulfuron1+0.018 kg/ha	1.96 (3.44)	11.17 (125)	8.03 (64.2)	2.26 (4.73)	12.97 (170)	9.31 (87.6)	9.14 (88)	24.67 (657)	18.84 (373)	10.72 (123)	20.59 (426)	16.53 (275)	1.41 (1.57)	5.79 (33.7)	4.22 (17.6)	1.59 (2.11)	6.71 (44.6)	4.88 (23.3)
Sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha	4.24 (20.5)	6.02 (37.7)	5.26 (29.1)	4.96 (28.4)	8.57 (73.0)	7.14 (50.7)	15.91 (270)	23.24 (545)	20.06 (408)	18.55 (366)	23.52 (559)	21.31 (463)	3.40 (11.1)	4.57 (26.5)	4.20 (18.8)	3.96 (15.2)	5.68 (31.8)	4.89 (23.5)
Metsulfuron 0.004kg/ha	4.82 (23.0)	6.08 (38)	5.50 (30.5)	5.61 (31.2)	12.81 (169)	9.91 (100)	17.47 (320)	22.62 (593)	20.72 (456)	20.34 (430)	28.07 (802)	24.67 (616)	3.71 (14.2)	5.13 (28.4)	4.53 (21.3)	4.32 (19.4)	5.63 (31.3)	5.07 (25.4)
Mesosulfuron + iodosulfuron 0.012+0.0024 kg/ha	2.14 (4.09)	2.54 (7.98)	2.44 (6.04)	2.46 (5.59)	6.19 (37.9)	4.71 (21.7)	8.35 (86)	14.10 (203)	11.77 (144)	9.83 (121)	18.15 (370)	14.79 (246)	1.30 (1.39)	1.35 (2.13)	1.34 (1.76)	1.44 (1.83)	3.62 (12.6)	2.78 (7.24)
Clodinafop + metsulfuron 0.06 + 0.004 kg/ha	8.56 (73.6)	5.35 (28.7)	7.14 (51.1)	10.00 (100)	5.64 (32.2)	8.16 (66.3)	17.84 (348)	13.92 (194)	16.23 (271)	20.80 (472)	14.95 (234)	18.50 (353)	2.69 (9.78)	1.30 (1.92)	2.23 (5.85)	3.07 (13.2)	3.45 (13.0)	3.34 (13.1)
2 Hand weeding	1.18 (1.35)	1.30 (1.92)	1.25 (1.63)	1.27 (1.76)	1.63 (3.85)	1.47 (2.8)	5.71 (33)	7.12 (50)	6.46 (41)	6.64 (44.2)	7.69 (58.8)	7.19 (51.5)	0.92 (0.45)	0.99 (0.64)	0.96 (0.54)	0.97 (0.59)	0.71 (0)	0.86 (0.29)
Unweeded control	8.70 (78.6)	12.59 (158)	10.85 (118)	10.16 (107)	13.73 (190)	12.12 (149)	21.05 (462)	28.14 (794)	24.91 (628)	24.60 (631)	30.55 (966)	27.74 (799)	4.89 (26.0)	11.75 (138)	9.04 (82.1)	5.69 (35.4)	14.35 (205)	10.97 (120)
LSD (p=0.05)	1.59	2.73	1.92	1.84	2.42	1.65	6.57	8.23	5.48	7.68	7.87	6.05	1.99	2.64	2.03	2.37	1.09	1.51

Figures in parentheses indicate original values subjected to square root transformation

application of clodinafop 0.06 kg/ha (**Table 4**). In general significant reduction in weed dry weight with application of clodinafop might be due to more effectiveness in controlling broad spectrum weeds than others.

Yield attributing parameters of wheat

Two hand weeding performed in wheat being similar to post-emergence application of clodinafop 0.06 kg/ha, pendimethalin + metribuzin (1.0 + 0.175 kg/ha), pre-emergence application of pendimethalin 1.0 kg/ha *fb* post-emergence application of sulfosulfuron 0.018 kg/ha and mesosulfuron 3% + iodosulfuron 0.6% (0.012 + 0.0024 kg/ha) recorded significantly higher total and effective tillers during 2014, 2015 and under pooled data. Maximum grains/ spike was recorded by pre-emergence application of pendimethalin 1.0 kg/ha *fb* post-emergence application of sulfosulfuron 0.018 kg/ha, similar to pre-emergence application of pendimethalin 0.75 kg/ ha, pendimethalin + metribuzin (1.0 + 0.175 kg/ha) and two hand weeding at 30 and 60 DAS. Maximum

Table 4. Effect of weed control methods on total weed dry matter (g/m^2) in wheat

Treatment	30 DAS		60 DAS		Pool		WCE (%)	
	2014	2015	2014	2015	30 DAS	60 DAS	30 DAS	60 DAS
Pendimethalin 0.75 kg/ha	12.10 (151.4)	19.53 (382.4)	14.21 (211.0)	25.29 (665.1)	16.28 (266.9)	20.72 (438.1)	65.56	57.29
Sulfosulfuron 0.025 kg/ha	15.97 (256.2)	21.38 (462.8)	18.66 (349.6)	13.26 (175.5)	18.88 (359.5)	16.19 (262.5)	55.41	73.33
Metribuzin 0.21 kg/ha	14.40 (209.1)	17.20 (328.1)	16.81 (284.6)	16.32 (290.6)	16.19 (268.6)	16.87 (287.6)	64.79	68.93
Clodinafop 0.06 kg/ha	7.45 (58.8)	9.02 (84.6)	8.65 (78.8)	10.89 (120.5)	8.34 (71.7)	9.98 (99.7)	90.61	89.24
Pendimethalin + metribuzin 1 + 0.175 kg/ha	9.18 (86.5)	9.06 (85.6)	10.69 (116.8)	14.76 (243.8)	9.13 (86.1)	13.15 (180.3)	88.55	79.46
Pendimethalin *fb* sulfosulfuron 1 + 0.018 kg/ha	9.44 (93.5)	27.85 (815.9)	11.08 (130.0)	25.24 (641.1)	20.96 (454.7)	19.58 (385.5)	45.40	59.60
Sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha	16.88 (302.0)	24.62 (609.2)	19.69 (409.7)	25.67 (664.1)	21.21 (455.6)	22.99 (536.9)	43.10	47.45
Metsulfuron 0.004 kg/ha	18.51 (357.2)	24.04 (659.3)	21.56 (480.8)	31.37 (1002.2)	21.93 (508.3)	27.07 (741.5)	40.18	26.21
Mesosulfuron + iodosulfuron 0.012 + 0.0024 kg/ha	8.74 (91.6)	14.44 (212.8)	10.28 (128.4)	19.62 (420.8)	12.08 (152.2)	15.84 (274.6)	79.30	68.72
Clodinafop + metsulfuron 0.06 + 0.004 kg/ha	20.03 (431.2)	14.99 (224.6)	23.37 (585.4)	16.38 (280.1)	17.87 (327.9)	20.51 (432.7)	57.94	56.41
2 Hand weeding	5.84 (34.5)	7.29 (52.7)	6.79 (46.6)	7.92 (62.7)	6.61 (43.6)	7.38 (54.6)	94.34	94.23
Unweeded control	23.28 (567.0)	32.98 (1091.2)	27.21 (773.6)	36.54 (1361.9)	28.61 (829.1)	32.23 (1067.8)	0.00	0.00
LSD (p=0.05)	6.60	7.94	7.71	7.43	5.48	5.92	20.51	18.15

Figures in parentheses indicate original values subjected to square root transformation

Table 5. Effect of weed control methods on yield attributing parameters of wheat

Treatment	Total tiller (no./m^2)			Effective tiller (no./m^2)			Grains/spike			Spike length (cm)			1000-seed wt. (g)		
	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
Pendimethalin 0.75 kg/ha	334	277	306	295	246	271	38	31	35	10.07	8.40	9.23	46.13	38.43	42.28
Sulfosulfuron 0.025 kg/ha	324	272	298	276	231	254	33	28	31	9.60	7.99	8.80	44.53	37.11	40.82
Metribuzin 0.21 kg/ha	328	273	300	286	241	264	35	29	32	9.13	7.62	8.38	46.33	38.63	42.48a
Clodinafop 0.06 kg/ha	393	329	361	345	289	317	28	23	26	8.67	7.22	7.94	45.73	38.09	41.91
Pendimethalin + metribuzin 1 + 0.175 kg/ha	383	320	352	340	286	313	38	32	35	7.27	6.22	6.74	46.40	38.69	42.54
Pendimethalin *fb* sulfosulfuron 1 + 0.018 kg/ha	379	319	349	333	279	306	42	35	39	11.17	9.29	10.23	47.67	39.70	43.68
Sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha	320	268	294	274	228	251	33	28	30	9.13	7.62	8.38	44.87	37.40	41.13
Metsulfuron 0.004 kg/ha	308	258	283	260	217	238	32	27	29	9.33	7.77	8.55	46.87	39.01	42.94
Mesosulfuron + iodosulfuron 0.012 + 0.0024 kg/ha	375	313	344	321	268	294	35	29	32	9.93	8.28	9.10	47.60	39.66	43.63
Clodinafop + metsulfuron 0.06 + 0.004 kg/ha	299	249	274	255	213	234	35	29	32	9.07	7.55	8.31	43.47	36.25	39.86
2 Hand weeding	402	337	370	350	293	321	40	33	36	10.07	8.40	9.23	48.80	40.65	44.73
Unweeded control	289	241	265	246	205	225	24	20	22	8.07	6.73	7.40	41.60	34.68	38.14
LSD (p=0.05)	66.59	90.10	54.01	66.98	87.08	59.28	4.31	6.09	4.30	NS	2.03	NS	1.32	NS	2.41

1000-grain weight was recorded by two hand weeding at 30 and 60 DAS similar to pre-emergence application of pendimethalin 1.0 kg/ha *fb* post-emergence application of sulfosulfuron 0.018 kg/ha, pre-emergence application of pendimethalin + metribuzin (1.0 + 0.175 kg/ha) and post-emergence application of mesosulfuron 3% + iodosulfuron 0.6% (0.012 + 0.0024 kg/ha) during 2014 and under pooled data (**Table 5**). Prolonged weed competition resulted in less number of grains/spike due to shortened ear head consequently less number of grains and less grain weight.

Yield and economics

Two hand weeding performed in wheat at 30 and 60 DAS recorded maximum grain and straw yield, higher net returns and B:C. While among herbicides, post-emergence application of clodinafop 0.06 kg/ha, similar to pre-emergence application of pendimethalin 0.75 kg/ha, pendimethalin + metribuzin (1.0 + 0.175 kg/ha), pendimethalin 1.0 kg/ha as pre-emergence *fb* post-emergence application of sulfosulfuron 0.018 kg/ha, and mesosulfuron 3% + iodosulfuron 0.6% (0.012 +0.0024 kg/ha) recorded 34.26% higher grain yield compared to weedy check, which was due to minimum yield loss percentage (**Table 6).** However, 51.31 and 48.12% higher net returns and B:C ratio was recorded with post-emergence application of clodinafop 0.06 kg/ha as compared to weedy check and was similar to pre-emergence application of pendimethalin + metribuzin

Table 6. Effect of weed control methods on yield of wheat

Treatment	Grain (t/ha)			Straw (t/ha)			Yield loss (%)		
	2014	2015	pooled	2014	2015	pooled	2014	2015	pooled
Pendimethalin 0.75 kg/ha	2.84	2.29	2.57	5.40	4.33	4.86	34.99	35.34	35.16
Sulfosulfuron 0.025 kg/ha	2.57	2.06	2.32	5.31	4.30	4.81	41.26	41.73	41.46
Metribuzin 0.21 kg/ha	2.79	2.26	2.52	5.33	4.30	4.81	36.25	36.25	36.25
Clodinafop 0.06 kg/ha	3.42	2.74	3.08	5.94	4.80	5.37	21.76	22.50	22.09
Pendimethalin + metribuzin 1 + 0.175 kg/ha	3.28	2.66	2.97	5.56	4.46	5.01	25.01	24.85	24.92
Pendimethalin *fb* sulfosulfuron 1 + 0.018 kg/ha	2.95	2.38	2.67	5.52	4.43	4.97	32.50	32.68	32.58
Sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha	2.52	2.01	2.26	5.07	4.10	4.59	42.51	43.14	42.77
Metsulfuron 0.004 kg/ha	2.41	1.95	2.18	4.95	4.00	4.47	45.01	44.95	44.97
Mesosulfuron + iodosulfuron 0.012 + 0.0024 kg/ha	2.84	2.31	2.58	5.42	4.38	4.90	35.02	34.72	34.88
Clodinafop + metsulfuron 0.06 + 0.004 kg/ha	2.35	1.90	2.12	4.74	3.81	4.28	46.24	46.40	46.31
2 Hand weeding	4.38	3.54	3.96	6.25	5.04	5.65	0.00	0.00	0.00
Unweeded control	2.24	1.81	2.03	4.42	3.57	4.00	48.75	48.83	48.79
LSD (p=0.05)	0.72	0.59	0.65	0.91	0.83	0.76			

Table 7. Effect of weed control methods on economics of wheat production

Treatment	Cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)			Net return (x10^3 `/ha)			B:C		
		2014	2015	pooled	2014	2015	pooled	2014	2015	pooled
Pendimethalin 0.75 kg/ha	24.08	53.15	42.72	47.94	29.08	18.64	23.86	1.21	0.77	0.99
Sulfosulfuron 0.025 kg/ha	23.11	49.35	39.69	44.52	26.24	16.57	21.40	1.14	0.72	0.93
Metribuzin 0.21 kg/ha	23.64	52.25	42.21	47.23	28.60	18.56	23.58	1.21	0.79	1.00
Clodinafop 0.06 kg/ha	24.16	62.32	50.04	56.18	38.16	25.88	32.02	1.58	1.07	1.33
Pendimethalin + metribuzin 1+0.175 kg/ha	25.34	59.34	47.93	53.64	34.00	22.59	28.30	1.34	0.89	1.12
Pendimethalin *fb* sulfosulfuron1+0.018 kg/ha	24.89	54.95	44.23	49.59	30.06	19.34	24.70	1.21	0.78	0.99
Sulfosulfuron + metsulfuron 0.03+0.002 kg/ha	23.08	47.91	38.46	43.18	24.82	15.37	20.10	1.08	0.67	0.87
Metsulfuron 0.004 kg/ha	23.33	46.12	37.28	41.70	22.79	13.95	18.37	0.98	0.60	0.79
Mesosulfuron + iodosulfuron 0.012+0.0024 kg/ha	25.88	53.22	43.15	48.18	27.33	17.26	22.30	1.06	0.67	0.86
Clodinafop + metsulfuron 0.06 + 0.004 kg/ha	25.66	44.78	36.09	40.44	19.12	10.43	14.78	0.75	0.41	0.58
2 Hand weeding	28.73	75.62	61.11	68.37	46.89	32.37	39.63	1.63	1.13	1.38
Unweeded control	22.73	42.41	34.24	38.32	19.67	11.50	15.59	0.87	0.51	0.69
LSD (p=0.05)		9.71	8.43	8.98	9.71	8.43	8.98	0.40	0.34	0.37

1.0 + 0.175 kg/ha (**Table 7**). These results were in conformity with Singh *et al.* (2017).

It was concluded that post-emergence application of clodinafop 0.06 kg/ha or pre-emergence application of pendimethalin + metribuzin (1.0 + 0.175 kg/ha) was as good as two hand weeding performed in wheat at 30 and 60 DAS for higher productivity and profitability.

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Indian Journal of Weed Science **49**(1): 41–43, 2017
DOI: 10.5958/0974-8164.2017.00010.7

Integrated weed management in pearl millet

P.P. Girase*, R.T. Suryawanshi, P.P. Pawar and S.C. Wadile
Bajra Research Scheme, College of Agriculture, Dhule, Maharashtra 424 004

Received: 18 January 2017; Revised: 2 March 2017

ABSTRACT

A field experiment was carried out during the rainy (*Kharif*) seasons of 2012 to 2014 in medium black soil at Bajra Research Scheme, Dhule, Maharashtra, to evaluate the effect of integrated weed management in rainfed pearl millet (*Pennisetum glaucum*) with pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS, four levels of post-emergence application of atrazine (0.1, 0.2, 0.3 and 0.4 kg/ha) along with one hand weeding at 35 DAS, two hand weeding and hoeing (at 20 and 40 DAS). The maximum grain yield was recorded with pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS, which was at par with two hand weeding and hoeing, and post-emergence application of atrazine 0.4 kg/ha + 1 HW at 35 DAS and increased the yield by 62.14% over weedy check. The higher grain yield may be owing to significantly lower weed dry weight, higher weed control efficiency which reflected in higher values of plant height, number of effective tillers/plant, earhead length and 1,000 grain weight. Maximum net returns (¹ 27,282/ha) and B:C ratio (2.73) were realized with pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS followed by post-emergence application of atrazine 0.4 kg/ha + 1 HW at 35 DAS which recorded net monetary returns of ¹ 25,404/ha and B:C ratio 2.62.

Key words: Herbicide, Pearl millet, Post-emergence, Pre-emergence, Weed control efficiency

Pearl millet (*Pennisetum glaucum* L.) is one of the important cereal crops globally after rice, wheat and maize. It is a unique crop among the major cereals and the staple food and fodder crop of the world's poor and most food insecure populations in the arid and semi-arid tropics. In India, the area and productivity of rainy (*Kharif*) season pearl millet during 2015-16 was 7.8 million hactares and 9.25 million tones, respectively with productivity of 1270 kg/ha. In Maharashtra, it is cultivated over an area of 0.80 million hactares with a production and productivity of 0.33 million tones and 416 kg/ha, respectively (GOI 2015-16). Weeds are a major obstacle in increasing the productivity of pearl millet especially during rainy season. Sharma and Jain (2003) reported upto 40% loss in grain yield due to weed competition in pearl millet. Under scarcity of human labour, use of herbicide is the best option to reduce the weed menace during early stages of growth. Some pre-mergence herbicides have been found effective against the weed of pearl millet (Das *et al.* 2013). However, neither herbicides nor mechanical cultivation are adequate for consistent and acceptable weed control. Therefore, present experiment was conducted to find out the effect of integrated weed management on productivity, weed dynamics and economics of rainy season pearl millet.

***Corresponding author:** premsinggirase2004@gmail.com

MATERIALS AND METHODS

Field experiment was carried out during the rainy (*Kharif*) seasons of 2012 to 2014 at Bajra Research Scheme Farm, College of Agriculture, Dhule (Maharashtra) under rainfed conditions on medium black soil. The soil of experimental field was clayey in texture, medium in organic carbon (0.51%), low in available nitrogen (213.0 kg/ha), with medium availability of phosphorus (15.8 kg/ha) and rich in potash (541.0 kg/ha). The soil was slightly alkaline in reaction (pH 8.1) with normal electrical conductivity (0.32 dS/m). The experiment was laid out in a randomized block design with four replications. Eight treatments comprised of weedy check, weed free, pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS, post-emergence application of atrazine 0.1 kg/ha + 1 HW at 35 DAS, post-emergence application of atrazine 0.2 kg/ha + 1 HW at 35 DAS, post-emergence application of atrazine 0.3 kg/ha + 1 HW at 35 DAS, post-emergence application of atrazine 0.4 kg/ha + 1 HW at 35 DAS and two hand weeding and hoeing at 20 and 40 DAS.

The pre-emergence herbicide was sprayed after sowing on wet soil and post-emergence herbicide was applied at 20 days after sowing (3rd leaf stage of weed) with the help of knapsack sprayer at a spray volume of 600 L/ha. Pearl millet hybrid *'86 M 64'* was sown at 45 x 15 cm spacing on 7 July 2012, 27 June 2013 and 20 July 2014. The delayed sowing during 2014 was due to late onset of monsoon. The gross plot size was 5.0 x 3.6 m and crop was fertilized with 60 kg N and 30 kg P/ha through urea and single super phosphate. At sowing 50% N along with full dose of P were applied and remaining 50% N was applied 30 days after sowing. Total rainfall (678.6 mm) in 2013 during the cropping period was higher than 2012 (527.7 mm) and 2014 (469.3 mm). Weed population and weed dry matter were recorded 30 days after sowing and at harvest from pre-marked quadrants of 1 m^2 area. Weed control efficiency and weed index were worked out to assess the efficiency of different weed-control treatments. The data on growth and yield attributes were recorded from 5 randomly selected plants at harvest. The crop was harvested on 19 October 2012, 21 October 2013 and 5 November 2014. The economics were calculated based on prevailing market prices of inputs and out puts. The data were statistically analyzed and pooled data of three years were presented.

RESULTS AND DISCUSSION

The major weed species observed in the experimental plot were grassy weeds like *Cynondon dactylon, Brachiaria eruciformis*; broad-leaf weeds like *Parthenium hysterophorus, Commelina benghalensis, Celosia argentea, Panicum isachmi, Amaranthus viridis, Euphorbia microphylla, Phyllanthus niruri, Alteranthera triandra;* and sedges *Cyperus rotundus.*

Weed density and weed control efficiency

All the weed control measures reduced weed density and dry matter of weeds over weedy check (**Table 1**). The weed density and weed dry matter were significantly lowest in 2 hand weeding and hoeing at 20 and 40 DAS. Among the integrated weed management treatment dry matter, it was lower in pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS when compared with its other doses. In weed free treatment, there was no weed dry matter due to absence of weeds. The weedy check recorded the highest weed biomass. Similar results were reported by Ramakrishna (1994) and Sharma and Jain (2003).

Two hand weeding and hoeing at 20 and 40 DAS recorded significantly higher weed control efficiency (88.92% and 90.95% at 30 DAS and at harvest, respectively) and it was at par with pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS (79.21% and 83.25% at 30 DAS and at harvest, respectively) followed by post- emergence application of atrazine 0.4 kg/ha + 1 HW at 35 DAS (**Table 1**). The weed free treatment was found significantly superior by recording 100% weed control efficiency. The results were collaborating with the findings of Sharma and Jain (2003)

Among the weed control treatments, pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS recorded lower weed index (3.71%) and it was at par with two hand weeding and hoeing at 20 and 40 DAS (4.36%). Weed free treatment recorded the lowest weed index (0%) indicating that there was no reduction in grain and fodder yields due to weed infestation. The highest weed index (40.39%) was recorded in weedy check (control) as a result of uncontrolled weed growth which leads to higher competition with the crop. Similar results were obtained by Gautam and Kaushik (1984), Banga *et al.* (2000) and Sharma and Jain (2003).

Table 1. Effect of weed management practices on weed intensity, weed biomass, weed control efficiency and weed index (pooled data of 3 years)

Treatment	Weed intensity (no./m^2)		Weed dry matter (g/m^2)		Weed control efficiency (%)		Weed index at harvest (%)
	30 DAS	At harvest	30 DAS	At harvest	30 DAS	At harvest	
Atrazine 0.5 kg/ha (PE) + 1 HW at 35 DAS	6.15 (37.43)	5.29 (27.50)	5.08 (25.40)	4.05 (15.96)	79.21	83.25	3.71
Atrazine 0.1 kg/ha (PoE) + 1 HW at 35 DAS	8.83 (77.50)	6.14 (37.25)	7.16 (51.04)	5.55 (30.37)	58.85	71.93	19.25
Atrazine 0.2 kg/ha (PoE) + 1 HW at 35 DAS	8.02 (63.87)	5.97 (35.25)	6.41 (40.68)	5.33 (27.94)	66.01	74.29	15.44
Atrazine 0.3 kg/ha (PoE) + 1 HW at 35 DAS	7.88 (61.70)	5.89 (34.17)	6.25 (38.78)	5.08 (25.33)	68.92	75.39	13.78
Atrazine 0.4 kg/ha (PoE) + 1 HW at 35 DAS	7.83 (60.76)	5.53 (30.16)	5.91 (34.46)	4.85 (23.04)	71.00	78.01	7.88
Two hand weeding and hoeing at 20 and 40 DAS	5.23 (27.00)	4.18 (17.08)	3.85 (14.51)	3.01 (8.62)	88.92	90.95	4.36
Control (weedy check)	9.63*(92.33)	8.23 (67.16)	11.59 (134.0)	10.17 (102.9)	0.00	0.00	40.39
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	100	100	0.00
LSD (p=0.05)	0.24 (3.01)	0.22 (1.90)	0.69 (10.71)	0.35 (5.79)	9.76	8.21	3.19

Values are subjected to square root $\sqrt{x+0.5}$ transformation; original values are in parentheses**;** DAS- Days after sowing, HW- Hand weeding; PE- Pre-emergence; PoE- Post-emergence

Table 2. Effect of weed management practices on growth and yield parameters of pearl millet (pooled data of 3 years)

Treatment	Plant height (cm)	No. of effective tillers/ plant	Earhead length (cm)	1,000 grain weight (g)	Grain yield (t/ha)	Fodder yield (t/ha)	Gross returns ($x10^3$ `/ha)	Cost of cultivation ($x10^3$ `/ha)	Net returns ($x10^3$ `/ha)	B:C ratio
Atrazine 0.5 kg/ha (PE) + 1 HW at 35 DAS	214.0	1.80	26.11	11.48	3.10	5.70	43.01	15.73	27.28	2.73
Atrazine 0.1 kg/ha (PoE) + 1 HW at 35 DAS	208.4	1.44	24.49	10.91	2.59	4.79	35.98	15.38	20.61	2.34
Atrazine 0.2 kg/ha (PoE) + 1 HW at 35 DAS	209.5	1.49	24.88	11.03	2.70	5.00	37.59	15.55	22.04	2.42
Atrazine 0.3 kg/ha (PoE) + 1 HW at 35 DAS	210.9	1.50	25.20	11.15	2.76	5.13	38.43	15.62	22.81	2.46
Atrazine 0.4 kg/ha (PoE) + 1 HW at 35 DAS	212.2	1.63	25.43	11.26	2.96	5.49	41.08	15.68	25.40	2.62
Two hand weeding and hoeing at 20 and 40 DAS	214.8	1.84	26.00	11.49	3.07	5.68	42.58	18.47	24.11	2.31
Control (weedy check)	201.3	1.03	23.22	10.53	1.91	3.59	26.58	12.44	14.14	2.14
Weed free	216.4	1.98	26.38	11.73	3.22	5.96	44.71	20.62	24.09	2.17
LSD (p=0.05)	4.38	0.27	0.96	0.24	0.14	0.28	1.41	-	1.35	0.08

HW- Hand weeding; PE- Pre-emergence; PoE- Post-emergence

Performance of pearl millet

All the weed control measures significantly increased the grain and fodder yield of pearl millet compared with weedy check (**Table 2**). The grain and fodder yields (3.22 and 5.96 t/ha, respectively) were recorded significantly higher in weed free treatment and were at par with pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS (3.10 and 5.70 t/ha, respectively). The next best treatment was two hand weeding and hoeing at 20 and 40 DAS and post-emergence application of atrazine 0.4 kg/ha + 1 HW at 35 DAS, which were at par with pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS. The lowest grain and fodder yield (1.91 and 3.59 t/ha, respectively) was recorded in weedy check because presences of more weeds interfered with growth and development of the crop and compete for nutrients, moisture, light and space. These results were in close conformity with those reported by Balyan *et al.* (1993), Ramakrishna (1994), Sharma and Jain (2003) and Deshveer (2005).

Economics

The cost of cultivation (` 20,620/ha) and gross monetary returns (` 24,090/ha) were significantly higher in weed free treatment. It was followed by two hand weeding and hoeing at 20 and 40 DAS and pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS. While, net monetary returns (` 27,282/ha) and B:C ratio (2.73) was significantly higher in pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS than rest of the weed control treatments. It was closely followed by post-emergence application of atrazine 0.4 kg/ha + 1 HW at 35 DAS, which recorded net monetary returns of ` 25,404/ha and B:C ratio 2.62 (**Table 2**). Weed free treatment registered lower net monetary returns due to high cost involved in repeated weeding to keep crop weed-free despite having highest grain and fodder yield.

It was concluded that pre-emergence application of atrazine 0.5 kg/ha followed by hand weeding at 35 DAS and post-emergence application of atrazine 0.4 kg/ha at 20 DAS followed by hand weeding at 35 DAS appeared to be the best integrated weed management practice.

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Indian Journal of Weed Science **49**(1): 44–46, 2017
DOI: 10.5958/0974-8164.2017.00011.9

Integrated weed management in *Kharif* blackgram

C.V. Patel, T.C. Poonia* and M.S. Pithia
Pulses Research Station, Junagadh Agricultural University, Junagadh, Gujarat 362 001

Received: 21 December 2016; Revised: 7 February 2017

ABSTRACT

A field experiment was conducted on medium black calcareous clayey soil at Pulses Research Station, Junagadh Agricultural University, Junagadh during three seasons of 2011-12, 2012-13 and 2014-15 to study the efficacy of pre-and post-emergence herbicides in *Kharif* blackgram (*cv. GU-1*). The quizalofop-ethyl 40 g/ha as post-emergence (PoE) at 20 days after seeding (DAS) + hand weeding (HW) at 40 days after seeding (DAS) and pendimethalin 900 g/ha as pre-emergence (PE) + hand weeding (HW) at 40 DAS were found equally effective to the weed-free check in controlling weeds and improving growth and yield attributes and ultimately seed yield (1.14 and 1.13 t/ha) and straw yield (1.26 and 1.33 t/ha) of blackgram. These treatments also recorded higher weed control efficiency (65.3 - 63.1%), herbicide efficiency index (81.1 - 82.3%), lower weed index (9.1 - 9.7%) and minimum weed dry biomass (273.9 - 291.7 kg/ha) and higher net returns (` 21,230 and ` 21,162 /ha). Integrated weed management practices with herbicides as a component were found effective and economical under south Saurashtra agro-climatic conditions of Gujarat.

Key words: Blackgram. Economics, Herbicides, Integrated weed management, Weed control efficiency

Cultivation of pulses in coastal areas of Gujarat is a common practice in *Kharif* and semi-*Rabi* seasons. In Gujarat, blackgram is grown in almost all the districts as a *Kharif* crop with 9.44 lakh ha area with 5.96 lakh tonnes production and 631 kg/ha productivity. In South Saurashtra region of Gujarat, blackgram is cultivated in 16.8 lakh ha with a production of 7.1 lakh tonnes and productivity of 2.48 t/ha (DAG, 2015). Among the different constraints in cultivation of *Kharif* blackgram, weed menace is major as weeds cause the yield reduction upto 53% (Appanna *et al.* 1998). Further, initial slow growth of blackgram seedlings makes itself poor competitor with more vigorous weeds. The normal methods of weed management like hand weeding is not practiced by farmers in blackgram cultivation because of the higher labour wages, problem of heavy rains and chances of trampling of crop during the weeding, which leads to loss of crop stand. Hence, selective herbicides use can be one of the best alternatives for economic and timely weed control in *Kharif* blackgram. Scanty scientific information is available regarding weed management in blackgram especially for South Saurashtra region of Gujarat. Hence, present experiment on bio-efficacy of different herbicides was undertaken to find out an appropriate integrated weed management practice for *Kharif* blackgram.

***Corresponding author:** pooniatc@gmail.com
College of Agriculture, JAU, Amreli, Gujarat

MATERIALS AND METHODS

A field experiment was carried out at Junagadh Agricultural University, Junagadh (Gujarat) on medium black calcareous soil during *Kharif* seasons of 2011-12, 2012-13 and 2014-15. The soil was clayey in texture and slightly alkaline in reaction (pH 7.8 and EC 0.35 dS /m), low in available nitrogen (203.5 kg N/ha), while medium in available phosphorus (81.9 kg P_2O_5/ha) and potash (215.7 kg K_2O/ha). Twelve treatments comprising of weed management practices, *viz.* pendimethalin 900 g/ha as pre-emergence (PE), oxyfluorfen 240 g/ha PE, pendimethalin 900 g/ha PE + hand weeding (HW) at 40 days after seeding (DAS), oxyfluorfen 240 g/ha PE + HW at 40 DAS, quizalofop-ethyl 40 g/ha post-emergence (POE) at 20 days after seeding (DAS), imazethapyr 75 g/ha PoE at 20 DAS, quizalofop-ethyl 40 g/ha PoE at 20 DAS + HW at 40 DAS, imazethapyr 75 g/ha PoE at 20 DAS + HW at 40 DAS, fenoxaprop 100 g/ha at 20 DAS + HW at 40 DAS, two hand weeding (HW) at 20 and 40 DAS, weed-free and unweeded control were evaluated in randomized block design replicated thrice. The gross and net plot sizes were 5.0 x 2.7 and 4.0 x 1.8 m, respectively. The blackgram variety '*GU-1*' was sown at 45 cm row spacing with standard package of practices. The crop was fertilized with 20-40-0 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. Weed density (no./m² area) were recorded at 20 and 40

DAS. Economics was worked out as per the prevailing market price.

RESULTS AND DISCUSSION

The weed flora of experimental field mainly comprised of *Cyperus rotundus*, *Commelina nudiflora*, *Cynodon dactylon*, *Digitaria sanguinalis*, *Digera arvensis*, *Trianthema portulacastrum*, *Euphorbia hirta* and *Physalis minima*. *Cyperus rotundus* was the major dominant sedge weed throughout the growing season.

Effect on weeds

The pooled data over three years indicated that different weed management treatments exerted their significant effect on weed density at 20 and 40 DAS and weed biomass at harvest. Next to weed-free, significantly the lowest weed density (2.68 /m²) at 20 days crop growth was recorded with oxyfluorfen PE at 240 g/ha and with quizalofop-ethyl 40 g/ha post-emergence (PoE) at 20 DAS + HW at 40 DAS. At 40 days crop growth stage, two HW (20 and 40 DAS) recorded significantly lowest weed density (5.39/m²) and statistically remained at par with all other herbicide treatments except quizalofop-ethyl applied at 40 g/ha PoE of 20 days crop growth. Significantly the lowest weed biomass (273.9 kg/ha) was recorded with application of quizalofop-ethyl 40 g/ha PoE at 20 DAS + HW at 40 DAS and closely followed by pendimethalin 900 g/ha as PE + HW at 40 DAS (291.7 kg/ha). However, both the treatments maintained statistical equivalence with oxyfluorfen 240 g/ha PE + HW at 40 DAS, imazethapyr 75 g/h PoE at 20 DAS alone or integrated with one HW at 40 DAS (**Table 1**) and hand weeding twice (20 and 40 DAS).

Mean data of weed control efficiency (WCE) and herbicide efficiency index (HEI) showed that next to weed-free check, application of quizalofop-ethyl at 40 g/ha PoE (20 DAS) + HW at 40 DAS recorded the highest WCE and HEI of 65.3 and 82.3%, respectively followed by treatment pendimethalin 900 g/ha PE + HW at 40 DAS (63.1 and 81%) (**Table 1**). Similarly, treatments, *viz*. quizalofop-ethyl PoE 40 g/ha at 20 DAS and pendimethalin 900 g/ha PE both integrated with one HW at 40 DAS recorded the lowest weed index (WI) of 9.1 and 9.7%, respectively that resulted in lower weed biomass production and higher crop yield. The results corroborate the findings of Appanna *et al.* (1998). Weedy situation witnessed the highest weed density, weed index and weed dry biomass owing to uncontrolled condition, which favored luxurious weed growth and resulted in 50% less seed yield over the weed free situation.

Effect on crop

Pre-emergence application of oxyfluorfen 240 g/ha caused phytotoxic effect on emerging blackgram seedlings resulting in moderate stunting growth of seedling and discoloration of developing leaves with negligible loss of crop stand. However, these symptoms were slowly recovered within a week and no abnormality was observed during the crop growth period. Gunsolus and Curran (2002) reported that oxyfluorfen treated potato plants do not die but may be stunted for a week or more and then recovered but was found highly toxic for onion crop (Sathya Priya 2013).

Various weed management practices significantly influenced growth and yield attributes of blackgram

Table 1. Effect of integrated weed management on weed parameters in *Kharif* blackgram (pooled over three years)

Treatment	Dose (g/ha)	Weed density (no./m^2)		Weed biomass (kg/ha) at harvest	Weed index (%)	Wed control efficiency (%)	Herbicide efficiency index (%)
		20 DAS	40 DAS				
Pendimethalin	900	2.56 (7.62)	2.64 (7.25)	22.32 (510.0)	19.8	35.4	60.7
Oxyfluorfen	240	1.74 (2.68)	3.08 (10.94)	24.91 (622.4)	26.5	21.2	47.4
Pendimethalin + HW at 40 DAS	900	2.32 (5.37)	2.67 (7.61)	16.04 (291.7)	9.7	63.1	81.0
Oxyfluorfen + HW at 40 DAS	240	2.56 (7.66)	2.50 (6.31)	17.35 (347.1)	25.8	56.1	48.7
Quizalofop-ethyl PoE at 20 DAS	40	2.47 (6.13)	3.27 (12.69)	23.29 (551.9)	17.8	30.1	64.7
Imazethapyr PoE at 20 DAS	75	2.68 (8.00)	2.71 (8.41)	19.15 (367.9)	22.5	53.4	55.4
Quizalofop-ethyl + HW at 40 DAS	40	2.69 (7.94)	2.35 (5.24)	16.04 (273.9)	9.1	65.3	82.3
Imazethapyr + HW at 40 DAS	75	2.40 (6.09)	2.34 (5.51)	16.55 (310.8)	21.6	60.7	57.2
Fenoxaprop at 20 DAS	100	2.56 (7.30)	2.92 (9.09)	21.77 (476.1)	22.9	39.7	54.5
Two HW at 20 and 40 DAS	-	2.57 (7.39)	2.24 (5.39)	16.98 (306.3)	19.8	61.2	
Weed free	-	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.0	100.0	
Weedy	-	3.69 (15.07)	4.13 (17.92)	28.11 (789.9)	50.1		
LSD (p=0.05)		0.95	0.95	5.04			

$\sqrt{x+0.5}$ Transformation (figure in parentheses are original values); PE - Pre-emergence; PoE - Post-emergence

Table 2. Effect of integrated weed management on growth, yield and economics of *Kharif* blackgram (pooled over 3 years)

Treatment	Dose (g/ha)	Plant height (cm)	Branches/ plant	Pods/ plant	Seeds/ pod	Yield (t/ha)		Cost of cultivation (x10³ `/ha)	Net return (x10³ `/ha)	B: C ratio
						Seed	Straw			
Pendimethalin	900	58.6	4.1	29.4	5.1	1.01	1.27	23.15	19.00	1.82
Oxyfluorfen	240	56.8	3.8	34.9	5.3	0.92	1.11	22.78	15.80	1.69
Pendimethalin +HW at 40 DAS	900	58.9	3.5	34.8	5.2	1.13	1.33	26.15	21.16	1.80
Oxyfluorfen +HW at 40 DAS	240	58.2	3.7	34.7	5.0	0.93	1.19	25.78	13.25	1.51
Quizalofop-ethyl PoE at 20 DAS	40	61.0	3.9	32.8	5.1	1.03	1.15	23.30	19.67	1.84
Imazethapyr PoE at 20 DAS	75	58.0	3.5	28.9	4.9	0.97	1.13	23.25	17.37	1.74
Quizalofop-ethyl + HW at 40 DAS	40	60.7	3.6	37.4	5.2	1.14	1.26	26.30	21.23	1.80
Imazethapyr + HW at 40 DAS	75	56.4	3.7	30.8	5.3	0.98	1.18	26.25	13.44	1.51
Fenoxaprop at 20 DAS	100	61.5	3.4	31.7	5.1	0.97	1.19	23.25	17.21	1.74
Two HW at 20 and 40 DAS	-	59.3	3.6	32.7	5.1	1.01	1.22	27.55	14.56	1.52
Weed free	-	61.8	4.5	42.1	5.6	1.25	1.42	32.05	20.27	1.63
Weedy	-	53.2	2.4	19.5	4.3	0.63	0.78	21.55	4.66	1.21
LSD (p=0.05)		NS	0.75	7.69	0.36	0.12	0.14			

(**Table 2**). Significantly, the highest number of branches/plant, pods/plant and seeds/pod were recorded under the weed-free check, however it remained at par with either pre-emergence application of pendimethalin at 900 g/ha or post-emergence of quizalofop-ethyl at 40 g/ha both integrated with one HW (40 DAS) in most of the cases. Significantly the lowest values of these growth and yield attributes were registered under the weedy check. Periodical control of weeds by hand weeding or herbicide application supplemented with hand weeding suppressed weeds, which in turn provided better weed-free environment to the crop during critical period of growth and development. Mundra and Maliwal (2012) also reported similar results.

Different weed management treatments significantly influenced the seed yield of blackgram. The weed-free check yielded by producing significantly the highest seed and straw yield of 1.25 and 1.42 t/ha, respectively and statistically remained at par with quizalofop-ethyl 40 g/ha PoE + HW at 40 DAS. The next best treatment in this regard was pendimethalin 900 g/ha PE + HW at 40 DAS. The better growing condition prevailed in weed-free situation significantly increased the seed yield of 629 kg/ha (100.5%) over unweeded check. Significantly the lowest seed and straw yield (626 and 779 kg/ha, respectively) was observed under the unweeded control which were due to uncontrolled weed growth and severe crop-weed competition (Naidu *et al.* 2012).

Economics

The quizalofop-ethyl 40 g/ha PoE + HW at 40 DAS recorded maximum net returns of ` 21,230/ha, closely followed by pendimethalin 900 g/ha PE + HW at 40 DAS and weed-free which gave net returns of ` 21,162 and ` 20,274/ha, respectively. Unweeded control recorded the lowest net returns (` 4,658/ha). The higher B:C ratio of 1.82 to 1.84 (**Table 2**) was accrued with application of either pendimethalin as pre-emergence or quizalofop-ethyl as post-emergence without hand weeding due to higher prevailing labour wages and closely followed by integration of hand weeding with these herbicides in blackgram.

It was concluded that in *Kharif* blackgram, effective control of weeds, higher yield and net returns could be achieved by application of quizalofop-ethyl 40 g/ha PoE at 20 DAS + HW at 40 DAS or pendimethalin 900 g/ha PE + HW at 40 DAS under south Saurashtra agro-climatic conditions of Gujarat.

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Indian Journal of Weed Science **49**(1): 47–50, 2017
DOI: 10.5958/0974-8164.2017.00012.0

Weed management in onion through oxyfluorfen and its effect on soil microflora and succeeding crop of blackgram

R. Poddar*, S. Bera and R.K. Ghosh
Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal 741 252

Received: 8 February 2017; Revised: 17 March 2017

ABSTRACT

A field experiment was carried out to study the bioefficacy and phytotoxicity of oxyfluorfen (23.5% EC) in onion variety '*Sukhsagar*' and its residual effect on the succeeding crop black gram variety '*Basant Bahar (PDU-1)'* in Inceptisol of West Bengal. Pre-emergence application of oxyfluorfen 400 g/ha followed by one hand weeding (HW) at 30 days after planting (DAP) caused significantly lower weed density, weed dry weight and higher weed control efficiency at all the stages. Application of oxyfluorfen 200 g/ha + one HW at 30 DAP kept the weed density and dry weight below the economic threshold level and increased the bulb yield in onion. Though micro flora population at the initial stage was reduced due to application of herbicides but later their population was significantly higher than initial. Succeeding crop blackgram sown immediately after the harvest of onion was not affected by the residues of new formulation of oxyfluorfen at all different doses.

Key words: Chemical control, Effect on succeeding crop, Microflora, Onion, Oxyfluorfen, Weed management

Onion is an important crop grown in *Rabi* season in West Bengal. It has many uses as vegetables, salad *etc*. besides having its medicinal properties. Uncontrolled weed growth reduces the bulb yield up to 40-80% depending upon the nature of intensity and duration of weed competition in onion field (Prakash *et al*. 2000). Hand weeding is becoming costly day by day due to higher wages and non-availability in time at critical crop weed competition stage of onion. Therefore, alternate weed management technology and safer herbicides are one of the better substitutes of costly hand weeding. But herbicides need to be monitored for their ill effect on soil and crop environment not only in the main crop but in succeeding crop also. Oxyfluorfen is one of the pre-emergence selective herbicides for onion, therefore, its different doses were tested alongiwth its effects on soil micorflora and succding crop of blackgram.

MATERIALS AND METHODS

The study was carried out during *Rabi* season 2012-13 and 2013-14 at farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani. The soil of the experimental field was sandy loam in texture with 6.8 pH and medium fertility status with low water holding capacity. The experiment was laid out with eight treatments consisted of oxyfluorfen 23.5% EC in five doses, *viz.* 150, 200, 250, 300 and 400 g/ha, pendimethalin 30% EC 750 g/ha, hand weeding twice at 15 and 30 DAP and unweeded control, replicated thrice in randomized block design. The herbicides were applied as pre-emergence by using 500 litres of water/ha with knapsack sprayer fitted with flat fan deflector nozzle on third day after planting followed by a hand weeding on 30 DAP. Thirty days old seedlings of onion variety '*Sukhsagar'* treated with *Trichoderma viride* at 4 g/kg were transplanted manually in the experimental field during first week of November 2012 and 2013. Adequate plant protection measures against insects and diseases were followed. Half of the recommended dose (50%) of nitrogen at 100 kg/ha through urea along with full phosphorus through SSP and full potash through MOP; both at 50 kg/ha were applied as basal during final land preparation. The remaining half N was top dressed twice in equal amount (25 kg/ha) *viz.* after the first and second weeding at 25 and 50 DAP, respectively.

After harvesting of onion crop, to know the residual effect of herbicides, without disturbing the layout, each plot was manually prepared for sowing of succeeding crop. Weed density and dry matter of weed was collected at 15 and 30 days after application (DAA) of herbicides. Weed control efficiency (WCE) and weed index (WI) were calculated by using formula as suggested by Misra and Tosh (1979) and Gill and Vijaykumar (1969), respectively.

***Corresponding author:** rpoddar.bckv@rediffmail.com

Soil samples from the experimental plots were collected from the space between the rows at a depth 0–15 cm on different dates, *viz.* initial (pr-treatment), 3, 10, 30 and 60 days after application (DAA) of herbicides or respective treatment. The soil sample taken from respective treatments were mixed together and then requisite composite samples of each treatment were taken for microbial analysis by dilution plating following standard methods. Soil dilutions were prepared in sterile distilled water by constant shaking and plating was done separately in replicates in specific media *viz.* for total bacteria (Thornton's agar medium at 10^{-6} dilutions), fungi (Martin's rose bengal streptomycin agar medium at 10^{-4} dilutions) and actinomycetes (Jensen's agar medium at 10^{-5} dilutions). The enumeration of the microbial population was done on agar plants following serial dilution technique and pour plate method (Pramer and Schmidt 1965). Plates were incubated at 30 °C. The counts were taken at the 3rd day of incubation. The data were subjected to statistical analysis by analysis of variance method (Gomez and Gomez 1984). As the error mean squares of the individual experiments were homogenous, combined analysis over the years were done through unweighted analysis. Data values wherever necessary were transformed into square root as applicable (Panse and Sukhatme 1978).

RESULTS AND DISCUSSION

Among the dominant grassy weeds, *Echinochloa colona* and *Digitaria sanguinalis*, recorded the maximum population. *Cyperus rotundus* among sedge and *Melilotus alba, Amaranthus viridis, Portulaca oleracea*, and *Physalis minima* among broad-leaf weeds showed higher population in comparison to other weed species present in this onion field (**Table 1**).

Pre-emergence application of oxyfluorfen at 200, 250, 300 and 400 g/ha followed by one hand weeding at 30 DAP resulted effective control of broad-leaved weeds, grasses and to some extent sedges due to its broad spectrum action. However, application of oxyfluorfen 400 g/ha resulted more than 75% control of weeds. Kavaliauskaite (2009) reported similar higher effect of oxyfluorfen used as pre-emergence. The left over weeds were controlled by manual weeding on 30 DAP.

Unweeded control treatment gave the highest weed index value (47.5) whereas, oxyfluorfen 400 g/ha recorded the lowest value (2.01), which was closely followed by oxyfluorfen 300 g/ha (4.92), oxyfluorfen 250 g/ha (6.55) and oxyfluorfen 200 (7.01). Weed index is related with crop yield, so unweeded control produced lowest yield and highest WI, whereas oxyfluorfen 400 g/ha recorded lowest WI because of higher bulb yield (**Table 2)**. Similar results were found by Bera *et al.* 2012.

Table 1. Effect of different weed management practices on total weed density and dry weight in onion (pooled data)

Treatment	Weed density/m^2		Weed dry weight (g/m^2)	
	15 DAA	30 DAA	15 DAA	30 DAA
Oxyfluorfen 150 g/ha + 1HW	10.34 (106.4)	14.01 (195.8)	26.6	34.4
Oxyfluorfen 200 g/ha + 1 HW	8.87 (78.2)	11.62 (134.6)	24.3	31.4
Oxyfluorfen 250 g/ha + 1 HW	8.62 (73.8)	11.09 (122.4)	22.6	30.7
Oxyfluorfen 300 g/ha + 1 HW	8.29 (68.2)	10.26 (104.8)	21.9	27.7
Oxyfluorfen 400 g/ha + 1 HW	7.79 (60.1)	9.38 (87.4)	21.4	26.9
Pendimethalin 750 g/ha + 1 HW	9.97 (99.0)	13.87 (191.9)	26.4	33.1
Hand weeding at 15 and 30 DAP	2.86 (7.7)	3.32 (10.6)	14.1	24.3
Unweeded control	15.85 (250.8)	18.89 (356.3)	92.5	116.0
LSD (p=0.05)	1.24	2.28	2.07	2.65

Figures in the parentheses are original values which were subjected to square root transformation; DAA - Days after application

Effect on crop

Pre-emergence application of oxyfluorfen 200 g/ha recorded higher pooled bulb yield of 25.9 t/ha due to better control of weeds at critical stages thus providing the favourable environment for better growth and development leading to enhanced bulb

Table 2. Effect of different weed management practices on weed control efficiency (WCE%) and bulb yield of onion (pooled data)

Treatment	WCE (%)		WI (%)	Bulb yield (t/ha)	Net production value NPV)
	15 DAA	30 DAA			
Oxyfluorfen 150 g/ha + 1HW	71.19	70.31	26.31	20.56	1.83
Oxyfluorfen 200 g/ha + 1 HW	73.78	72.93	7.01	25.94	2.79
Oxyfluorfen 250 g/ha + 1 HW	75.52	73.55	6.55	26.07	2.66
Oxyfluorfen 300 g/ha + 1 HW	76.29	76.14	4.92	26.52	2.59
Oxyfluorfen 400 g/ha + 1 HW	76.86	76.84	2.01	27.33	2.45
Pendimethalin 750 g/ha + 1 HW	71.45	71.42	21.04	22.02	2.28
Hand weeding at 15 and 30 DAP	84.71	79.01	0.00	27.89	1.98
Unweeded control	0.00	0.00	47.51	14.64	1.11
LSD(p=0.05)	-	-	-	2.48	-

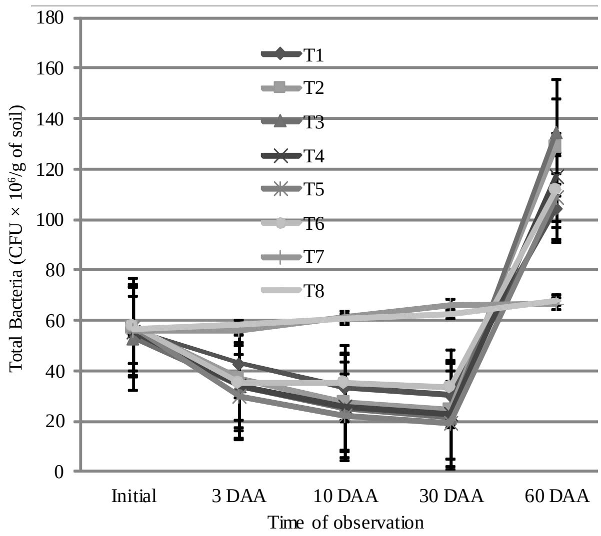
yield. Higher doses of oxyfluorfen at 250, 300 and 400 g/ha showed statistical higher bulb yield in both the years as compared with oxyfluorfen 200 g/ha. Hand weeding at 15 and 30 days was the best treatment compared all doses of oxyfluorfen and recorded highest bulb yield. The productivity of onion is mainly decided by the weed control efficiency of weed management methods as earlier observed by Uygur *et al.* (2010).

Microbial properties

Total bacteria (10^6 cfu/g): At the initial stage, there was no significant influence on the population of total bacteria in rhizosphere of onion. Significant variations of the bacterial population were found between the treated and non-treated plots after application of herbicides and the population decreased up to 30 DAA. After 60 DAA, the population increased considerably in the herbicidal treated plots as compared to hand weeding and untreated control plots (**Figure 1**). At 60 DAA, herbicidal treatments recorded 50.49 to 97.57% higher population of total bacteria than control.

Actinomycetes (10^5 cfu/g): Similar types of variations in actinomycetes population were recorded between the herbicide treated plots and the hand weeding and control plots after application of herbicides (**Figure 2**). At 60 DAA, herbicidal treatments recorded 15.29% to 39.49% higher population of actinomycetes than control. Similar findings were reported by Sapundjieva *et al.* (2008).

Fungi (10^4 cfu/g): Up to one month after application of the herbicides, slight adverse effect on the population of fungi in rhizosphere region was observed. The data showed increase in population and higher than the initial population of the fungi at 60 DAA. Further higher fungi population was recorded in all the herbicide treated plots than hand weeding and untreated control plots (**Figure 3**). Herbicidal treatments recorded 24.5% to 61.8% higher population of fungi than control at 60 DAA. However total bacteria, fungi and actinomycetes did not vary significantly in all the doses of the herbicide Having the ability to degrade herbicides, microorganisms utilize them as a source of biogenic elements for their own physiological processes. As herbicides have toxic effects on microorganisms; they reduce their abundance, activity and consequently, the diversity of their communities before degradation. Immediately after application, the toxicity of herbicides is normally most severe as their concentration in soil is highest. With advancement of time, microorganisms degraded the herbicides and their concentration and toxic effect gradually declined up to half-life. After that, carbon released from degraded organic herbicide leads to an increase of the soil microflora population (Bera and Ghosh 2013).



T_1-Oxyfluorfen 23.5% EC at 150 g/ha + 1 HW, T_2-Oxyfluorfen 23.5% EC at 200 g/ha + 1 HW , T_3-Oxyfluorfen 23.5% EC at 250 g/ha + 1 HW, T_4-Oxyfluorfen 23.5% EC at 300 g/ha+ 1 HW, T_5-Oxyfluorfen 23.5% EC at 400 g/ha + 1 HW, T_6-Pendimethalin 30% EC at 750 g/ha + 1 HW, T_7-Hand weeding at 15 and 30 DAP, T_8-Unweeded control. *Bars represent the standard error.

Fig. 1. Influence of treatments on total bacteria (CFU x 10^6/g of soil)

Table 3. Residual effect of oxyfluorfen on the plant population and seed yield and stover yield of succeeding crop (black gram) of onion

Treatment	Plant population/m² at 30 DAS			Seed yield (t/ha)		Stover yield (t/ha)	
	2012-13	2013-14	Pooled	2012-13	2013-14	2012-13	2013-14
Oxyfluorfen 150 g/ha + 1HW	5.73(32.3)*	5.67(31.7)	5.70(32.0)	1.162	1.168	2.174	2.093
Oxyfluorfen 200 g/ha + 1 HW	5.79(33.0)	5.58(30.7)	5.70(32.0)	1.151	1.179	2.238	2.238
Oxyfluorfen 250 g/ha + 1 HW	5.67(31.7)	5.73(32.3)	5.70(32.0)	1.162	1.199	2.274	2.289
Oxyfluorfen 300 g/ha + 1 HW	5.73(32.3)	5.64(31.3)	5.67(31.7)	1.206	1.258	2.391	2.331
Oxyfluorfen 400 g/ha + 1 HW	5.58(30.7)	5.64(31.3)	5.61(31.0)	1.214	1.269	2.463	2.375
Pendimethalin 750 g/ha + 1 HW	5.79(33.0)	5.79(33.0)	5.79(33.0)	1.166	1.113	2.103	2.063
Hand weeding 15 and 30 DAP	5.58(30.7)	5.73(32.3)	5.67(31.7)	1.345	1.154	2.078	2.166
Unweeded control	5.49(29.7)	5.58(30.7)	5.55(30.3)	1.066	1.061	2.055	2.001
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS

Data given in parentheses are original values subjected to square root transformation

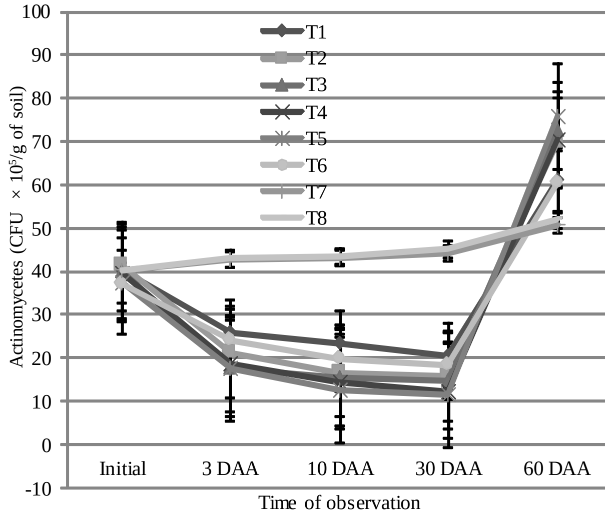


Fig. 2. Influence of treatments on actinomycetes (CFU x 10^5/g of soil)

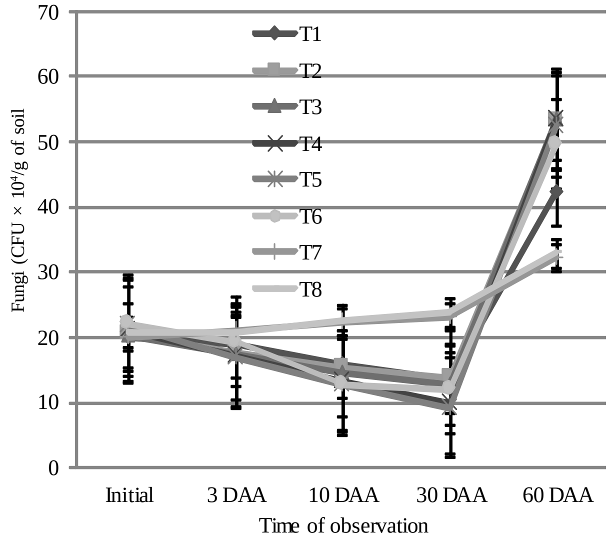


Fig. 3. Influence of treatments on fungi (CFU x 10^4/g of soil)

Net production value (NPV): Highest NPV was noted under oxyfluorfen 200 g/ha coupled with hand weeding at 30 DAP (pooled NPV = 2.79) owing to higher seed yield and comparatively lower cost under this treatment (**Table 2**). Whereas the lowest NPV was noted in control (pooled NPV = 1.11). Though twice hand weeding treatment recorded highest yield but it failed to obtain most profitable result with respect to net production value (pooled NPV = 1.98) due to higher cost of cultivation particularly labour wages.

Effect on succeeding crop: Result revealed that the population of succeeding blackgram recorded at 30 DAS was not significantly affected by residual effect of herbicide applied to irrigated onion. Yield of blackgram showed no distinct variation due to different dose of oxyfluorfen. This was corroborated with the findings of Priya *et al.* (2012).

It was concluded that onion - blackgram crop sequence can be grown in Gangetic uplands of South West Bengal and oxyfluorfen 200 g/ha could be used for the weed management in onion as an alternative of traditional costly hand weeding in spite of 7.54% less yield in this treatment (2.78), which was also superior over the hand weeding twice (1.98) as it gives higher NPV.

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Indian Journal of Weed Science **49**(1): 51–57, 2017
DOI: 10.5958/0974-8164.2017.00013.2

Weed management in turmeric

S.S. Rana*, Neelam Sharma, D. Badiyala and Rajinder Kumar
Department of Agronomy, Forages and Grassland Management, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh 176 062

Received: 24 January 2017; Revised: 18 March 2017

ABSTRACT

Pre-emergence metribuzin 0.7 kg/ha, pendimethalin 1.0 kg/ha and atrazine 0.75 kg/ha each followed by i) hand weeding (HW) (45 and 75 DAP, days after planting), ii) fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha (45 DAP) and iii) mulch + HW (75 DAP); pre-emergence oxyflourfen 0.3 kg/ha and oxadiargyl 0.25 kg/ha and post-emergence glyphosate 1.23 and 1.85 kg/ha (25 DAP) each followed by HW (45 and 75 DAP); HW (25, 45 and 75 DAP) and untreated control were evaluated at Palampur during 2014, 2015 and 2016 to develop an effective weed management strategy in turmeric for mid hill conditions of Himachal Pradesh. Treatments constituting fenoxaprop + metsulfuron-methyl were phyto-toxic resulting in poor turmeric crop canopy formation thereby more growth of *Ageratum* sp. and lower plant height, plant stand, daughter corms/mother corm, rhizome yield and economics. Other weed control treatments were effective in controlling *Echinochloa colona* and other grassy weeds. With every g/m^2 increase in weed dry weight, the fresh turmeric rhizome yield was reduced by 64.2 kg/ha. Pre-emergence atrazine/metribuzin/pendimethalin *fb* mulch *fb* hand weeding had effectively controlled weeds and increased the fresh rhizome yield by 54.1 to 54.9%, cured rhizome yield by 57.6 to 59.4% and net return by 66.4 to 68.3% being comparable to hand weeding thrice. However, hand weeding thrice was the costliest treatment. Atrazine/metribuzin/pendimethalin *fb* mulch *fb* hand weeding had lower weed persistence index and weed index and higher weed management index, agronomic management index, integrated weed management index and overall impact index than other treatments. Residues of metribuzin, atrazine, pendimethalin, oxyfluorfen and metsulfuron –-methyl in soil and rhizomes of turmeric were found below detectable level. Based on overall impact index metribuzin *fb* mulch *fb* hand weeding, atrazine *fb* mulch *fb* hand weeding and pendimethalin *fb* mulch *fb* hand weeding in that order are recommended as an alternative to hand weeding thrice in turmeric.

Key words: Impact, Herbicides, Loss, Turmeric, Weed management, Yield

India is the largest turmeric producer, consumer and exporter. Turmeric is the most important spice crop of low and mid hill areas of Himachal Pradesh. It is finding an important place as an alternative to maize particularly in wild boars, stray animals and porcupines infested areas. It is a long duration slow growing crop. Turmeric takes a long time to emerge and develop a canopy structure sufficient to compete with weeds. Thus it is invaded by a variety of summer and winter annuals as well as perennial weeds. Weeds compete with crop for nutrients, moisture and space and cause 35-80% (Krishnamurthy and Ayyaswamy 2000, Kaur *et al.* 2008) or even higher (Tadesee Eshetu *et al.* 2015) yield reduction. Non availability of labour hinders the timely removal of weeds. Use of straw and tree leaves as mulch in turmeric is another approach adopted by farmers that conserve soil moisture and moderates soil temperature for the benefit of crop (Mahey *et al.* 1986, Kaur *et al.* 2008, Manhas *et al.* 2011), besides controlling weeds (Hossain 2005). Pre-emergence application of pendimethalin (Kumar and Reddy 2000, Channappagoudar *et al.* 2013), atrazine (Singh and Mahey 1992), metribuzin (Gill *et al.* 2000), oxyflourfen or oxadiargyl save the crop from severe weed competition at an early stage. However, sole dependence on any single method may not provide an effective weed management in a long duration crop like turmeric. Integration of herbicides and mulches (Dillon and Bhullar 2014; Kaur *et al.* 2008) or herbicides and hand weeding/hoeing (Kaur *et al.* 2008, Singh *et al.* 2002) or application of pre- and post-herbicides sequentially (Barla *et al.* 2015) have been adjudged as the best practices for managing weeds in turmeric. Keeping these points in view, a study was initiated to develop an effective weed management strategy in turmeric for the mid-hill conditions of Himachal Pradesh.

*Corresponding author: ranassdee@gmail.com

MATERIALS AND METHODS

The field experiment was conducted for three consecutive years of 2014, 2015 and 2016 at the Research Farm of Department of Agronomy, Forages and Grassland Management in randomized block design to evolve herbicide based integrated weed management schedule in turmeric. The experimental soil was silty clay loam in texture, acidic in reaction, medium in available nitrogen, phosphorus and high in available potassium. The treatments consisted of pre-emergence application of metribuzin 0.7 kg/ha *fb* (followed by) hand weeding at 45 and 75 DAP; pre-emergence metribuzin 0.7 kg/ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha at45 DAP; pre-emergence metribuzin 0.7 kg/ha *fb* straw mulch 5 t/ha (5-10 DAP) *fb* hand weeding at 75 DAP; pre-emergence pendimethalin 1.0 kg/ha *fb* hand weeding at45 and 75 DAP; pre-emergence pendimethalin 1.0 kg/ha *fb* fenoxaprop 67g/ha + metsulfuron-methyl 4 g/ha at 45 DAP; pre-emergence pendimethalin 0.7 kg/ha *fb* straw mulch 5 t/ha at 5-10 DAP *fb* hand weeding at75 DAP, pre-emergence atrazine 0.75 kg/ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha at 45 DAP, pre-emergence atrazine 0.75 kg/ha *fb* straw mulch 5 t/ha at 5-10 DAP *fb* hand weeding at 75 DAP; pre-emergence oxyflourfen 0.30 g/ha *fb* hand weeding at 45 and 75 DAP, pre-emergence oxadiargyl *fb* hand weeding at 45 and 75 DAP; glyphosate 1230 g/ha *fb* hand weeding at 45 and 75 DAP; glyphosate 1845 g/ha *fb* hand weeding at 45 and 75 DAP, hand weeding at 25, 45 and 75 DAP and weedy check (**Table 1**). Turmeric variety '*Palampur Pitamber*' was planted on July 1, 2014, May 15, 2015 and May 31, 2016 with recommended package of practices except treatments. The crop was harvested on 15 January 2015, 25 December 2015 and 19 December 2016. Herbicides were applied with knapsack power sprayer using 600 L water per hectare. Data on density and dry weight of weeds were recorded one month after the treatments imposed.

The data obtained were subjected to statistical analysis by analysis of variance (ANOVA) for the randomized block design to test the significance of the overall differences among the treatments by the "F" test and conclusion was drawn at 5% probability level. Standard error of mean was calculated in each case. When the 'F' value from analysis of variance tables was found significant, the least significant difference was computed to test the significance of the difference between the two treatments. The data on weed count and dry weight were subjected to square root transformation ($\sqrt{x+0.5}$). The economic threshold (=economic injury level), the weed density at which the cost of treatment equals the economic benefit obtained from that treatment, was calculated after Rana and Kumar (2014) as below:

Economic threshold = Gain threshold/Regression coefficient

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

The different impact indices were worked out after Rana and Kumar (2014) as follow:

$$WPI = \frac{\textit{Weed weight in treated plot}}{\textit{Weed weight in control plot}}\ x\ \frac{\textit{Weed count in control plot}}{\textit{Weed count in treated plot}}$$

Weed management index (WMI)

$$WMI = \frac{\textit{Percent yield over control}}{\textit{Percent control of the pest}}$$

Agronomic management index (AMI)

$$AMI = \frac{\textit{Percent yield over control} - \textit{Percent control of the pest}}{\textit{Percent control of the pest (weed)}}$$

Integrated Management index (IWMI)

$$IWMI = \frac{WMI + AMI}{2}$$

Efficiency index (EI)

$$EI = \frac{\frac{\textit{Yield of treatment} - \textit{Yield of control}}{\textit{Yield of control}}\ x\ 100}{\frac{\textit{Weed weight in treatment}}{\textit{Weed weight in control}}\ x\ 100}$$

Additionally 'overall impact index' based on weed control efficiency, yield and economic parameters was determined, by calculating firstly the 'comparable unit value' where the value under a particular treatment of a parameter was divided by the respective arithmetic mean value of treatments for that parameter as given below:

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

Where U_{ij} is the unit value for i^{th} treatment corresponding to j^{th} parameter, V_{ij} is the actual measured value for i^{th} treatment and j_{th} parameter and AM_j is the arithmetic mean value for j^{th} parameter.

Secondly, the overall impact index was calculated as an average of unit values (U_{ij}) of all the parameters under consideration:

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

where OI_i is the overall impact index for i^{th} treatment and N is the number of parameters considered in deriving the index.

Soil and turmeric rhizome samples were collected at harvest to determine the residue of the applied herbicides. The residues of metribuzin, pendimethalin, atrazine and oxyflourfen were quantified on GC equipped with electron capture detector. Metsulfuron-methyl was analyzed using Shimadzu HPLC.

RESULTS AND DISCUSSION

Effect on weeds

The major weeds of the experimental field were *Echinochloa colona, Digitaria sanguinalis, Panicum dichotomiflorum, Commelina benghalensis, Cyperus iria, Ageratum* sp. (*A. conyzoides, A. houstonianum*) *Polygonum* sp., *Physalis minima, Bidens pilosa* and *Aeschynomene indica*. Weed control treatments brought about significant variation in the count of *Echinochloa colona* (**Table 1**). All the weed control treatments except atrazine 750 g/ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha and metribuzin *fb* hoeing significantly reduced the population of *Echinochloa colona* and other grassy weeds over weedy check. Metribuzin *fb* straw mulch *fb* hoeing, pendimethalin *fb* hoeing, pendimethalin *fb* fenoxaprop + metsulfuron-methyl, pendimethalin *fb* straw mulch *fb* hoeing and atrazine *fb* straw mulch *fb* hoeing were as good as weed free in reducing the population of *E. colona* and other grassy weeds.

Weed control treatments could significantly affect the count of *Ageratum* sp. during 2015 and 2016. Metribuzin 700 g/ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha, pendimethalin *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha and atrazine *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha had completely eliminated *Ageratum* up to 60 DAP. Lateron *Ageratum* appeared in large number. Thus in most of the treatments, its count were either equal or higher than weedy check. In the weedy check, count of *Ageratum* was maximum at 60 DAS and decreased thereafter probably owing to intra- or inter-specific competition. The trend in the count of other weeds was similar as *Ageratum* sp. However,

Table 1. Effect of weed control treatments on count (no/m²) of weeds

Treatment	Dose (kg/ha, t/ha)	Time (DAP)	*Echinochloa* sp. 2015	*Echinochloa* sp. 2016	Other grassy weeds 2015	Other grassy weeds 2016	*Ageratum* 2015	*Ageratum* 2016	Other broad-leaf weeds 2015	Other broad-leaf weeds 2016
Metribuzin *fb* two hand weeding	700	0-2, 45, 75	4.57 (14.0)	1.6 (2.0)	2.62 (5.9)	2.3 (5.3)	4.2 (15.4)	3.5 (13.0)	2.28 (4.3)	0.7 (0.0)
Metribuzin *fb* fenoxaprop + metsulfuron	700, 67 + 4	0-2, 45	3.50 (11.2)	2.6 (6.7)	3.76 (13.2)	4.5 (20.7)	1.0 (0.0)	18.7 (350.0)	2.21 (3.9)	0.7 (0.0)
Metribuzin *fb* straw mulch *fb* HW	700, 5	0-2, 0-5, 75	1.51 (1.3)	1.2 (1.0)	1.0 (0.0)	3.9 (15.0)	1.7 (1.9)	1.2 (1.0)	1.87 (2.5)	0.7 (0.0)
Pendimethalin *fb* 2 HW	1000	0-2, 45, 75	1.48 (1.2)	1.3 (1.3)	1.0 (0.0)	2.4 (5.3)	3.6 (12.0)	4.9 (24.0)	4.31 (17.6)	2.3 (8.7)
Pendimethalin *fb* fenoxaprop + metsulfuron	1000, 67 + 4	0-2, 45	2.21 (3.9)	1.9 (3.3)	1.0 (0.0)	5.2 (26.7)	1.0 (0.0)	19.5 (380.0)	2.28 (4.2)	2.6 (9.7)
Pendimethalin *fb* straw mulch *fb* HW	1000, 5	0-2, 0-5, 75	1.41 (1.0)	1.1 (0.7)	1.0 (0.0)	4.6 (21.0)	4.23 (16.9)	1.3 (1.7)	2.93 (7.6)	1.9 (4.0)
Atrazine *fb* two HW	750	0-2, 45, 75	4.18 (16.5)	1.3 (1.7)	4.33 (17.8)	2.9 (8.0)	1.0 (0.0)	4.8 (23.3)	2.62 (5.9)	1.4 (2.0)
Atrazine *fb* fenoxaprop + metsulfuron	750, 67 + 4	0-2, 45	4.08 (15.7)	1.2 (1.3)	3.86 (13.9)	5.6 (31.7)	1.51 (1.3)	18.0 (325.0)	2.21 (3.9)	1.4 (1.7)
Atrazine *fb* straw mulch *fb* HW	750, 5	0-2, 0-5, 75	2.73 (6.5)	1.7 (2.7)	3.24 (9.5)	3.8 (16.7)	3.86 (13.9)	2.6 (8.3)	2.42 (4.9)	1.0 (0.7)
Oxyfluorfen *fb 2* HW	300	0-2, 45, 75	2.30 (4.3)	2.1 (4.0)	2.5 (5.7)	3.7 (14.7)	3.30 (9.6)	5.4 (28.3)	3.25 (10.6)	3.0 (11.3)
Oxadiargyl *fb 2* HW	250	0-2, 45, 75	1.37 (2.9)	2.5 (7.0)	2.38 (4.7)	3.6 (14.3)	3.0 (8.0)	4.6 (21.7)	3.40 (9.5)	2.3 (6.3)
Glyphosate *fb 2* HW	1230	25, 45, 75	1.26 (0.6)	1.0 (0.7)	1.48 (1.2)	3.6 (15.7)	1.9 (2.6)	7.6 (68.3)	1.51 (1.3)	1.2 (1.3)
Glyphosate *fb 2* HW)	1845	25, 45, 75	1.22 (0.5)	1.2 (1.3)	1.41 (1.0)	1.7 (3.0)	1.73 (2.0)	4.3 (21.3)	1.41 (1.0)	1.9 (3.3)
Hand weeding threee	Thrice	25, 45, 75	1.26 (0.6)	0.9 (0.3)	1.73 (2.0)	1.7 (3.0)	2.52 (3.1)	4.2 (23.3)	1.73 (2.0)	0.9 (0.3)
Weedy check			5.41 (28.3)	3.6 (12.7)	5.68 (31.3)	10.2 (103.3)	4.92 (23.5)	1.7 (3.0)	4.41 (18.5)	1.8 (3.0)
LSD (p=0.05)			1.59	1.0	0.39	1.6	0.37	2.8	0.11	NS

Herbicide, kg/ha; Mulch, t/ha; Figures in parentheses are the means of original values; Data transformed to square root transformation ($\sqrt{x+1}$); DAP - Days after planting treatment differences were not significant during 2016. This indicated contiguous or sporadic distribution of the weeds rather than uniform. Moreover, under Palampur conditions *Ageratum* usually appears by end of July or August in the available vacant space created after weeding or herbicidal control of other weeds. The lasting control of *Ageratum* is seldom achieved with pre-emergence herbicidal treatment only, so post emergence directed application is recommended.

Significantly highest total weed count (**Table 2**) was recorded under weedy check during 2014 and 2015. However, due to phytotoxicity of fenoxaprop + metsulffuron-methyl and subsequent higher emergence of *Ageratum*, total weed count under metribuzin/pendimethalin/atrazine *fb* fenoxaprop + metsulfuron treated plots was tremendously higher than other treatments as well as untreated check. However, other treatments resulted in significantly lower weed count than weedy check. Almost similar trend was observed with respect to dry weight of weeds where significantly minimum dry weight of weeds was recorded in metribuzin 700 g/ha *fb* hoeing remaining at par with pendimethalin 1000 g/ha *fb* hoeing and weed free treatment. Similar trend was observed with respect to weed control efficiency. The superior control of weeds due to integration of herbicides and mulches (Dillon and Bhullar 2014, Kaur *et al.* 2008) or herbicides and hand weeding/ hoeing (Kaur *et al*. 2008, Singh *et al*. 2002) or application of pre and post herbicides sequentially (Barla *et al.* 2015) in turmeric has been documented.

Effect on crop

There was significant variation in plant population due to treatments at harvest (**Table 3**). Due to phytotoxicity, pendimethalin/atrazine/ metribuzin *fb* fenoxaprop + metsulfuron-methyl resulted in significantly lower plant stand over the other treatments at harvest. The other treatments did not significantly differ from each other. Atrazine/ metribuzin/pendimethalin *fb* mulch *fb* hand weeding resulted in significantly higher daughter rhizomes over other treatments. Owing to phytotoxicity, metribuzin/pendimethalin/atrazine *fb* fenoxaprop + metsulfuron-methyl had significantly lower daughter rhizomes/mother rhizome over the other treatments. Oxyflourfen *fb* hand weeding also had lower rhizomes than hand weeding thrice or untreated

Table 2. Effect of treatments on total weeds count (no./m²), total weed dry weight accumulation (g/m²) and weed control efficiency

Treatment	Dose (g/ha; t/ha)	Time (DAP)	Total weed count (no./m2)				Total weed dry matter (g/m2)				WCE (%)			
			2014	2015	2016	Mean	2014	2015	2016	Mean	2014	2015	2016	Mean
Metribuzin *fb* two hand weeding	700	0-2, 45, 75	6.86 45.7)	6.37 (39.6)	4.4 (20.3)	5.9 (35.2)	4.94 (23.5)	6.04 (35.6)	4.4 (19.0)	5.1 (26.0)	65.9	62.5	95.3	86.2
Metribuzin *fb* fenoxaprop + metsulfuron	700, 67 + 4	0-2, 45	5.84 (33.20	5.41 (28.3)	19.4 (377.3)	10.2 (146.3)	1.70 (19.2)	4.92 (23.2)	17.6 (308.3)	9.0 (116.9)	72.1	75.6	23.2	38.0
Metribuzin *fb* straw mulch *fb* HW	700, 5	0-2, 0-5, 75	2.86 (7.2)	2.58 (5.7)	4.2 (17.0)	3.1 (10.0)	2.30 (4.3)	2.66 (6.1)	3.9 (16.7)	3.0 (9.0)	93.7	93.5	95.9	95.2
Pendimethalin *fb* 2 HW	1000	0-2, 45, 75	6.33 39.1)	5.64 (30.8)	6.3 (39.3)	6.1 (36.4)	4.72 (21.3)	5.21 (26.2)	5.4 (29.0)	5.1 (25.5)	69.0	72.5	92.8	86.5
Pendimethalin *fb* fenoxaprop + metsulfuron	1000, 67 + 4	0-2, 45	5.50 29.2)	5.05 (24.6)	20.5 (419.7)	10.3 (157.8)	4.27 17.2)	4.69 (21.0)	17.7 (314.3)	8.9 (117.5)	75.8	77.9	21.7	37.7
Pendimethalin *fb* straw mulch *fb* HW	1000, 5	0-2, 0-5, 75	4.07 (15.6)	6.41 (40.1)	5.3 (27.3)	5.2 (27.7)	1.31 (7.3)	3.40 (10.6)	5.6 (33.3)	4.0 (17.1)	89.4	88.8	91.7	90.9
Atrazine *fb* two HW	750	0-2, 45, 75	6.64 (43.1)	6.30 (38.8)	5.9 (35.0)	6.3 (39.0)	5.22 (26.3)	5.58 (30.2)	4.3 (18.3)	5.0 (24.9)	61.6	68.3	95.4	86.8
Atrazine *fb* fenoxaprop + metsulfuron	750, 67 + 4	0-2, 45	6.28 (38.5)	5.98 (34.8)	19.0 (59.7)	10.4 (144.3)	4.76 (21.9)	5.10 25.1)	17.4 (301.7)	9.1 (116.2)	68.2	73.6	24.9	38.4
Atrazine *fb* straw mulch *fb* HW	750, 5	0-2, 0-5, 75	6.50 41.3)	5.98 (34.8)	5.1 (28.3)	5.9 (34.8)	4.58 20.0)	4.82 (22.2)	4.4 (20.0)	4.6 (20.7)	70.9	76.7	95.0	89.0
Oxyfluorfen *fb 2* HW	300	0-2, 45, 75	5.86 (33.4)	5.59 (30.2)	7.5 (58.3)	6.3 (40.6)	4.79 (22.0)	5.31 (27.1)	5.2 (26.7)	5.1 (25.3)	68.0	71.5	93.4	86.6
Oxadiargyl *fb 2* HW	250	0-2, 45, 75	5.48 (29.1)	5.10 (25.6)	6.8 (49.3)	5.9 (34.7)	3.94 14.6)	4.50 (19.2)	5.6 (31.7)	4.7 (21.8)	78.8	79.8	92.1	88.4
Glyphosate *fb 2* HW	1230	25, 45, 75	3.22 (9.4)	2.58 (5.7)	8.5 (86.0)	5.0 (33.7)	4.02 (15.2)	4.25 (17.1)	5.4 (31.7)	4.6 (21.3)	77.9	82.0	92.1	88.7
Glyphosate *fb 2* HW)	1845	25, 45, 75	2.68 (6.2)	2.34 (4.5)	5.1 (29.0)	3.4 (13.2)	2.19 (3.8)	3.19 (9.2)	4.4 (20.0)	3.2 (11.0)	94.4	90.3	95.0	94.2
Hand weeding threee		25, 45, 75	2.50 (5.3)	2.94 (7.7)	4.8 (27.0)	3.5 (13.3)	2.0 (3.0)	1.97 (2.9)	4.1 (16.7)	2.6 (7.5)	95.6	96.7	95.9	96.0
Weedy check			8.08 (63.6)	10.12 (101.6)	11.1 (122.0)	9.7 (95.7)	8.36 (68.9)	9.81 (95.3)	20.1 (401.7)	12.7 (188.6)	0.0	0.0	0.0	0.0
LSD (p=0.05)			1.74	0.45	2.8	2.7	2.14	1.54	1.8	3.2	-	-		

Herbicide, kg/ha; Mulch, t/ha; Figures in parentheses are the means of original values; Data transformed to square root transformation ($\sqrt{x+1}$)

control. The rest of the treatments were comparable to hand weeding or weedy check in influencing daughter rhizomes/mother rhizome (**Table 3**). The weed control treatments brought about significant variation in the rhizome yield. All treatments were significantly superior to weedy check in influencing fresh rhizome yield. Metribuzin 700 g/ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha, pendimethalin *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha and atrazine *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha were phytotoxic. The canopy formation could not take place and lately in these treatments *Ageratum* appeared prolifically. The yield was lower than other treatments probably owing to toxicity induced by the application of metsulfuron–methyl. This was in confirmation to earlier findings at this centre (Sachdeva *et al.* 2015). Barla *et al.* (2015) also reported toxicity of these treatments in turmeric at Birsa Agricultural University, Ranchi. Mulch proved to be the extremely important practice as the treatments constituting the straw mulch *viz*. pendimethalin/metribuzin/atrazine *fb* mulch *fb* hoeing resulted in significantly higher fresh rhizome yield over other treatments. Swain *et al.* (2007) also reported significantly higher fresh weight of rhizome per plant with application of paddy straw mulch as compared to no mulch. Weeds in unweeded check reduced the rhizome yield by 77.6% over the best treatment *i.e*. metribuzin/pendimethalin *fb* straw mulch *fb* hoeing. Metribuzin/pendimethalin/atrazine *fb* mulch *fb* hoeing increased fresh rhizome yield by three times over weed free. The corresponding cured rhizome yield under these treatments was also three times higher over weed free. The treatments metribuzin/pendimethalin *fb* hoeing was comparable to weed free in influencing the fresh and cured rhizome yield. The reduction in yield with increasing weed density has also been reported by Hossain *et al.* (2008).

Impact assessment

The economic threshold levels of weeds at the current prices of treatment and crop production on the basis of weed infestation in turmeric are given in **Table 4**. The economic threshold levels with the weed management practices studied varied between 4.8 to 11.2 g/m^2. It is clearly indicated that any increase in the cost of treatment would lead to higher value of economic threshold whereas an increase in price of crop produce would result in lowering the economic threshold. Hand weeding thrice had higher cost tending to increase the economic threshold more than the integrated weed management treatments. The linear relationship between weed dry weight (x) and fresh rhizome yield (Y) of turmeric is given here as under,

$$Y= 14132 - 64.2x \quad .... \quad (R^2= 0.602)$$

The equation explains that 60.2% variation in fresh rhizome yield due to weed dry weight could be explained by the regression equation. With every one gram per m^2 increase in weed weight, the fresh rhizome yield was expected to fall by 64.2 kg/ha.

Due to higher rhizome yield gross returns were highest following the application of atrazine *fb* mulch *fb* hand weeding. This was followed by metribuzin *fb*

Table 3. Effect of treatments on fresh and cured rhizome yield (t/ha)

Treatment	Dose (g/ha)	Time (DAT)	Daughter rhizome/ mother rhizome	Plant population (no./m^2)	Fresh rhizome yield (t/ha)				Cured rhizome yield (t/ha)			
			2016	2016	2014	2015	2016	Mean	2014	2015	2016	Mean
Metribuzin *fb* two hand weeding	700	0-2, 45, 75	3.6	9.7	12.2	8.6	15.4	12.1	7.5	5.3	9.5	7.4
Metribuzin *fb* fenoxaprop + metsulfuron	700, 67 + 4	0-2, 45	0.8	6.2	3.6	5.4	1.7	3.6	2.6	3.8	1.2	2.5
Metribuzin *fb* straw mulch *fb* HW	700, 5	0-2, 0-5, 75	4.8	9.5	16.7	15.9	18.2	16.9	10.9	11.0	12.6	11.5
Pendimethalin *fb* 2 HW	1000	0-2, 45, 75	3.7	9.8	11.2	9.6	13.3	11.4	7.8	6.5	9.0	7.8
Pendimethalin *fb* fenoxaprop + metsulfuron	1000, 67 + 4	0-2, 45	1.0	5.9	4.2	5.3	2.0	3.8	3.2	3.3	1.3	2.6
Pendimethalin *fb* straw mulch *fb* HW	1000, 5	0-2, 0-5, 75	4.7	9.8	17.4	14.8	18.2	16.8	11.2	10.0	12.3	11.2
Atrazine *fb* two HW	750	0-2, 45, 75	3.9	10.1	11.2	5.0	17.0	11.1	8.1	3.2	10.9	7.4
Atrazine *fb* fenoxaprop + metsulfuron	750, 67 + 4	0-2, 45	1.1	6.0	3.5	4.6	1.6	3.2	2.1	2.6	0.9	1.9
Atrazine *fb* straw mulch *fb* HW	750, 5	0-2, 0-5, 75	5.4	9.4	16.5	11.2	22.2	16.6	12.1	8.5	14.4	11.7
Oxyfluorfen *fb 2* HW	300	0-2, 45, 75	2.7	9.5	11.5	10.9	10.9	11.1	8.9	8.4	7.3	8.2
Oxadiargyl *fb 2* HW	250	0-2, 45, 75	3.7	9.5	14.3	11.7	15.4	13.8	9.8	8.9	10.1	9.6
Glyphosate *fb 2* HW	1230	25, 45, 75	3.3	9.6	11.4	8.5	12.5	10.8	5.9	4.5	6.6	5.7
Glyphosate *fb 2* HW)	1845	25, 45, 75	3.4	9.9	11.9	8.9	11.3	10.7	6.2	4.9	6.2	5.8
Hand weeding threee		25, 45, 75	3.8	9.9	13.7	13.4	15.8	14.3	11.1	11.0	9.8	10.6
Weedy check			3.7	9.5	7.9	2.9	12.1	7.6	4.9	1.8	7.5	4.7
LSD (p=0.05)			0.9	1.5	4.1	2.8	5.0	4.1	3.0	2.1	3.2	2.7

Herbicide, kg/ha; Mulch, t/ha; Values given in parentheses are the means of original values

Table 4. Effect of treatments on economics and impact indices

Treatment	Dose (g/ha, t/ha)	Time (DAP)	GR	COC	NR	B:C	WI	WPI	WMI	AMI	IWMI	TEI	OIi	Gt	Et
Metribuzin *fb* two hand weeding	700	0-2, 45, 75	353083	98237	254847	2.59	3.1	0.38	1.82	0.45	1.14	4.13	1.04	311	7.1
Metribuzin *fb* fenoxaprop + metsulfuron	700, 67 + 4	0-2, 45	120333	93557	26777	0.29	87.8	0.41	1.41	0.29	0.85	-0.75	0.41	230	5.2
Metribuzin *fb* straw mulch *fb* HW	700, 5	0-2, 0-5, 75	546250	98587	447663	4.54	-28.6	0.46	2.55	0.61	1.58	29.89	1.55	317	7.2
Pendimethalin *fb* 2 HW	1000	0-2, 45, 75	368917	99062	269855	2.72	8.2	0.36	1.90	0.47	1.19	4.74	1.06	326	7.4
Pendimethalin *fb* fenoxaprop + metsulfuron	1000, 67 + 4	0-2, 45	123500	93182	30318	0.33	86.7	0.38	1.46	0.31	0.89	-0.72	0.43	223	5.1
Pendimethalin *fb* straw mulch *fb* HW	1000, 5	0-2, 0-5, 75	530417	100612	429805	4.27	-25.5	0.31	2.59	0.61	1.60	15.01	1.50	353	8.0
Atrazine *fb* two HW	750	0-2, 45, 75	351500	97877	253623	2.59	-11.2	0.32	1.80	0.44	1.12	4.26	1.01	305	6.9
Atrazine *fb* fenoxaprop + metsulfuron	750, 67 + 4	0-2, 45	88667	92397	-3730	-0.04	90.8	0.41	1.03	0.03	0.53	-0.98	0.34	210	4.8
Atrazine *fb* straw mulch *fb* HW	750, 5	0-2, 0-5, 75	554167	98627	455540	4.62	-46.9	0.30	2.77	0.64	1.70	13.33	1.50	318	7.2
Oxyfluorfen *fb 2* HW	300	0-2, 45, 75	389500	99912	289588	2.90	25.5	0.32	2.00	0.50	1.25	5.47	1.10	340	7.7
Oxadiargyl *fb 2* HW	250	0-2, 45, 75	456000	98300	357700	3.64	-3.1	0.32	2.29	0.56	1.43	8.89	1.29	312	7.1
Glyphosate *fb 2* HW	1230	25, 45, 75	269167	96908	172259	1.78	32.7	0.32	1.35	0.26	0.80	1.74	0.91	288	6.6
Glyphosate *fb 2* HW)	1845	25, 45, 75	273917	97694	176223	1.80	36.7	0.42	1.29	0.23	0.76	3.74	0.94	302	6.9
Hand weeding threee		25, 45, 75	505083	108737	396347	3.65	0.0	0.29	2.34	0.57	1.46	31.26	1.41	494	11.2
Weedy check			224833	80337	144497	1.80	23.5	1.00	-	-	-	0.00	0.51	311	-
LSD (p=0.05)			-	-	-	-	-	-	-	-	-	-	-	-	-

Herbicide, g/ha; Mulch, t/ha; GR- gross return (`/ha); COC- cost of cultivation (`/ha); NR- net return (`/ha); B:C- benefit cost ration; WI- weed index; WPI- Weed persistence index; WMI- Weed management index; AMI- Agronomic management index; IWMI- Integrated weed management index; TEI- Treatment/herbicide efficiency index; OIi- Overall impact index; Gt- Gain threshold; Et- Economic threshold.

mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding and hand weeding thrice. Net returns followed the trend almost similar to gross returns. However, net returns under metribuzin/ pendimethalin/atrazine *fb* fenoxaprop + metsulfuron-methyl were lower than the untreated check. B:C was highest under atrazine *fb* mulch *fb* hand weeding (4.62), followed by metribuzin *fb* mulch *fb* hand weeding (4.54), pendimethalin *fb* mulch *fb* hand weeding (4.27), hand weeding thrice (3.65) and oxadiargyl *fb* hand weeding ((3.64). Weed index, a measure of the efficiency of a particular treatment as percentage of yield potential under weed free (hand weeding thrice in the present investigation) was minimum under atrazine *fb* mulch *fb* hand weeding (-46.9), followed by metribuzin *fb* mulch *fb* hand weeding (-28.6), pendimethalin *fb* mulch *fb* hand weeding (-25.5), atrazine *fb* hand weeding (-11.2) and oxadiargyl *fb* hand weeding (-3.1). The rest of the treatments had plus value of weed index indicating that much percent loss in yield under them relative to the weed free. Due to phytotoxicity, atrazine/ metribuzin/pendimethalin *fb* fenoxaprop + metsulfuron-methyl, glyphosate *fb* hand weeding and oxyflourfen *fb* hand weeding had higher weed index than untreated check. Weed persistence index was lowest under hand weeding thrice followed by atrazine *fb* mulch *fb* hand weeding and pendimethalin *fb* mulch *fb* hand weeding. Weed management index, agronomic management index and integrated weed management index were highest under atrazine *fb* mulch *fb* hand weeding followed by metribuzin *fb* mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding and hand weeding thrice. Efficiency index indicating the weed killing potential of a herbicide/treatment and its phytotoxicity on the crop, was highest under hand weeding thrice followed by metribuzin *fb* mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding and atrazine *fb* mulch *fb* hand weeding.

Since the treatments were not consistent or differed in performance with respect to the parameters studied, an overall impact index (OI_i) considering efficiency of weed control, yield and economics was drawn to have a valid inference. The overall impact index was highest for metribuzin *fb* mulch *fb* hand weeding, followed by atrazine *fb* mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding, hand weeding thrice and oxadiargyl *fb* hand weeding. Oxyflourfen *fb* hand weeding, pendimethalin *fb* hand weeding, metribuzin *fb* hand weeding and atrazine *fb* hand weeding also had higher overall impact index than the threshold value of one. The other treatments had lower overall impact index than the threshold value.

Herbicide residues

Metribuzin, pendimethalin, atrazine, oxyflourfen and metsulfuron-methyl residues in soil and turmeric samples collected at harvest were found to be below detectable levels. The sensitivity of technique was 0.001 µg/ml for metribuzin and atrazine; 0.05 ng/ml for pendimethalin and 0.01 ng/ml for oxyflourfen. Recoveries of metribuzin residues from fortified soil (0.05, 0.10 and 1.0 µg/g) and turmeric (1.00 and 2.00 µg/g) ranged from 89.2 to 98.2% in soil and 80.6 to 83.8% in rhizome. The calibration curve of pendimethalin was linear over the concentration range upto 10 mg/ml. Recoveries of pendimethalin residues from fortified soil and turmeric rhizome ranged from 79.3 to 83.8% in soil and 79.1 to 88.2%, respectively, The calibration curve was linear over the concentration range of 1 mg/ml to 10 mg/ml of atrazine and that of oxyflurofen over the concentration range of 0.01 to 10 mg/ml. The recovery of oxyflurofen residues ranged from 78.9 to 89.0% in soil and 82.9 to 90.6% in turmeric. The calibration curve showed linearity over the concentration range from 0.01 to 2 µg/ml for metsulfuron-methyl. The per cent recoveries of metsulfuron-methyl were 86.0, 83.0 and 84.2 in soil and 80.6, 79.0 and 78.0 in turmeric rhizome, respectively. The durations of persistence of glyphosate under Indian conditions are less than one month; of metribizin, oxyflourfen and metsulfuron-methyl are 1-3 months; of pendimethalin 3-6 months and of atrazine are more than 6 months (Janaki *et al.* 2015). Thus it was obvious that the herbicides used in the present investigation were below detectable level in the soil and rhizomes of turmeric.

This study concluded that in order of preference metribuzin *fb* mulch *fb* hand weeding, followed by atrazine *fb* mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding, hand weeding thrice and oxadiargyl *fb* hand weeding can be recommended for effective weed management in turmeric under mid hill conditions of Himachal Pradesh.

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Indian Journal of Weed Science **49**(1): 58–62, 2017
DOI: 10.5958/0974-8164.2017.00014.4

Herbicides and polythene mulching effects on yield of cassava

M. Nedunchezhiyan*, G. Byju[1], S.S. Veena[1] and V. Ravi[1]
ICAR-Central Tuber Crops Research Institute, Regional Centre, Bhubaneswar, Odisha 751 019

Received: 2 March 2017; Revised: 25 March 2017

ABSTRACT

A field experiment was conducted to study the effects of weed management practices on cassava under irrigated conditions in Bhubaneswar (Odisha), India for consecutive three years (2010-11 to 2012-13). The results revealed that four rounds of manual weeding at 1, 2, 3 and 4 months after planting (MAP) and black polythene mulching resulted in taller plants, more number of nodes and leaves per plant, maximum number of storage roots per plant, maximum length and girth of storage roots as well as fresh storage roots yield per plant with lower weed biomass. Mean fresh root yield due to black polythene mulching was at par with four rounds of manual weeding (at 1, 2, 3 and 4 MAP). Black polythene mulching resulted in higher dry matter partitioning efficiency and soil microbial population. The root yield decreased by 9.6%, due to pre-emergence application of oxyfluorfen + two rounds of manual weeding (at 2 and 3 MAP) treatment and 10.1% in two rounds of manual weeding (at 1 and 2 MAP) + post-emergence application of glyphosate (at 3 MAP) compared to four rounds of manual weeding (at 1, 2, 3 and 4 MAP).

Key words: Cassava, Chemical control, Mulching, Polyethene, Root yield, Weed control efficiency

The carbohydrate rich cassava (*Manihot esculenta* Crantz) is grown for food, feed and raw material for industries. Cassava is grown throughout tropics. In India, it is largely grown in states like Tamil Nadu, Kerala, Andhra Pradesh, Maharashtra, Gujarat, Odisha and North-Eastern States in a total area of 0.24 million hactares with an annual production of 9.94 million tonnes of roots (NHB 2013). In Kerala, Odisha and North-Eastern states, cassava is grown for table purpose, whereas in Tamil Nadu, Andhra Pradesh and Maharashtra states it is mainly grown for industries.

Weeds are the major crop pests in humid and sub humid tropics where adequate rainfall, temperature, high sunshine and humidity favour cassava growth (Nedunchezhiyan *et al.* 2013). Cassava plants cover the ground after three months due to initial slow growth and wide plant spacing (Srinivasan and Maheswarappa 1993). Weed infestation at early stage causes severe yield losses and it may go up to 100% (Ambe *et al.* 1992). It is one of the major constraints for cassava production. Weeding consumes about 30% of total labour input and about 150-200 man days/ha. Under irrigated conditions in India, farmers do up to 5 rounds of manual weeding for cassava (Ravindran and Ravi 2009). Chemical method of weed control can reduce the dependency on manual weeding. Herbicides are likely to become inevitable method of weed control in cassava especially where labour is scarce or expensive or farm size is large (Agahiu *et al.* 2011). Mulching suppresses the weed growth and development. Black polythene mulching even prevents germination of weed seeds by arresting sun light and solarizing the soil, while the soil remains undisturbed. Beneficial effects of black polythene mulching for weed control in widely spaced crops were reported (Halemani *et al.* 2009, Mamkagh 2009). However, information on herbicides and polythene mulching on irrigated cassava is not available. Therefore, the present study was conducted to ascertain whether high level of weed control could be obtained by combining hand weeding with the use of a pre-emergence or post-emergence herbicide, and also to compare such combined treatment with the use of black polythene ground cover as a mulch cover in cassava.

***Corresponding author:** mnedun@gmail.com
[1]ICAR- Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala 695 017

MATERIALS AND METHODS

A field experiment was carried out for consecutive three years (2010-11 to 2012-13) at the ICAR-Central Tuber Crops Research Institute, Regional Centre, Dumuduma, Bhubaneswar, Odisha under irrigated conditions on Alfisols (Typic Rhedustalfs). The experiment was laid out in a randomized block design (RBD) with three replications. The treatments consisted of weedy check, two rounds of manual weeding at 1 and 2 months after planting (MAP), four rounds of manual weeding (at 1, 2, 3 and 4 MAP), oxyfluorfen 0.06 kg/ha as pre-emergence application at 1 day after planting (DAP), oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + 1 round of manual weeding (at 3 MAP), oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + 2 rounds of manual weeding (at 2 and 3 MAP), glyphosate 2.0 kg/ha (post-emergence application at 1 MAP), one round of manual weeding (at 1 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 2 MAP), two rounds of manual weeding (at 1 and 2 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 3 MAP) and black polythene mulching. The pre-emergence herbicide oxyfluorfen 0.06 kg/ha was applied at 1 DAP cassava on the ground directly leaving the setts. Post-emergence herbicide glyphosate 2.0 kg/ha was applied directly on weeds with protection hood. Black polythene (100 µ thickness) was spread on ground to cover the ridge and furrows before planting and the ends were covered with soils. The variety '*H-226*' was planted at 75 x 75 cm spacing. In black polythene mulching treatment, cassava setts were planted after making 5 cm diameter holes with GI pipe. The crop was irrigated through drips as and when required. Irrigation was withheld 15 days before harvest. Farmyard manure (FYM) 12.5 t/ha and N-P_2O_5-K_2O 100-75-100 kg/ha was applied. FYM was incorporated in the last plough. Full dose of phosphorus (single super phosphate) and half doses of nitrogen (urea) and potassium (white potash) were applied as basal at the time of planting and the remaining half doses of nitrogen and potassium were applied three months after planting (MAP) through drip irrigation after dissolving in water with ventury system. The crop was harvested at 10 MAP. Data on weed dry biomass, yield and economics were recorded.

Data on weeds (x) were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. Data were analyzed using SAS 11.0 version. Analysis of variance (ANOVA) was carried out appropriate to the design of experiment. Treatment means were compared using least significant difference (LSD) at 5% probabilities.

RESULTS AND DISCUSSION

Weed flora and weed control efficiency

The major weed species observed in the cassava fields were one sedge - *Cyperus rotundus* L.; four grasses - *Dactyloctenium aegyptium* (L.) Beauv., *Digitaria sanguinalis* L., *Cynodon dactylon* L., *Echinochloa crusgalli* (L.) Beauv. and seven broad-leaved species - *Borreria hispida* L., *Celosia argentia* L., *Ageratum conyzoides* L., *Commelina benghalensis* L., *Cleome viscosa* L., *Mimosa pudica* L., *Phyllanthus niruri* Hook. f. In the present study on alfisols (Typic Rhedustalfs), continuous favourable moisture regimes due to drip irrigation and high rainfall resulted in sedge, grasses and broad-leaved weed species grew in flushes as soon as cassava was planted. Among weed species, *Celosia argentia* L., *Digitaria sanguinalis* L. and *Cleome viscosa* L. grew robustly and quickly, and dominated the other weed flora. Similar findings were reported in sweet potato (*Ipomoea batatas* L.) and taro (*Colocasia esculenta* Schott.) under Typic Rhedustalfs soils of Bhubaneswar, India by Nedunzhiyan *et al*. (1996) and Nedunzhiyan *et al*. (1998). *Cynodon dactylon* L. creeping on the ground remained throughout the crop growth period. After manual weeding at 3 MAP, *Synedrella nudiflora* L., *Oldenlandia corymbosa* L., *Oldenlandia biflora* L. and *Triumfetta rhomboidea* L. appeared under partial shade.

At harvest, four rounds of manual weeding (at 1, 2, 3 and 4 MAP) resulted in significantly lower weed dry biomass, due to regular and frequent removal of weeds (**Table 1**). Manual weeding either one (at 1 MAP) or two (at 1 and 2 MAP) rounds + post-emergence application of glyphosate (at 2 or 3 MAP) resulted in lower level of weed dry biomass at harvest. Black polythene mulching significantly reduced total weed dry biomass, owing to complete cover of the ground did not allow weeds to germinate and emerge. Pre-emergence application of oxyfluorfen and two rounds of manual weeding (at 2 and 3 MAP) treatments were resulted in relatively higher total weed dry weight.

Under rainfed conditions, pre-emergence herbicide with one round of manual weeding resulted in maximum yield (Tan 1988). Pre- and post-emergence herbicides were effective up to 20-30 days only (Balusamy and Pothiraj 1989).

The total dry biomass production of weeds is directly related to weed control efficiency (WCE). The WCE of different weed management methods ranged 60.9-98.5% (**Table 2**). Higher WCE of 98.5% was achieved with black polythene mulching and it was followed by 90.8% with four rounds of manual weeding (at 1, 2, 3 and 4 MAP) because of their lower weed dry biomass. Better WCE with polythene mulching was reported by Ramakrishna *et al*. (2006), Nalayini *et al*. (2009). One (at 1 MAP) or two (at 1 and 2 MAP) rounds of manual weeding + post-emergence application of glyphosate resulted in 84.3-86.9% WCE.

Cassava growth and yield

All the treatments resulted in significantly taller plants, more number of nodes and leaves per plant than weedy check (**Table 2**). Lesser weed infestation (weed dry biomass) in the above treatments reduced competition for water, nutrients and space. It was optly indicated by high WCE in the above treatments (**Table 1**).

All the weed management treatments resulted in greater number of roots/plant (**Table 2**). Two (at 1 and 2 MAP) and four rounds of manual weeding (at 1, 2, 3 and 4 MAP), black polythene mulching as well as two rounds of manual weeding (at 1 and 2 MAP) + post- emergence application of glyphosate (at 3 MAP) resulted in maximum number of roots/plant. Four rounds of manual weeding (at 1, 2, 3 and 4 MAP), black polythene mulching and pre-emergence application of oxyfluorfen + two rounds of manual weeding (at 2 and 3 MAP) resulted in longer roots with maximum girth. Significantly lower number of roots/plant, smaller and lesser girth roots was noticed with weedy check. All the weed management methods resulted in significantly higher fresh root weight than weedy check. Four rounds of manual weeding (at 1, 2, 3 and 4 MAP) and black polythene mulching resulted in maximum fresh root weight (**Table 2**).

Table 1. Weed control efficiency and nutrient uptake as influenced by weed management practices (3 years pooled analysis)

Treatment	Weed dry biomass beforehand weeding (g/m^2)	Weed dry biomass before herbicide application (g/m^2)	Weed dry biomass at harvest (g/m^2)	Total weed dry biomass (g/m^2)	Weed control efficiency (%)
Two rounds of manual weeding (at 1 and 2 MAP)	3.9 (14.2)*	-	7.1 (49.7)	8.1 (63.9)	69.9
Four rounds of manual weeding (at 1, 2, 3 and 4 MAP)	4.3 (17.8)	-	1.6 (1.7)	4.4 (18.6)	90.8
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP)	-	-	9.2 (83.0)	9.2 (83.0)	60.9
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + one rounds of manual weeding (at 3 MAP)	4.8 (22.1)	-	4.7 (21.2)	6.7 (43.3)	79.6
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + two rounds of manual weeding (at 2 and 3 MAP)	4.6 (20.2)	-	4.4 (18.0)	6.3 (38.2)	82.0
Glyphosate 2.0 kg/ha (post-emergence application at 1 MAP)	-	3.1 (8.8)	7.0 (48.3)	7.6 (57.1)	73.1
One rounds of manual weeding (at 1 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 2 MAP)	3.2 (9.1)	2.5 (5.4)	4.4 (18.8)	5.9 (33.3)	84.3
Two rounds of manual weeding (at 1 and 2 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 3 MAP)	3.8 (13.6)	2.5 (5.2)	3.2 (9.0)	5.4 (27.8)	86.9
Black polythene mulching	-	-	2.0 (3.2)	2.0 (3.2)	98.5
Weedy check	-	-	14.6 (212.4)	14.6 (212.4)	-
LSD (p=0.05)	-	-	0.4	0.5	-

*Figures in parentheses indicate original values. Data transformed to square root transformation $(\sqrt{x+1})$; MAP: Months after planting; DAP: Day after planting

Table 2. Cassava growth and yield attributes as influenced by weed management practices (3 years pooled analysis)

Treatment	Plant height (cm)	No. of nodes/ plant	No. of leaves/ plant	No. of tubers/ plant	Root length (cm)	Root girth (cm)	Fresh root weight (g/plant)
Two rounds of manual weeding (at 1 and 2 MAP)	140	121	87	8	26.0	12.7	1525
Four rounds of manual weeding (at 1, 2, 3 and 4 MAP)	162	136	102	8	32.4	15.2	2062
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP)	130	110	76	6	24.2	12.4	1395
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + one rounds of manual weeding (at 3 MAP)	145	122	86	7	30.0	13.1	1718
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + two rounds of manual weeding (at 2 and 3 MAP)	152	130	94	7	30.7	14.3	1864
Glyphosate 2.0 kg/ha (post-emergence application at 1 MAP)	137	115		6	26.4	12.8	1565
One rounds of manual weeding (at 1 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 2 MAP)	144	124	90	7	29.1	13.4	1790
Two rounds of manual weeding (at 1 and 2 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 3 MAP)	148	129	92	8	30.2	13.8	1853
Black polythene mulching	156	132	108	8	31.8	14.0	1926
Weedy check	78	53	40	4	15.4	9.1	706
LSD (p=0.05)	13	11	8	1	2.1	1.3	172

MAP: Months after planting; DAP: Day after planting

Four rounds of manual weeding (at 1, 2, 3 and 4 MAP) and black polythene mulching resulted in significantly higher root yield compared to other treatments (**Table 3**). The root yield with black polythene mulching was just 6.6% lower compared to four rounds of manual weeding (at 1, 2, 3 and 4 MAP) (**Table 3**). Effective control of weeds (**Table 1**) and marked improvement in the crop growth and yield attributes (**Table 2**) led to more root yield in these treatments (**Table 3**). Nedunzhiyan *et al.* (1998) observed negative linear relationship between dry biomass of weeds and tuber yield. The root yield of pre-emergence application of oxyfluorfen + two rounds of manual weeding (at 2 and 3 MAP) and two rounds of manual weeding (at 1 and 2 MAP) + post-emergence application of glyphosate (at 3 MAP) was comparable and were the next best treatments. The root yield was lower by 9.6% with pre-emergence application of oxyfluorfen + two rounds of manual weeding (at 2 and 3 MAP) and 10.1% with two rounds of manual weeding (at 1 and 2 MAP) + post-emergence application of glyphosate (at 3 MAP) compared to four rounds of manual weeding (at 1, 2, 3 and 4 MAP) (**Table 3**). Keeping weed free relatively for longer period improved growth parameters which reûected on yield attributes as well as root yield in the above treatments. This provides farmers alternative weed management options. Stiff weed competition at later stages in post-emergence application of glyphosate (at 1 MAP) alone or two rounds of manual weeding (at 1 and 2 MAP) and pre emergence application of oxyûuorfen alone caused signiûcant reduction in growth and yield attributes, which ûnally led to lower root yields. The root yield reduction ranged between 24.1 and 32.3% in these treatments compared to four rounds of manual weeding (at 1, 2, 3 and 4 MAP). Though number of roots/plant was not affected, root length and girth was affected by the presence of weeds in two rounds of manual weeding (at 1 and 2 MAP) treatment. Whereas, in pre-emergence application of oxyfluorfen or post-emergence application of glyphosate (at 1 MAP), all the yield attributing factors (number of roots per plant, root length and girth) were affected by the weeds. Lower cassava growth and yield attributes due to suppression of weeds led to lower root yield (59.7-71.5% reduction) in weedy check in all the years. This may be due to season long crop-weed competition in weedy check plots, which was indicated by lower WCE (**Table 1**) as well as lower cassava growth and yield attributes (**Table 2**).

Shoot yield also followed similar trend of root yield with respect to weed management methods (**Table 3**). Partitioning efficiency (root: shoot ratio) indicated that the root yield increased in parallel with the shoot yield. The root: shoot ratio of cassava in four rounds of manual weeding (at 1, 2, 3 and 4 MAP) and black polythene mulching was ≥1, which indicated that the said treatments were efficient in partitioning dry matter to the economic part (root). The partitioning efficiency of cassava plants due to pre-emergence application of oxyfluorfen + two rounds of manual weeding (at 2 and 3 MAP) and two rounds of manual weeding (at 1 and 2 MAP) + post-emergence application of glyphosate (at 3 MAP) were also higher and equal. This indicated that these weed management methods were also having higher efficacy.

Economics

Maximum cost of cultivation was incurred in four rounds of manual weeding (at 1, 2, 3 and 4

Table 3. Cassava root and shoot yield, and root: shoot ratio as influenced by weed management practices

Treatment	Fresh root yield (t/ha)				Shoot yield (t/ha)				Root: shoot ratio
	2010-11	2011-12	2012-13	Mean	2010-11	2011-12	2012-13	Mean	
Two rounds of manual weeding (at 1 and 2 MAP)	27.0	27.8	26.2	27.0	32.2	28.4	28.2	29.6	0.91
Four rounds of manual weeding (at 1, 2, 3 and 4 MAP)	38.0	34.5	36.9	36.5	35.8	33.8	34.2	34.6	1.05
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP)	25.3	23.7	25.0	24.7	27.8	26.5	27.0	27.1	0.91
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + one rounds of manual weeding (at 3 MAP)	31.7	28.7	30.7	30.4	32.6	31.9	31.5	32.0	0.95
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + two rounds of manual weeding (at 2 and 3 MAP)	35.3	30.5	33.1	33.0	34.4	32.4	34.6	33.8	0.98
Glyphosate 2.0 kg/ha (post-emergence application at 1 MAP)	30.6	25.5	26.9	27.7	29.6	30.4	30.3	30.1	0.92
One rounds of manual weeding (at 1 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 2 MAP)	31.8	30.7	32.5	31.7	32.8	33.6	32.6	33.0	0.96
Two rounds of manual weeding (at 1 and 2 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 3 MAP)	34.3	30.0	34.2	32.8	33.1	33.0	34.4	33.5	0.98
Black polythene mulching	34.4	33.1	34.9	34.1	34.2	33.5	34.3	34.0	1.00
Weedy check	13.0	13.9	10.5	12.5	14.8	13.8	14.0	14.2	0.88
LSD (p=0.05)	4.3	2.6	1.8	2.7	3.1	2.9	2.6	2.8	-

Table 4. Cassava economics as influenced by weed management practices (3 years pooled analysis)

Treatment	Cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio
Two rounds of manual weeding (at 1 and 2 MAP)	51.10	108.00	56.90	2.11
Four rounds of manual weeding (at 1, 2, 3 and 4 MAP)	69.95	146.00	76.05	2.09
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP)	34.20	98.80	64.60	2.89
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + one rounds of manual weeding (at 3 MAP)	46.05	121.60	75.55	2.64
Oxyfluorfen 0.06 kg/ha (pre-emergence application at 1 DAP) + two rounds of manual weeding (at 2 and 3 MAP)	56.25	132.00	75.75	2.35
Glyphosate 2.0 kg/ha (post-emergence application at 1 MAP)	36.75	110.80	74.05	3.01
One rounds of manual weeding (at 1 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 2 MAP)	48.55	126.80	78.25	2.61
Two rounds of manual weeding (at 1 and 2 MAP) + glyphosate 2.0 kg/ha (post-emergence application at 3 MAP)	58.40	131.20	72.80	2.25
Black polythene mulching	62.45	136.40	73.95	2.18
Weedy check	27.75	50.00	22.25	1.80
LSD (p=0.05)	3.25	7.48	5.14	0.12

*sale price of tuber ` 4/kg

MAP) treatment and it was followed by black polythene mulching (**Table 4**). Inclusion of herbicide reduced the cost of cultivation. Maximum gross return was obtained with four rounds of manual weeding (at 1, 2, 3 and 4 MAP) and it was followed by black polythene mulching. Though, higher gross return was obtained with four rounds of manual weeding (at 1, 2, 3 and 4 MAP) and black polythene mulching due to higher root yields, net returns and B:C ratio were lower because of higher human labour requirement and their wages in the former case and higher cost of black polythene in the latter case. However, net returns and B:C ratio was higher with the inclusion of herbicides which reduced the cost of cultivation (**Table 4).**

It was concluded that black polythene mulching is considered a good weed management option, where weeds are a serious problem and drip irrigation facilities are available. Pre-emergence application of oxyfluorfen (0.06 kg/ha) (1 DAP) + two hand weeding (at 2 and 3 MAP) or two hand weeding (at 1 and 2 MAP) + post-emergence application of glyphosate (2.0 kg/ha) (at 3 MAP) can be a weed management option, where labourers are scarce. However, alternative herbicides should be rotated, along with cultural management to prevent herbicide resistance weeds.

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Indian Journal of Weed Science **49**(1): 63–66, 2017
DOI: 10.5958/0974-8164.2017.00015.6

Bio-efficacy of fenoxaprop-p-ethyl for grassy weed control in onion and its residual effect on succeeding maize crop

Rohitashav Singh*, Biswajit Pramanick, A.P. Singh, Neelam, Sanjeev Kumar, Akhilesh Kumar and Gajendra Singh
G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand 263 145

Received: 15 January 2017; Revised: 1 March 2017

ABSTRACT

A field experiment was conducted during *Rabi* seasons of 2008 and 2009 at Crop Research Center of GBPUA&T, Pantnagar (Uttarakhand) to study the effect of fenoxaprop-p-ethyl 9 EC for grassy weed management in onion and its residual effect on succeeding maize crop. All treatments reduced the density of major weed species of onion and dry weight of weeds. Yield attributes and bulb yield were increased significantly over unweeded check. Application of fenoxaprop-p-ethyl 78.75 g/ha was the best tretment and subsequently recorded maximum bulb yield of onion as compared to other doses of fenoxaprop-p-ethyl (56.25, 67.50 g/ha) and quizalofop-p-ethyl 37.5 g/ha. This herbicide did not show any phytotoxic effect on onion crop. Similarly, post-harvest study on succeeding crop of maize indicated the absence of no residual phytotoxic effect of fenoxaprop-p-ethyl tested in onion.

Key words: Bio-efficacy, Chemical control, Fenoxaprop-p-ethyl, Onion, Phytotoxicity, Residual effect, Weeds

Onion (*Allium cepa* var. *aggregatum* L.) is one of the prime bulbous vegetable with immense economic significance and extensively cultivated crop all over the world, with particular distribution in the Asian continent and in Europe. It is one of the most important vegetable crops in India accounting for one third of the world production. In India, it occupies an area of 1.02 Mha with production of 14.82 MT and productivity of 14.6 t/ha during 2009-10 (Anonymous 2011). Its poor competitive ability with slow initial growth and lack of adequate foliage makes onion weak against weeds. In addition, their cylindrical upright leaves do not shade the soil to block weed growth. Uncontrolled weed growth reduces the bulb yield upto 40 – 80% depending upon the nature of intensity and duration of weed competition in onion field (Prakash *et al.* 2000).

Chemical weed control is a better supplement to conventional methods and forms an integral part of the modern crop production. Thus, use of herbicides is one of the option left with the farmers to eliminate crop weed competition at early growth stage of crop. The common weed management practice for onion is pre-emergence application of selective herbicides like pendimethalin, oxyfluorfen and oxadiazon followed by one hand weeding or use of quizalofop-ethyl as post-emergence (Kalhapure *et al.* 2014, Sinare *et al.* 2014). Under chemical method of weed management, the rotation of herbicides is more essential to prevent the weeds to develop resistance to herbicides. Beneath these backdrops, newer formulation of herbicides is coming in the market with wide spectrum of weed control efficiency. The new herbicide formulations are to be evaluated for their bio-efficacy of controlling wide range of weed flora, better crop growth and yield of onion. In view of the above facts, an experiment was done to see the bio-efficacy and phytotoxicity of fenoxaprop-p-ethyl for grassy weed control in onion crop and its residual effect on succeeding crop.

***Corresponding author:** singh.rohitash5@gmail.com

MATERIALS AND METHODS

A field trial was conducted during *Rabi* 2008-09 and 2009-10 at Crop Research Center of GBPUA&T, Pantnagar (Uttarakhand) to evaluate the bio-efficacy of fenoxaprop-p-ethyl for grassy weed control in onion. The experiment comprised of six treatments, *viz.* fenoxaprop-p-ethyl 9 EC 56.25, 67.50 and 78.75 g/ha along with quizalofop-p-ethyl 37.5 g/ha applied at 3-4 leaves stage of grassy weeds, hand weeding at 30 and 55 days after transplanting (DAT) and untreated control for comparison with four replications, was laid out in randomized block design. Onion variety '*Nasik Red*' was transplanted at a spacing of 20 x 10 cm and recommended package and practices were followed to raise the crop. All the herbicides were applied at standard time of their application by using a foot sprayer fitted with flat fan nozzle with spray volume of 375 liters water/ha.

Weeds other than grassy were removed from the field. Observations on density of grassy weeds and their dry weight were taken at 20 and 45 day after herbicide application in onion crop. Onion bulb yield (t/ha) was recorded at the time of harvesting of crop. The data on density and dry weight of grassy weeds were subjected to log transformation by adding 1.0 to original values prior to statistical analysis.

Three separate treatments were also kept for studying the phytotoxicity of fenoxaprop-p-ethyl 78.75 and 157.50 g/ha in onion crop along with weedy check. The parameters on phytotoxicity were taken as stunting, yellowing/chlorosis, necrosis, epinasty and hyponasty. The observations were recorded using 0 -10 rating scale at the interval of 1, 5, 10, 15 and 20th day after application, where 0= no phytotoxicity and 10= complete death of crop plant.

To see the residual effect of fenoxaprop-p-ethyl on succeeding maize crop in the same plots of the trial layout, maize was sown consequently in the *Kharif* season of year 2009 and 2010 after one month of harvesting of onion crop and the crop was raised as per the standard package of practices. Visual observations on phytotoxicity, *viz.* yellowing, stunting, wilting and deformities due to the effect of herbicidal treatments on succeeding crop plants were recorded at 15 and 30 days after sowing by using rating of 0-10 scale where, 0= no effect on plants and 10= complete death of the plant. Similarly percent seed germination at 15 days after sowing and grain yield of succeeding crop at harvest were also recorded during both the years of investigation. Data were analyzed using analysis of variance (ANOVA) following randomized block design (Gomez and Gomez 1984). Differences were considered significant at 5% level of probability.

RESULTS AND DISCUSSION

Phalaris minor and *Avena* spp. were the predominant grassy weeds observed in the weedy plots of experimental field during both the years of study.

Effect on density and dry weight of weeds

All the treatments caused significant reduction in the density of total weeds over weedy cheek during both the years (**Table 1**). The lowest density of total weeds was observed under hand weeding twice at 30 and 50 DAT during both the years of experiment. Amongst the herbicidal treatments, application of fenoxaprop-p-ethyl 67.5 and 78.75 g/ha and quizalofop-p-ethyl 37.5 g/ha exhibited no statistical divergence in the density of total weeds at 20 days after herbicide application (DAA) throughout the study. However, at 45 DAA, fenoxaprop-p-ethyl 78.75 g/ha showed significantly lower density of total weeds than other treatments in the year 2008-09 but in the 2nd year it was at par with fenoxaprop-p-ethyl 67.5 g/ha and quizalofop-p-ethyl at 37.5 g/ha. Similar trends were also observed with the density of *P. minor* with both the herbicides with respective application stages. Application of both the herbicides also reduced the density of *Avena* spp. Fenoxaprop-p-ethyl 78.75 g/ha registered 100% better control of *Avena* spp. over weedy check during both the stages of crop growth in 2008-09 while in 2009-10, it showed 100% and 50% better control of that weed over weedy check during 20 and 45 DAA respectively. In case of controlling *P. minor,* fenoxaprop-p-ethyl 78.75 g/ha exhibited 47-53% better result over weedy check during both the years. The scientific reason behind such reduction in the density of weeds through the application of fenoxaprop-p-ethyl is that this herbicide is very much effective in the inhibition of acetyl CoA carboxylase (ACCase) activity which is very much important in inhibition of beta oxidation or the activation of lipid biosynthesis. Effectiveness of various herbicides against different weed species in onion crop have been previously reported by Angiras and Suresh (2005) and Tripathi *et al.* (2008).

Dry weight of grassy weeds varied significantly due to different weed control measures (**Table 2**). Similar to the weed density, execution of hand weeding twice was again recorded significantly lower dry weight of grassy weeds in comparison to weedy check during both the years of experimentation. As hand weeding twice significantly reduced the total weed density, naturally dry weight was decreased too. Fenoxaprop-p-ethyl 78.75 g/ha being at par with fenoxaprop-p-ethyl 67.5 g/ha caused significant reduction in the dry weight of grassy weeds over fenoxaprop-p-ethyl 56.28 g/ha and quizalofop-p-ethyl at 37.5 g/ha at 20 DAA during both the years. At later stage of herbicide application *i.e.* at 45 DAA, the application of fenoxaprop-p-ethyl 78.75 g/ha recorded significant lower dry weight than other herbicide treatments. The fenoxaprop-p-ethyl 67.5 and 56.25 g/ha and quizalofop-p-ehtyl 37.5 g/ha also proved very effective in reducing the dry weight of grasses. Similar results were also reported by Kolhe (2001) and Ghadage *et al.* (2006).

Effect on bulb yield

Application of herbicides significantly augmented the number of bulbs/m^2 and average bulb weight (g) over unweeded plots (**Table 3**).

Table 1. Weed density as influenced by different treatments in onion crop

Treatment	Dose (kg/ha)	Weed density (no./m²) 20 DAA P. minor 2008-09	P. minor 2009-10	Avena spp. 2008-09	Avena spp. 2009-10	Total 2008-09	Total 2009-10	45 DAA P. minor 2008-09	P. minor 2009-10	Avena spp. 2008-09	Avena spp. 2009-10	Total 2008-09	Total 2009-10
Fenoxaprop-p-ethyl	56.25	3.66 (38)	3.71 (40)	1.79 (5)	1.61 (4)	3.78 (43)	3.81 (44)	3.83 (45)	3.89 (48)	2.08 (7)	1.79 (5)	3.97 (52)	3.99 (53)
Fenoxaprop-p-ethyl	67.5	3.26 (25)	3.18 (23)	1.39 (3)	1.39 (3)	3.37 (28)	3.30 (26)	3.43 (30)	3.64 (37)	1.39 (3)	1.39 (3)	3.53 (33)	3.71 (40)
Fenoxaprop-p-ethyl	78.75	3.00 (19)	2.77 (15)	0.00 (0)	0.00 (0)	3.00 (19)	2.77 (15)	2.64 (13)	2.83 (16)	0.00 (0)	1.10 (2)	2.64 (13)	2.94 (18)
Quizalofop-p-ethyl	37.5	3.40 (29)	3.22 (24)	0.69 (1)	1.39 (3)	3.43 (30)	3.33 (27)	3.76 (42)	3.71 (40)	1.10 (2)	1.61 (4)	3.81 (44)	3.81 (44)
Two hand weeding	-	1.79 (05)	1.39 (3)	0.69 (1)	0.69 (1)	1.95 (6)	1.61 (4)	1.61 (4)	1.39 (3)	0.00 (0)	0.00 (0)	1.61 (4)	1.39 (3)
Untreated control	-	5.88 (357)	5.89 (362)	2.71 (14)	2.48 (11)	5.92 (371)	5.92 (373)	5.53 (252)	5.58 (264)	2.49 (11)	2.20 (8)	5.58 (263)	5.61 (272)
LSD (p=0.05)		0.64	0.64	1.09	1.07	0.69	0.67	0.68	0.74	1.00	1.05	0.73	0.89

Values in parentheses are original value transformed to log $(\sqrt{x+1})$; DAA=Days after application

Table 2. Weed dry weight as influenced by different treatments in onion crop

Treatment	Dose (kg/ha)	Weed dry weight (g/m²) 2008-09 20 DAA	2008-09 45 DAA	2009-10 20 DAA	2009-10 45 DAA
Fenoxaprop-p-ethyl	56.25	3.42 (29.67)	3.55 (33.78)	3.22 (24.13)	3.85 (45.97)
Fenoxaprop-p-ethyl	67.5	2.85 (16.35)	3.08 (20.69)	2.93 (17.69)	3.52 (32.86)
Fenoxaprop-p-ethyl	78.75	2.46 (10.75)	2.25 (8.47)	2.55 (11.87)	2.45 (10.64)
Quizalofop-p-ethyl	37.5	4.21 (66.04)	3.31 (26.48)	4.33 (75.01)	3.61 (35.97)
Two hand weeding	-	1.90 (5.67)	1.50 (3.48)	2.75 (14.65)	1.56 (3.77)
Untreated control	-	5.45 (232.7)	5.04 (153.87)	5.34 (207.04)	5.11 (164.75)
LSD (p=0.05)		0.47	0.63	0.53	0.78

Values in parentheses are original value transformed to log $(\sqrt{x+1})$; DAA=Days after application

Concerning the number of bulbs/m², fenoxaprop-p-ethyl 78.75 and 67.6 g/ha and quizalofop-p-ethyl 37.5 g/ha exhibited statistical similar result with hand weeding twice. Weeds under uncontrolled condition in onion field reduced the bulb yield by 74% than hand weeding twice (**Table 3**). The highest bulb yield *i.e.* 1.30 and 1.36 t/ha were observed with hand weeding twice at 30 and 50 DAT during 2008-09 and 2009-10, respectively. Application of fenoxaprop-p-ethyl at higher rate *i.e.* 78.75 g/ha recorded higher bulb yield being at par with fenoxaprop-p-ethyl 67.5 g/ha during both the years and with quizalofop-p-ethyl 37.5 g/ha during second year only. The higher bulb yields under these treatments were due to more number of bulbs/m² and higher average bulb weight. Because of the favorable environment in the root zone resulting in absorption of more water, nutrients and good control of weeds which resulted into less weed crop competition throughout the growth stage of crop and enhance availability of nutrient, water, light and space which might have accelerated the photosynthetic rate thereby increasing the supply of carbohydrates and overall improvement in vegetative growth, which favorably influenced the bulb diameter, fresh and dry bulb weight and ultimately resulted into increased bulb yield. These findings are in close vicinity in those of Ghadage *et al.* (2006), Chopra (2007), Saraf *et al.* (2007) and Warade *et al.* (2008).

Phytotoxicity and residual effects

There were no phytotoxicity symptoms, *viz.* stunting, yellowing/ chlorosis, necrosis, epinasty and hyponasty after the application of fenoxaprop-p-ethyl either at 78.75 or 157.5 g/ha during the entire onion crop season.

There was no adverse effect of fenoxaprop-p-ethyl at their 1x and 2x doses *i.e.* 78.25 and 157.50 g/ha on growth and development of succeeding crop

Table 3. Yield attributing characters and fresh bulb yield of onion as influenced by different treatments during 2008-09 and 2009-10

Treatment	Dose (kg/ha)	Number of bulbs/m^2		Avearge bulb weight (g)		Fresh bulb yield (t/ha)	
		2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
Fenoxaprop-p-ethyl	56.25	54	57	22.8	24.5	1.00	0.95
Fenoxaprop-p-ethyl	67.5	60	61	25.1	28.7	1.11	1.14
Fenoxaprop-p-ethyl	78.75	64	62	26.5	30.5	1.21	1.22
Quizalofop-p-ethyl	37.5	57	60	23.6	26.3	1.03	1.07
Two hand weeding	-	67	62	28.8	35.5	1.30	1.36
Untreated control	-	40	42	8.6	8.8	0.33	0.36
LSD (p=0.05)	-	12	11	5.0	4.8	0.10	0.15

Table 4. Effect of fenoxaprop-p-ethyl on seed germination and yield of succeeding maize crop in (mean of four replications)

Treatment	Dose (g/ha)	% germination		Grain yield (t/ha)	
		2009	2010	2009	2010
Fenoxaprop-p-ethyl (Whip Super 9 EC)	78.75	86.8	86.3	0.39	0.39
Fenoxaprop-p-ethyl (Whip Super 9 EC)	157.50	85.6	87.4	0.37	0.37
Untreated control	-	88.3	86.7	0.38	0.38

and there was no phytotoxicity symptoms, *viz*. yellowing, stunting, wilting and deformities observed on the succeeding crop. Percent germination recorded at 15 days after sowing and grain yield of maize were also recorded almost similar (**Table 4**) in all the treatments including untreated check plot during both the years. These findings corroborated the finding of Rathod *et al.* (2014).

It was concluded that the application of fenoxaprop-p-ethyl can keep the grassy weed density and dry weight reasonably at lower level and enhance the productivity of *Rabi* onion resulting in no phytotoxic effect on the crop without affecting the growth and yield of succeeding maize crop.

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Indian Journal of Weed Science 49(1): 67–69, 2017
DOI: 10.5958/0974-8164.2017.00016.8

Control of broomrape in Bidi tobacco by different management practices

C.J. Patel*, K.M. Gediya, H.K. Patel and A.R. Patel
Bidi Tobacco Research Station, Anand Agricultural University, Anand, Gujarat 388 110

Received: 21 January 2017; Revised: 4 March 2017

ABSTRACT

An experiment was conducted on loamy sand soil at Bidi Tobacco Research Station Farm, Anand Agricultural University, Anand, Gujarat during *Kharif-Rabi* season of 2011-12 and 2012-13. Twenty treatment combinations comprising of four levels of fertilizer management and five levels of herbicide management were tested in a factorial RBD with four replications. It was concluded that for controlling broomrape effectively and securing maximum cured leaf yield of Bidi tobacco as well as economic returns with management through different fertilizers, an application of ammonium sulphate at 200 kg/ha along with irrigation should be carried out. With regard to management of broomrape, manual weeding of broomrape was found to be the best practice.

Key words: Bidi tobacco, Broomrape, Management, *Orobanche ramosa*

Tobacco (*Nicotiana tabacum* L.) is the most important non-food crop cultivated in more than 100 countries on approximately 4.2 million hectares of land (Anonymous 2010). Tobacco (*Nicotiana tabacum* L. and *Nicotiana rustica* L.) belongs to the order tubiflorae and family solanaceae and is believed to have been introduced in India from its native Central America by Portuguese in 1603. The major tobacco growing countries in the world are China, U.S.A., India, Brazil, Turkey, Russia, Italy and Zimbabwe. 'Bidi' (type of cheap cigarette made of unprocessed tobacco wrapped in leaves) tobacco industry is essentially a cottage industry employing more than 0.3 million of rural population. *Bidi* tobacco plays a vital role in the national economy in generating employment and revenue. Thus, Gujarat is the largest 'Bidi' tobacco growing state in the country. (Anonymous 2006[b]). Among different types of tobacco grown in the country, 'Bidi' tobacco (*Nicotiana tabacum* L.) accounts for the highest area, production and productivity accounting for 32% area and 36% total production in the country.

Weed growth is an important constraint in proper harvest of the crop. Simultaneous emergence and rapid growth of weeds lead to severe crop-weed competition for light, moisture, space and nutrients. Broomrape (*Orobanche* spp.) is an annual, root holoparasitic herb propagated by seeds. It is one of the most serious weeds in the tobacco crop. The host root exudates induce germination of seed within soil. The parasite seedlings then infect the nearby host roots forming haustoria on them. Soon thereafter, the broomrape emerges through the soil as pale shoots devoid of chlorophyll. Broomrape is thus a total parasite. Each plant produces more than a million seeds in a short period of about eight weeks. Considering the importance of management practices on broomrape (*Orobanche ramosa*.) control in bidi tobacco, the present experiment was conducted.

*Corresponding author: chiragjpatel@aau.in

MATERIALS AND METHODS

A field experiment was conducted during the *Kharif-Rabi* season of the years 2011 and 2012 at Bidi Tobacco Research Station, Anand Agricultural University, Anand, Gujarat. The texture of the soil was loamy sand. The soil was very deep and fairly moisture retentive and was low in organic carbon and nitrogen, high in available phosphorus and medium in potassium with pH 7.6. The soil was free from any kind of salinity/sodicity hazards. Twenty treatment combinations comprising of four levels of fertilizer management Control, ammonium sulphate; 200 kg/ha, castor cake 200 kg/ha and neem cake 200 kg/ha and five levels of herbicide management *viz*., unweeded, manual weeding, pendimethalin 1.0 kg / ha, isoproturon 1.0 kg/ha and glyphosate 1.0 kg/ha were tried out in a factorial RBD with four replications. The gross plot size of plot was 4.50 x 6.00 m and net plot size was 2.70 x 4.50 m. Herbicides were applied during emergence of *Orobanche* along with irrigation.

RESULTS AND DISCUSSION

Effect of different levels of management through fertilizers

The results revealed that *Orobanche* panicles emerged late with use of ammonium sulphate at 200 kg/ha, *i.e.* 148 and 138 days as compared to early emergence of 119 days in control (**Table 1**). This might be due to inhibitory effect of ammonium form of nitrogen to broomrape and primary inhibition of elongation of seedling and reduction in radical length. The present findings were supported from the results reported by Westwood and Foy (1999).

Effect of different levels of management through herbicides

Manual weeding recorded significantly lowest dry weight of broomrape, *i.e.* 45.56 and 44.35 kg/ha during 2011-12 and 2012-13, respectively but it was statistically at par with glyphosate 1.0 kg/ha during 2011-12. Significantly highest dry weight of broomrape, *i.e.* 126.0 and 123.6 kg/ha was recorded by unweeded during 2011-12 and 2012-13, respectively (**Table 1**). It might be due to manual weeding, which was most efficient and widely practiced method in India for all crops that suffer from their parasites. The present findings were supported from the results reported by Krishnamurthy and Rao (1976), Dhanapal (1996) and Ramchandra Prasad (2011).

The interaction effect was found non-significant in days to broomarape emergence and dry weight of broomrape (kg/ha) during both the years.

Economics

The results revealed that maximum net realization of ` 32588/ha along with BCR value of 1.97 was recorded under the treatment ammonium sulphate 200 kg/ha followed by control with net realization of ` 27586/ha along with BCR value of 1.88. On the contrary, treatment of neem cake 200 kg/ha recorded minimum net realization of ` 26513/ha with BCR value of 1.75. This might be due to higher cured leaf yield of Bidi tobacco recorded in treatment ammonium sulphate 200 kg/ha). Similar results have been reported by Abu-Irmaileh (1981), Westwood and Foy (1999), Mariam and Suwanketnikom (2004).

Manual weeding was found superior by recording the highest value of net realization ` 31257/ha with BCR of 1.88 followed by isoproturon 1.0 kg/ha with net realization of ` 29082/ha and BCR of 1.87. Unweeded showed the lowest value of net realization ` 26248/ha and BCR of 1.83 followed by pendimethalin 1.0 kg/ha with net realization of ` 27465/ha and BCR of 1.81 (**Table 2**). The increase in profit was mainly due to more cured leaf yield of *bidi* tobacco. Similar results were found by Kataria *et al.* (2003), Anonymous (2009-10) and Ramchandra Prasad (2011).

Table 1. Days to broomrape emergence, dry weight of broomrape at harvest of *bidi* tobacco as influenced by management through fertilizers and herbicides

Treatment	Days to broomrape emergence			Dry weight of broomrape (kg/ha)		
	2011-12	2012-13	Pooled	2011-12	2012-13	Pooled
Management through fertilizer						
Ammonium sulphate 200 kg/ha at emergence of *Orobache* with irrigation	148	138	143	8.00(81.7)	9.40(96.6)	8.70(89.2)
Castor cake 200 kg/ha at 3rd week after transplanting	131	128	129	8.76(87.9)	8.32(75.0)	8.54(81.4)
Neem cake 200 kg/ha at 3rd week after transplanting	137	132	134	8.42(77.7)	8.52(77.5)	8.47(77.6)
Control	119	118	118	9.29(93.3)	8.78(83.4)	9.03(88.4)
LSD (p=0.05)	5.07	2.98	8.48	NS	NS	NS
Management through herbicide						
Manual weeding as and when required	134	129	131	5.99(45.6)	6.13(44.3)	6.06(45.0)
Pendimethalin 1.0 kg/ha at emergence of *Orobache* with irrigation	134	130	132	9.99(102)	9.81(100)	9.89(101.8)
Isoproturon 1.0 kg/ha at emergence of *Orobache* with irrigation	132	129	130	8.20(78.8)	8.37(76.0)	8.28(77.4)
Glyphosate 1.0 kg/ha at emergence of *Orobache* with irrigation	135	131	133	7.91(72.7)	8.20(71.0)	8.06(71.8)
Unweeded	132	127	130	11.00(126)	11.08(124)	11.04(125)
LSD(p=0.05)	NS	NS	NS	1.958	1.21	1.14

Figures in parentheses are original values subjected to transformed values to square root $(\sqrt{x+1})$. Figures indicating common letters in column do not differ significantly from each other at 5% level of significance according to Duncan new multiple range test

Table 2. Economics as influenced by different levels of management through fertilizers and herbicides (average of two years)

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

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

It was concluded that for effective control of broomrape and securing maximum cured leaf yield of Bidi tobacco as well as economic returns, fertilizer ammonium sulphate 200 kg/ha along with irrigation should be applied. However, manual weeding of broomrape was found to be the best practice.

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Indian Journal of Weed Science **49**(1): 70–74, 2017
DOI: 10.5958/0974-8164.2017.00017.X

Detection of bispyribac sodium + metamifop 14% SE residue in soil by bioassay method

Sheeja K Raj* and Elizabeth K Syriac[1]
Coconut Research Station, Balaramapuram, Kattachalkuzhy, Thiruvananthapuram, Kerala 695 501

Received: 14 January 2017; Revised: 9 February 2017

ABSTRACT

Bioassay studies were carried out to assess the residual effect of herbicide mixture, bipyribac-sodium + metamifop 14% SE in soil with indicator plant. A screening trial with three test crops, *viz*. cucumber, sunflower and maize indicated that maize was the best indicator plant, because it recorded the highest regression co-efficient for the parameters tested such as fresh and dry weight of shoot, shoot length and root length. The shoot dry weight of maize was identified as the best parameter to detect the phytotoxic residue in soil. The bioassay conducted with maize as an indicator plant in the post experiment soil revealed that there was no significant difference among the treatments (bispyribac-sodium + metamifop at 60, 70, 80, 90 g/ha, bispyribac applied alone at 25 g/ha, hand weeding twice and weedy check) during both the seasons in germination percentage, shoot length, root length, fresh weight and dry weight of maize plant. Thus it can be inferred that the herbicide mixture, bispyribac-sodium + metamifop did not leave any phytotoxic residues in soil.

Key words: Bioassay, Bispyribac-sodium + metamifop, Indicator plant, Maize, Residue

The non-judicious use of herbicides is a source of concern, which has a growing interest in the environment, nature conservation and public health in general. Detection of herbicide residues is of great importance because of the risk of phytotoxicity on other species which are not direct object of the treatment, the risk involved in rotational crops due to the accumulation of phytotoxic residues in the field or herbicide drift during the application of the herbicide (Pestemer and Zwerger 1999). Plant bioassay is the viable alternative to the instrumental procedures for the determination of herbicide residue in soil. It is a simple, inexpensive, accurate and direct method of determining herbicide residues present in the soil at concentrations high enough to adversely affect crop growth yield and quality. Hernández-Sevillano *et al.* (1999) pointed out that it is a valuable tool that provides an overview of soil-plant-herbicide relationships. Instrumental methods such as gas chromatography or high performance liquid chromatography requires several solvent or solid phase extractions and clean up procedures before sample analysis and determine the total amount of active ingredient present in the soil (Szmigielski *et al.* 2012). The amount of residue extracted chemically may differ from the amount of residue biologically available to cause phytotoxic responses to bioassay species (Strachan *et al.* 2011). In contrast, bioavailable herbicide is determined by bioassay procedures (Szmigielski *et al.* 2009) because plant response varies with soil type and generally decreases in soils of high organic matter and clay contents and low soil pH. There are various procedures to undertake herbicide bioassays. Shoot and root bioassays with sensitive plants were suggested for herbicide bioassays (Vicari *et al.* 1994, Hermandez-Sevillano *et al.* 2001). For detecting the ALS herbicide residues, maize, sunflower and oriental mustard (Szmigielski *et al.* 2008) were used as indicator plants. Cotton (Grey *et al.* 2007) and sugar beet (Szmigielski *et al.* 2009) have been reported as the suitable indicator plants for detection of protox inhibiting herbicides in soil. With this back ground, the present bioassay study was planned to find out the residual effects in soil due to the application of bispyribac-sodium + metamifop, a combination product of broad spectrum herbicide, bispyribac-sodium (3.8%) and a grass effective herbicide metamifop (9.5%). Bispyribac sodium beongs to chemical group thiobenzoate inhibiting the biosynthesis of aminoacids and metamifop belongs to aryloxyphenoxypropionate inhibiting acetyl coenzyme-A carboxylase (ACCase) leading to growth retardation of weeds.

***Corresponding author:** sheejakraj70@gmail.com
[1]Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala 695 522

MATERIALS AND METHODS

The bioassay experiments were conducted in Department of Agronomy, College of Agriculture Vellayani Thiruvananthapuram and field experiments were conducted in the farmers' field during *Kharif* 2014 and *Rabi* 2014-15 at Upaniyoor padashekaram, in Kalliyoor Panchayat, Nemom block, Thiruvananthapuram district, Kerala, India. Bioassay experiments comprised of two parts. The first part was the screening of indicator plants to identify the most sensitive indicator plant, among the three test crops *viz*. cucumber, sunflower and maize. The second part was the detection of phytotoxic residue of bispyribac-sodium + metamifop 14% SE in the post experiment soil using the most sensitive indicator plant identified.

Screening of indicator plants: Screening of the best indicator plant was conducted in CRD with 8 treatments. The treatments comprised of seven different concentrations of bispyribac-sodium + metamifop, *viz*. 100 µL/L, 10 µL /L, 5 µL/L, 1 µL/L, 0.5 µL/L, 0.05 µL/L, 0.01 µL/L and 0 µL/L (control). Separate experiments were conducted for each test crop in three replications. Soil was collected from the herbicide free area, washed thoroughly with water and air dried. Then it was fortified with different concentrations of bispyribac-sodium + metamifop (as per the treatments) and mixed thoroughly and 300 g soil was taken in small plastic pots of 500 ml capacity separately. Ten seeds of each test species were dibbled in each pot at uniform depth of 2 cm. Germination count was taken at 4 DAS and then the plants were thinned to three per pot to avoid competition. At 14 DAS, the plants were uprooted from each pot without causing any damage to the roots. Shoot length and root length were recorded. The root system was removed using a sharp knife and the fresh shoot weight was recorded. Shoot dry weight was recorded after the plants were dried in hot air oven at 60 °C to constant weight. Data on shoot length, root length, shoot fresh and dry weight of indicator plants were statistically analyzed using ANOVA and regression equations were developed. The test crop which showed the highest R^2 value for all the tested parameters was selected as the best indicator plant and the parameter which showed the highest R^2 value was selected as the best parameter to detect the residual effects of herbicide mixture, bispyribac-sodium + metamifop. The response curve was also developed for the tested parameters of the best indicator plant.

Field experiments were laid out in randomized block design with seven treatments and three replications. The treatments were bispyribac- sodium + metamifop at 60, 70, 80 and 90 g/ha, bispyribac-sodium applied alone 25 g/ha, hand weeding twice and weedy check. The herbicides were applied at 15 DAS as per the treatment schedule using knapsack sprayer fitted with flat fan nozzle. The spray fluid was used at 500 L/ha for the study. The variety used was '*Kanchana'*, a short duration variety released from Regional Agricultural Research Station, Pattambi. The crop was fertilized with 70:35:35 kg/ha N, P and K, with one third N and K and half P applied on 15 DAS (days after sowing), one third N and K and half P on 35th day and remaining one third N and K on 55th day of sowing. All the Agronomic and plant protections were adopted as per package of practices recommendations of Kerala (KAU 2011).

Detection of phytotoxic residue: For the determination of bispyribac-sodium + metamifop residue in the soil, composite soil sample was collected from each treatment plot at a depth of 15 cm after the harvest of the crop. From this sample, 300 g soil was weighed and transferred into plastic containers of 500 ml capacity and 10 seeds of the most sensitive indicator plant, *i.e*. maize was dibbled in each pot at a uniform depth of 2 cm. Germination count was taken at 4 DAS and then the plants were thinned to three per pot to avoid competition. Observations on shoot and root length and shoot fresh and dry weight were recorded as in the screening trial described above.

The data generated were statistically analyzed using analysis of variance technique (ANOVA) and difference between the treatments means were compared at 5% probability level.

RESULTS AND DISCUSSION

Screening of indicator plants

The effect of different concentrations of herbicide mixture, on shoot length, root length, shoot fresh and dry weight of cucumber, sunflower and maize are presented (**Tables 1, 2** and **3**). The data on germination percentage of cucumber, sunflower and maize were not statistically analyzed, since no graded variation was observed among the treatments. In general, as the concentration of herbicide mixture increased, a decrease in the growth parameters were observed in the tested crops. Quadratic ($Y= a+ b X^2$) and logarithmic linear regression equation, $Y= a + b \ln (X)$ were fitted for shoot fresh weight, shoot dry weight, shoot length and root length for cucumber, sunflower and maize and among the two equations, logarithmic linear regression equation, $Y= a + b \ln (X)$ were best fitted and adopted for the study.

Table 1. Effect of different concentrations of bispyribac sodium + metamifop on the growth parameters of cucumber

Treatment (concentrations of bispyribac-sodium + metamifop)	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)
100 µL/L	30.0	0.56	0.49	0.09	0.011
10 µL/L	40.0	0.80	0.79	0.11	0.012
5 µL/L	60.0	3.22	1.60	0.18	0.015
1 µL/L	66.0	4.36	1.48	0.21	0.018
0.5 µL/L	63.0	5.53	3.30	0.32	0.023
0.05 µL/L	74.1	7.82	4.50	0.60	0.042
0.01 µL/L	90.0	9.00	6.99	0.61	0.049
Control	90.0	9.54	7.03	0.76	0.057
LSD (p=0.05)	-	1.58	1.72	0.13	0.011

Table 2. Effect of different concentrations of bispyribac sodium + metamifop on the growth parameters of sunflower

Treatment (concentration of bispyribac-sodium + metamifop)	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)
100 µL/L	76.7	2.16	0.65	0.28	0.036
10 µL/L	80.0	3.22	0.81	0.30	0.037
5 µL/L	80.0	5.42	0.87	0.38	0.039
1 µL/L	76.7	5.67	1.05	0.44	0.047
0.5 µL/L	80.0	7.73	1.53	0.49	0.048
0.05 µL/L	80.0	8.02	2.23	0.55	0.049
0.01 µL/L	86.7	14.08	4.08	0.80	0.056
Control	93.3	16.15	4.61	0.87	0.057
LSD (p=0.05)	-	1.950	0.520	0.156	0.0083

Table 3. Effect of different concentrations of bispyribac sodium + metamifop on the growth parameters of sunflower

Treatment (concentration of bispyribac-sodium + metamifop)	Germination, (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)
100 µL/L	80.00	0.37	0.74	0.08	0.001
10 µL/L	86.67	3.94	1.50	0.13	0.026
5 µL/L	83.33	17.65	3.74	0.64	0.082
1 µL/L	86.67	29.48	7.57	1.08	0.133
0.5 µL/L	90.00	30.95	13.47	1.35	0.157
0.05 µL/L	90.00	32.80	18.45	1.40	0.181
0.01 µL/L	100.00	37.30	26.76	1.60	0.188
Control	100.00	37.69	27.93	1.64	0.192
LSD (p=0.05)	-	4.455	4.000	0.246	0.020

The different concentrations of bispyribac-sodium + metamifop significantly influenced the shoot fresh weight, shoot dry weight, root length and shoot length of cucumber. The percentage reduction in shoot fresh weight and dry weight, shoot length and root length of cucumber at 0.01 to 100 µl/L concentrations of bispyribac-sodium + metamifop ranged from 19.74 to 88.16, 14.04 to 80.70, 5.66 to 94.13 and 0.57 to 93.03%, respectively compared to control. Logarithmic linear regression equations developed for shoot fresh weight, shoot dry weight, shoot length and root length of cucumber were Y= 0.2714-0.06155 ln (X), Y= 0.0223 - 0.00414 ln (X), Y= 3.950 - 0.9871 ln (X) and Y= 2.385 - 0.6645 ln (X), respectively.

Similar to that of cucumber, the different concentrations of bispyribac-sodium + metamifop significantly influenced the shoot fresh weight, shoot dry weight, root length and shoot length of sunflower also. The percentage reduction in shoot fresh weight and and dry weight, shoot length and root length of sunflower at 0.01 µL/L to 100 µL/L concentrations of bispyribac-sodium + metamifop ranged from 8.05 to 67.82, 1.75 to 36.84, 12.82 to 86.63 and 11.50 to 85.90, respectively compared to control. Logarithmic linear regression equations developed for the shoot fresh weight, shoot dry weight, shoot length and root length of sunflower were Y= 0.4349 - 0.0513 ln (X), Y= 0.0434 -0.0022 ln (X), Y= 6.0154 -1.1373 ln (X) and Y= 1.4383 - 0.3132 ln (X), respectively.

The effect of different concentrations of bispyribac-sodium + metamifop on the growth parameters of maize was also statistically analyzed. The shoot fresh weight and dry shoot weight, root length and shoot length of maize were also significantly influenced by the different concentrations of bispyribac-sodium + metamifop. The percentage reduction in shoot fresh weight, shoot dry weight, shoot length and root length at 0.01 µL/L to 100 µL/L concentrations of bispyribac-sodium + metamifop ranged from 2.44 to 95.12, 2.08 to 99.48, 1.03 to 99.02 and 4.19 to 97.35, respectively compared to control. The logarithmic linear regression equations developed for shoot fresh weight, shoot dry weight, shoot length and root length of maize were Y= 0.7980 - 0.1890 ln (X), Y= 0.0977 -0.0230 ln (X), Y= 19.4270-4.4705 ln (X) and Y= 8.8401- 2.8056 ln (X), respectively.

Results revealed that, among the three indicator plants tested, *viz*. cucumber, sunflower and maize, maize plant was the most sensitive indicator plant to determine the residues of bispyribac-sodium + metamifop in soil, since it recorded the highest R^2 values (regression co-efficient values) for shoot dry weight, shoot fresh weight, root length and shoot length, the parameters tested (**Table 4, Figure 1a, 1b, 1c** and **1d**) and also the percentage reduction in the shoot fresh weight, shoot dry weight, shoot length and root length was more than in the case of cucumber and sunflower. Szmigielski *et al*. (2012) reported that, selecting a suitable plant species for bioassay is critical and parameter measured in the bioassay should correlate well with herbicide concentration.. Yadav *et al*. (2013) reported cucumber as the best indicator plant for the residue studies of pyrazosulfuron-ethyl in soil. The best parameter for the detection of residue in the soil was maize shoot dry weight (**Table 4, Figure 1d**), since it recorded the highest R^2 value (0.9548) compared to other tested parameters of maize. Vicari *et al.* (1994) and Stork and Hannah (1996) opined that plant height and dry or fresh weight of shoot has been found to be the sensitive parameters for the detection of sulfonyl urea herbicide residue in soil.

Table 4. R^2 values of different parameters of tested indicator plants, Y= a + b ln (X)

Parameter	Cucumber	Sunflower	Maize
Shoot fresh weight	0.7861	0.8245	0.9379
Shoot dry weight	0.7501	0.8772	0.9548
Shoot length	0.9325	0.8454	0.9310
Root length	0.8039	0.6670	0.8408

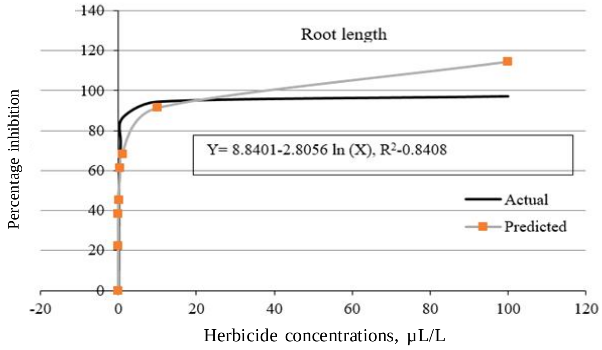

Figure 1a. Percentage growth inhibition in the root length of maize, as influenced by different concentrations of bispyribac-sodium + metamifop

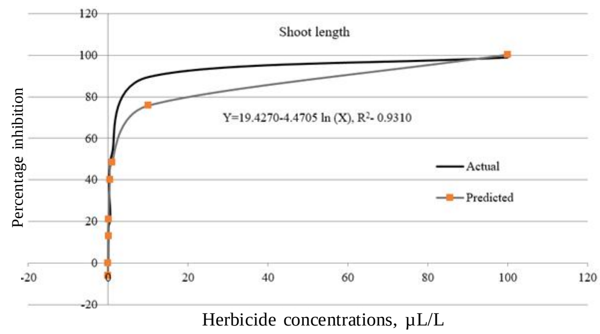

Figure 1b. Percentage growth inhibition in the shoot length of maize, as influenced by different concentrations of bispyribac-sodium + metamifop

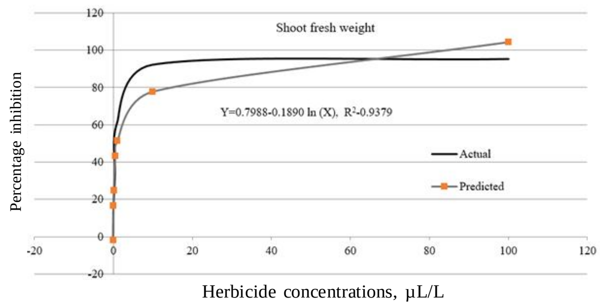

Figure 1c. Percentage growth inhibition in the shoot fresh weight of maize, as influenced by different concentrations of bispyribac-sodium + metamifop

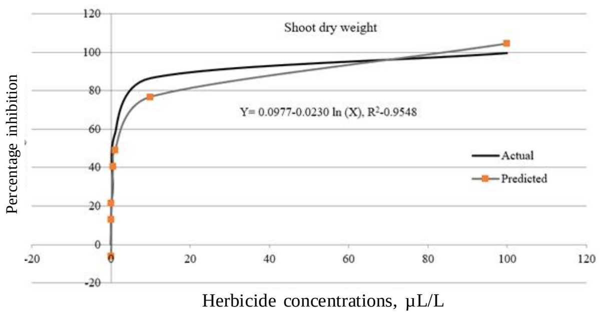

Figure 1d. Percentage growth inhibition in the shoot dry weight of maize, as influenced by different concentrations of bispyribac-sodium + metamifop

Herbicide residue in post experiment soil

Results revealed that there was no significant difference among the treatments during both the seasons in the parameters studied, *viz*. germination percentage, shoot length, root length, fresh weight and dry weight of maize plant. Thus, it can be assumed that the herbicide mixture applied at 60, 70, 80 and 90 g/ha did not leave any residue in soil. Ramani and Khanpara (2010) reported that the post-emergence herbicides *viz*. oxadiargyl 90 g/ha, quizalofop-ethyl 40 g/ha and fenoxaprop-P-ethyl 75 g/ha when applied at 60 DAS showed no reduction in germination percentage, plant height and dry weight of indicator plants, sorghum and cucumber indicating no residual phytotoxic effect.

It was concluded that maize was the best indicator plant among the three test crops to detect the phytotoxic residue of bispyribac-sodium + metamifop in soil and shoot dry weight of maize was adjudged as the most sensitive parameter to detect the phytotoxic residue of bispyribac-sodium + metamifop in soil. Results of the bioassay study with maize plant as the indicator plant during *Kharif* 2014 and *Rabi* 2014-15 indicated that post-emergence application of bispyribac-sodium + metamifop at 60, 70, 80 and 90 g /ha did not leave any phytotoxic residue in the soil to cause any growth inhibition in the growth parameters of maize, germination percentage, shoot fresh weight, shoot dry weight, shoot length and root length.

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Indian Journal of Weed Science **49**(1): 75–78, 2017
DOI: 10.5958/0974-8164.2017.00018.1

Nutritive value and safety of greater club rush as livestock feed

P. Gayathri Karthikeyan*, Sansamma George and C.R. Chithrima[1]
Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala 695 522

Received: 7 December 2016; Revised: 24 January 2017

ABSTRACT

The present study was undertaken to assess the nutritive value of greater club rush (*Scirpus grossus* L. f) and safety of the weed biomass as a livestock feed. The results showed that the nutrient composition of the weed biomass was comparable to some of the popular cultivated fodder crops like guinea grass. Heavy metal content of the sedge plant was mostly within the permissible limits as recommended by World Health Organisation (WHO). However, the cadmium concentration was found to be more than the safe limit, indicating possible risk in allowing free grazing in contaminated soils. The data on the transfer and accumulation of heavy metals from soils to plant shoots/roots as estimated through biological concentration factor (BCF), translocation factor (TF) and bio accumulation coefficient (BAC) also indicated that there is a need for caution when animals are allowed to graze freely on the luxuriant growth of greater club rush in wetland ecosystem.

Keywords: Greater club rush, Heavy metals, Nutrient value, Proximate analysis, *Scirpus grossus*

Greater club rush or giant bulrush (*Scirpus grossus* L. f) is an emergent hydrophyte which is a native of South-East Asia, found naturalized throughout India, Malaysia, and tropical Australia (Naskar 1990). It belongs to a small, worldwide group of the family Cyperaceae, often called the "tuberous bulrushes" and is one of the major sedge weed infesting rice growing tracts around the world (Hakim *et al.* 2010). The plant with its erect, robust stature grows to a height of about 1.5 to 2.5 m and produces large quantities of lush green biomass. In Kerala (India), greater club rush locally known as "*Korapullu*" has already infested vast tracts of wetland paddy fields. Once infested, the aggressive weed spreads fast and the cost involved in removing it and recovering the field becomes prohibitively high, forcing many farmers even to abandon rice cultivation. Farmers' practice of destroying the weed either through tillage or burning has been found to have only short effect, as the weed is propagated through underground rhizome fragments. However, it has been observed that farmers utilise greater club rush as a livestock feed especially to free grazing. This plant at its active growth stage is also cut and fed to cattle. These plants regenerate very fast from the underground propagules and the perennial growth habit of the large robust plant provides the farmers with a luxuriant and cheap source of forage year round. According to Sreethu (2011), greater club rush is capable of producing a plant dry weight of more than 20 t/ha.

It is true that the highly productive wetland ecosystems support a wide variety of flora and fauna, but the abandoned condition of the fields in many cases also encourage the disposal of industrial waste, sewage water, electronic wastes, *etc*. into the ecosystem. This is a matter of concern as there are chances of heavy metal contamination in such wetlands. Pollutants from contaminated soil later enter into livestock production systems and then into the food chain (Rajaganapathy *et al.* 2011). Earlier studies have indicated that greater club rush is a phytoaccumulator and has the potential to be used for phytoremediation of heavy metal contaminated environment (Tangahu *et al.* 2013). Food chain contamination is one of the major routes for entry of metals into the animal system and therefore, monitoring metals in contaminated soil, food stuff and water are of a paramount concern (Udiba *et al.* 2013). Hence, present study was undertaken to assess the nutritive value and safety of greater club rush biomass as a livestock feed.

MATERIALS AND METHODS

Study was conducted during January-August 2016, by collecting soil and plant samples from wetlands of approximately 10 ha, heavily infested with greater club rush (*Scirpus grossus* L. f). The selected field was lying close to an industrial area,

***Corresponding author:** gayathrikpappu@yahoo.com
[1]College of Veterinary and Animal Sciences, Mannuthy, Thrissur, Kerala 690 656

located at 8° 28' 14.03" N latitude and 76° 59' 38.36" E longitude in Thiruvananthapuram district, Kerala. The rice field remained uncultivated for the past 8–10 years and the weed was reported to be spreading fast. Many farmers reported their helplessness in containing the weed. Waste water from the industrial area, sewage water, electronic wastes *etc*. were being discharged/dumped into the abandoned field and hence it was hypothesized to be contaminated with heavy metals. Local farmers have been using the land for cattle grazing for the past few years.

Approximately one kilogram each of soil samples were collected randomly from ten different points at 0-15 cm plough depth, air dried at room temperature for two weeks, crushed and pulverized to pass through 2 mm sieve and composite samples were drawn after homogenous mixing. The plant samples were also collected from the same location from where soil was collected. In order to analyse the proximate principles and heavy metal content in the plant samples, the uprooted plants were thoroughly washed to clean the mud and dirt especially from the entangled root mass, dried in shade for 2 weeks and then oven dried at 65 °C till they attained constant weights. The oven dried shoot and root samples were ground to fine powder and homogenized samples were drawn for further analysis.

Sample preparation and basic chemical analysis of soil were conducted according to routine analytical methods. Soil organic matter was determined by Walkley and Black method, pH was determined by pH meter and EC was measured using conductivity meter. Available nitrogen was estimated by alkaline potassium permanganate method, phosphorus by Bray colourimetric method, potassium by ammonium acetate method and organic carbon by chromic acid wet digestion method. As the soil organic matter contains approximately 58% carbon, a factor of 1.72 was used to convert organic carbon to soil organic matter.

The nutritive value of the plant samples was assessed by the analysis of proximate principles based on the Official Methods of analysis (AOAC, 2012). Total ash, acid insoluble ash, crude protein (CP), crude fibre (CF), ether extract/crude ash (EE) and nitrogen free extract (NFE) were determined on dry weight basis.

NFE (%) = 100 - (CF% + CP% + EE% + Ash %)

Total nitrogen content of the plant samples was determined by modified micro Kjeldahl method. One g each of the plant samples were digested in diacid digestion mixture containing concentrated nitric and perchloric acid (9:4), till a clear extract was obtained and made up to 100 ml using distilled water. This extract solution was used to determine P, K, Ca, Mg and the heavy metals. Phosphorus was determined by vanadomolybdophosphoric yellow colour method and total potassium content was determined by EEL flame photometer. Calcium and magnesium were determined by EDTA titration method. The heavy metals, *viz*. lead (Pb), nickel (Ni), chromium (Cr) and cadmium (Cd) in both the soil and plant samples were determined by the Atomic Absorption Spectrophoto meter (AAS) method.

The efficiency of different plants in absorbing metals is evaluated by either plant uptake or soil-to plant transfer factors of the metals (Chandran *et al*. 2012). In the present study, the transfer and accumulation of heavy metals from soil to roots and shoots were estimated in terms of biological concentration factor (BCF), translocation factor (TF) and bioaccumulation coefficient (BAC) in line with the reports of Rezvani and Zaefarian (2011).

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

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

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

RESULTS AND DISCUSSION

Soil properties

The soil was strongly acidic (4.97), nonsaline (0.25 ds/m) and very high in organic matter content (5.14%). The nutrient status of the soil was medium (**Table 1**).

As per the regulatory standards for agricultural soils in USA as reported by He *et al*. (2015), the contents of chromium, nickel and lead in the selected sites were within safe limits (**Table 2**). High organic matter has been shown to decrease heavy metal availability through immobilization (Yi *et al.* 2007) and that was probably the reason for the low content of these metals in the soil. However, in case of cadmium, the content was above the permissible limit indicating contamination. According to Elinder (1992), concentration of available cadmium in soil

Table 1. Chemical properties of the wetland soil under greater club rush

Parameter	Composition	Rating
pH	4.97	Strongly acidic
EC (ds/m)	0.25	Non saline
Organic carbon (%)	2.99	High
Organic matter (%)	5.14	High
Available N (kg/ha)	339.00	Medium
Available P(kg/ha)	22.51	Medium
Available K(kg/ha)	278.10	Medium

Table 2. Heavy metal composition of the soil

Heavy metal	Composition (ppm)	Max. Permissible limit (ppm) #
Lead (Pb)	13.43	200
Nickel (Ni)	2.94	72
Chromium (Cr)	0.92	11
Cadmium (Cd)	0.67	0.48

increased with increase in soil acidity and strongly acidic nature of the selected site explained the high cadmium content.

Nutritive value of greater club rush

The nutritive value of greater club rush was found comparable with that of cultivated fodder crops like guinea grass, justifying its use as a livestock feed (**Table 3**). The crude protein and crude fibre content of the weed biomass were 7.5% and 26.75% respectively.

Table 3. Nutritive value of greater club rush (*Scirpus grossus* L. f)

Parametre	Composition (%)
Moisture	66.66
Dry matter	33.34
Total ash	7.96
Acid insoluble ash	2.30
Crude protein	7.50
Crude fibre	26.79
Ether extract (crude fat)	1.21
Nitrogen free ether	56.40
[(*K*/(*Ca+Mg*)]	1.39

The proximate analysis is a quantitative analysis technique of the different macronutrients in feed developed by Henneberg and Stohmann in 1865 (Lloyd *et al.* 1978). According to KAU (2011), the crude protein and crude fibre content of guinea grass (*Panicum maximum*) vary from 8 to 14% and 28 to 36 %, respectively, while gamba grass (*Andropogon gayanus*) has 5.5 % crude protein and 32.6% crude fibre. As per the standards set for silage quality, a crude protein range of 7 to 8% is considered good and moisture content of less than 70% is considered excellent (Rivera and Parish, 2010). Evidently, greater club rush with a crude protein content of 7.5% and moisture content of 66% could also be considered for silage making. In forage grasses, K/(Ca+Mg) ratio above 2.20 may cause grass tetany, which is a metabolic disease caused due to magnesium deficiency, especially in the cool season (Kumar and Soni, 2014). In greater club rush, the tetany ratio was 1.39, which is definitely within safe limits as a livestock feed.

Heavy metal accumulation in greater club rush

The results showed that the order of concentration of the heavy metals in the plant tissue was Ni > Cr > Pb > Cd (Table 4). Presence of heavy metals in feed can cause several health hazards directly to animals and indirectly to human beings who consume these animal products. Toxic heavy metals like cadmium affect biological functions, affecting hormone systems and growth (Rajaganapathy *et al.* 2011). Among the elements, lead, nickel and chromium contents were well within the permissible limit recommended by WHO (Nazir *et al*. 2015). However, the cadmium content was substantially higher than the regulatory standards for feed materials for cattle. Evidently, greater club rush being a phytoaccumulator had bioaccumulated higher level of cadmium from the cadmium contaminated soil. According to Blaylock and Huang (2000), the heavy metals that are available for plant uptake are those that are present as soluble components in the soil solution or those that are easily solubilized by root exudates. Even though the presence of high organic matter is likely to bind more of cadmium, the metal was available to plants in organically bound form as observed by Nigam *et al.* (2000). Further, the acidic soil pH must have also favoured cadmium uptake (Elinder 1992).

The values of biological concentration factor (BCF), translocation factor (TF) and bioaccumulation factor (BAC) of the heavy metals in greater club rush are shown in (**Table 4)**. Biological concentration factor (BCF) is an index of the ability of the plant to accumulate a particular metal in its roots with respect to its concentration in the soil (Ghosh and Singh 2005). The value was the highest for chromium followed by nickel, cadmium and lead. The BCF value more than 1, as in the case of chromium (1.67) indicated the plants' ability to act as a biostabiliser for chromium. On the other hand, the translocation factor (TF) was highest for cadmium (1.01)

Table 4. Heavy metal composition and transfer by greater club rush

Heavy Metal	Composition (ppm)	Max. Permissible limit (ppm)##	BCF	TF	BAC
Lead	0.10	2.0	0.02	0.43	0.01
Nickel	0.40	10.0	0.19	0.71	0.14
Chromium	0.39	1.3	1.67	0.25	0.42
Cadmium	0.03	0.02	0.05	1.01	0.05

##Nazir *et al*. 2015

BCF= Biological concentration factor; TF= Translocation factor; BAC= Bioaccumulation coefficient indicating that greater club rush was highly efficient in transfer of the heavy metal from the root to the shoot. The result is in line with the reports of Smolders (2001) who observed that cadmium is a metal which is easily absorbed by plant roots and transferred to the above-ground parts. The higher TF value also explained the higher concentration of cadmium in the plant tissues in the present study. This information is a matter of concern, since in many cases the weed may be growing in abandoned and consequently contaminated soils. Since metal concentrations consistently biomagnify from one trophic level to the next (Monteiro 1996), it is probable that animals higher in the food chain may accumulate toxic concentration of cadmium, especially when they are allowed free grazing on a luxuriant weed growth, as in the present case.

It can be concluded that the use of greater club rush as a livestock feed as practiced by local farmers is allowable in terms of its nutritional value. However, considering its potential as a phytoaccumulator, free grazing need to be curbed if the plants are growing in localities likely to be contaminated with heavy metals.

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Indian Journal of Weed Science 49(1): 79–81, 2017
DOI: 10.5958/0974-8164.2017.00019.3

Short communication

Weed management in lowland rice in Makurdi, Nigeria

P.A. Shave* and M.S. Anzenge
Department of Crop and Environmental Protection,
Federal University of Agriculture, P. M. B. 2373, Makurdi, Nigeria

Received: 29 January 2017; Revised: 27 March 2017

Keyword: Conventional tillage, Management, Methods, Yield, Lowland rice

Rice includes over twenty wild species and two cultivated species *Oryza sativa* Linn, (Asian rice) and *Oryza glaberrima* Steud (African rice) (Nwapu 2003). It is the grain with second-highest worldwide production after maize. Asian rice (*Oryza sativa* L.) has taken the pride of place in Africa over the traditional *Oryza glaberrima* and is being grown by farmers across the continent (Ng *et al.* 1988). Sub-Sahara Africa, and West Africa is the leading producer and consumer of rice. West Africa accounts for 64.2% and 61.2% of total rice production and consumption in the sub-Sahara Africa, respectively. Nigeria is said to rank highest as the producer and consumer of rice in the sub-region with figures slightly above 50%. In Nigeria, the crop is very important in the food economy, and is the only crop that is cultivated in all agro-ecological zones from coastal swamp to Sahel. The annual average consumption of the stable for an average Nigerian is as high as 24.8 kg of rice, which represent 9% of the total calorie intake.

Rice production in Benue state accounts for as much as 40% of total grown in Nigeria (Avav and Uza 2002). The fertile Fadama or flood plains of river Benue support much of the production. Most farms ranged in size from about 0.5 - 3.0 ha. However, the yield of rice is greatly affected by weeds. The weeds along with harboring insects, compete with crop for water, light and plant nutrient and adversely affect the micro-climate around the plant (Nojavan 2001). Therefore, study was done to determine the effect of some weed management methods on the yield of lowland rice at Makurdi, Nigeria.

The experiment was conducted between July to December, 2012 at the Teaching and Research Farm of Federal University of Agriculture, Makurdi (07^0 41^0N, 08^0E and 98m above sea level) in Southern Guinea Savannah agro-ecology zone in Nigeria. The experiment contained seven treatments in a randomized complete block design (RCBD) with three replications. The gross plot size was 4 x 4 m (16 m^2). The experimental site was sprayed with glyphosate at 1.44 kg/ha, 18 days before cultivation of the land. Thereafter, when the sprayed field had dried the land was cleared of the dried grasses and trees by slashing with cutlasses. The land was tilled by hand and made into flat seed beds using a hoe. The variety of rice *'Faro 44 (SIPI 692033)'* was used. Sowing was done on the 14^{th} July, 2012 by broadcasting the rice seeds at 80 kg/ha. Two hoe weeding were carried out according to treatments. The first hoe-weeding was done 3 weeks after sowing (WAS) while the second hoe-weeding was done 6 WAS. Herbicides were applied according to treatments as conventional tillage followed by (*fb*) 2,4-D at 1.44 kg/ha at 3 weeks after planting (WAS), conventional tillage *fb* propanil at 1.44 kg/ha at 3 WAS, conventional tillage *fb* one hoe weeding at 3 WAS, conventional tillage *fb* pendimethalin at 0.66 kg/ha, conventional tillage *fb* hoe weeding at 3 and 6 WAS, conventional tillage *fb* 2,4-D + propanil at 1.44 kg/ha at 3 WAS, conventional tillage and no weed control. Data was collected to determine the effect of the different weed management methods on the yield of lowland rice, Before the land was sprayed with glyphosate (1.44 kg/ha), an identification of the exiting weeds was made. Data on weed count was taken at 3 WAS using one meter square quadrant randomly. Three plants were selected at random from a replicated treatment and the number- of tillers per plant were counted. The height of rice plant was determined at maturity by taking three plants at randomly from each replication. Yield pareamers and yield data were taken. The experimental data was subjected to analysis of variance and the treatments were separated based on the fisher's least significant difference (F–LSD) at 5% level of probability (0.05--).

*Corresponding author: mosesanzenge@yahoo.com

Effect on weeds

The composition of weeds in the rice at 8 WAS had more of grasses and broad-leaved weeds dominating the experimental sites (**Table 1**). Treatment with 2,4-D at 3 WAS had the highest

Table 1. Common weeds at the experimental site

Family	Name of Weed	Level of Infestation
Grasses		
Poaceae	*Panicum laxum* Sw	+++
Poaceae	*Imperata cylindrica L.*	+++
Poaceae	*Rottboaellia cochinchinensis* Lour	+++
Poaceae	*Paspalum scrobiculatum* Linn	++
Poaceae	*Leptochloa caerulescens* Steud	+
Poaceae	*Echinochloa colona* Linn	+
Broad-leaves		
Asteraceae	Ageratum conyzoides	+++
Asteraceae	Tridax procumbens Linn	++
Poaceae	Panicum subalbidum Kunth	++
Onagraceae	Ludwigia hyssopifolia	+
Onagraceae	Ludwigia abyssinica A. rich	+
Amaranthaceae	Alternanthera sessilis Linn	+
Araceae	Pistia stratioles Linn	+

+++ = High Infestation; ++ = Medium Infestation; + = Low Infestation

number of grasses while 2,4-D + propanil at 3 WAS had the highest composition of broad-leaved weeds. The dominance of the experimental site by grasses indicated that grasses dominate the natural fallow in the study area. The dominance of grasses in plots treated with 2,4-D at 1.44 kg/ha was due to its low effect on grasses as conformed with Akobundu's report (1987). The dominance of broad-leaved weed in 2,4-D + propanil plots at 1.44 kg/ha + 1.44 kg/ha was due to the fact that the mixture of such herbicide does not have severe effect on broad-leaved weeds as single application does (**Table 2**). The synergistic effect as shown by Akobundu (1987) on weed has more effect on grasses than on broad-leaves, therefore favoring the establishment of broad-leaved weeds over grasses.

Effect of weed control on growth

The highest number of tillers (68.3) was found in plots treated with propanil at 3 WAS and 2 hoe weeding at 3 and 6 WAS gave 58.7 and 57.3 tillers, respectively. However, 44.0 number of tillers were obtained in treatment of 2,4-D at 3 WAS, which was the lowest among all other treatments, but was significantly superior to control plot (**Table 3**). This was explained by Fageria *et al.* (1997) that the decrease in the number of tillers per plant was attributed to the death of some of the last tillers as a result of their failure in competition for light and nutrient. Hoe weeded plots at 3 and 6 WAS enhanced plant height upto 113.9 cm at full maturity, followed by plots treated with propanil at 3 WAS, which resulted plant height of 133.9 cm at full maturity. Plots of 2,4-D + propanil resulted 114.8 cm plant height at maturity.

Effect on yield

The number of grains per panicle was not significantly affected by treatments including the

Table 2. Effect of weed management methods on weed composition

Treatment	Grasses (%)	Broad-leaved (%)
Conventional tillage followed by (*fb*) 2,4-D at 1.44 kg/ha at 3 Weeks after planting (WAS)	56.30	43.70
Conventional tillage *fb* propanil at 1.44 kg/ha at 3 WAS	51.10	48.90
Conventional tillage *fb* one Hoe weeding at 3 WAS	53.70	46.30
Conventional tillage *fb* pendimethalin at 0.66 kg/h	48.80	51.20
Conventional tillage *fb* Hoe weeding at 3 and 6 WAS	46.10	53.90
Conventional tillage *fb* 2,4-D + propanil at 1.44 kg/ha at 3 WAS	45.80	54.20
Conventional tillage, no weed control	54.00	46.00
LSD (p=0.05)	NS	NS

Table 3. Effect of weed control methods on number of tillers per plant and plant height

Treatment	Number of tillers per plant at 6 WAS (no./plant)	Plant Height at 9 WAS (cm)	Number of grains/ panicle	Grain yield (t/ha)	1000-grain weight (g)
Conventional tillage followed by (*fb*) 2,4-D at 1.44 kg/ha at 3 Weeks after planting (WAS)	44.00	85.90	186	1.07	24.00
Conventional tillage *fb* propanil at 1.44 kg/ha at 3 WAS	58.70	133.90	312	1.41	26.00
Conventional tillage *fb* one Hoe weeding at 3 WAS	46.30	104.80	268	2.03	25.27
Conventional tillage *fb* pendimethalin at 0.66 kg/h	46.70	103.40	237	1.22	23.17
Conventional tillage *fb* Hoe weeding at 3 and 6 WAS	57.30	141.70	300	2.45	25.37
Conventional tillage *fb* 2,4-D + propanil at 1.44 kg/ha at 3 WAS	47.70	114.80	356	2.33	25.10
Conventional tillage, no weed control	68.30	110.40	281	0.83	24.47
LSD (p=0.05)	NS	NS	NS	NS	NS

SE = Standard Error; $LSD_{0.05}$ = Least Significant Different; NS = Not significantly different at 5% level of probability (FLSD) control plots. The plots with treatments of 2,4-D + propanil at 3 WAS had the highest number of grains/ panicle as 356.00. This was followed by plots of 2 hoe weeding, which resulted in 281.0 number of grains/panicle while one hoe weeding resulted 268.0 number of grains/ panicle. Plots of pendimethalin had 237.0 number of panicle while 186.0 grains/panicle were obtained from 2,4-D treated plots (**Table 3**). Akobundu and Ahissou (1984) found that weed interference in rice adversely affect greatly, yield component such as tillering, panicle numbers as well as number of grains per panicle. The hoe weeding at 3 and 6 weeks gave the highest yield of 2.45 t/ha. Although, this was not significantly different from plots applied with 2,4-D + propanil at 3 WAS, which yielded 2.33 t/ha. Propanil at 3 WAS and pendimethalin *fb* 2, 4-D at 3 WAS also yielded 1.41 t/ ha and 1.07 t/ha respectively. The lowest yield of 0.83 t/ha was obtained in control plots. Singh *et al.* (1994) reported that combine application of herbicide and 2 mechanical hoe weeding was more effective in reducing weed growth and maximizing grain yield.

It was concluded that relative high yield was obtained from herbicides treated plots especially with 2,4-D + propanil For higher yield in lowland rice production at Makurdi, 2 hoe weeding at 3 and 6 WAS or application of a mixture of 2,4-D + propanil at 1.44 kg/ha + 1.44 kg/ha can be recommended.

SUMMARY

A trial was conducted on the research farm of Federal University of Agriculture, Makurdi, Nigeria during 2012 cropping season to evaluate the effect of weed management methods on the yield of lowland rice using the variety '*FARO 44 (SIPI 692030)*'. Seven treatments included conventional tillage (CT) with 2,4-D at 1.44 kg/ha at 3 WAS, CT followed by propanil applied at 1.44 kg/ha at 3 weeks after planting (WAS), CT followed by one hoe weeding at 3 WAS, CT followed by pendimethalin applied at 1.44 kg/ha, CT followed by 2 hoe weeding at 3 and 9 WAS, CT followed by 2,4-D + propanil 3 WAS at 1.44 kg/ha + 1.44 kg/ha, CT, no weed control. Results indicated that, although there was no significant differences. Trend showed that CT followed by 2 hoe weeding at 3 and 9 WAS gave the highest ($p<0.005$) yield of 2.45 t/ha followed by CT followed by 2,4-D + propanil at 1.44 kg/ha + 1.44 kg/ ha with 2.33 t/ha. Lowest yield of 0.83 t/ha was obtained from the control plot.

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Indian Journal of Weed Science **49**(1): 82–84, 2017
DOI: 10.5958/0974-8164.2017.00020.X

Short communication

Comparative performance of manual weeders under system of rice intensification in Indo-Gangetic plains

Bikash Sarkar, S.K. Singh, Rakesh Kumar, J.S. Mishra*, Ajay Kumar, Vikash Yadav, R.B. Reddy and B.P. Bhatt

ICAR-Research Complex for Eastern Region, ICAR Parisar, P.O: B.V. College, Patna, Bihar 800 014

Received: 19 January 2017; Revised: 19 March 2017

Key words: SRI, weeder, field capacity, weeding efficiency

Rice (*Oryza sativa* L.) is grown under diverse ecologies ranging from irrigated to rainfed upland, lowland and deep water. Traditional crop establishment, *i.e.* puddling and transplanting, requires large amount of water, energy and labour, which are becoming scarce and expensive (Mishra and Singh 2012). Weeds are considered to be one of the major biotic constraints in achieving the higher crop productivity as they cause a reduction of 10-90% grain yield in rice field (Kumar *et al.* 2016). System of Rice Intensification (SRI) is a modern and alternative method of rice cultivation for reduced use of seed, water and labour and to increase the crop productivity. But this system is much infested with weeds because growing under the limited water management. *Echinochloa* spp., *Cynodon dactylon, Portulaca quadrifida* and *Cyperus* spp. are the major weeds associated with SRI. Herbicides were proved effective but the continuous and indiscriminate use of herbicides for a longer period may result in buildup of problematic weeds and development of herbicide resistance. Adoption of rotary or cono-weeder use in SRI plays a significant role in improving the growth, yield and economics of rice. Weed management with improved tools not only uproot the weeds between crop rows but also ensuring the better soil aeration. Different type of weeders are available for weeding but all these designs are location specific and designed to meet the requirement of soil type, crop grown, cropping pattern and availability of the local resources (Goel *et al.* 2008). Hence, performance of promising manual weeders was evaluated in SRI under the middle Indo-Gangetic plains.

A field experiment was conducted at ICAR Research Complex for Eastern Region, Patna (25°35' N latitude and 85° 04' E longitude) during the *Kharif* 2016 to study the performance of weeders *i.e.* cono and Mandava weeder under the irrigated ecosystem. Soil of the experimental plot was clay loam (sand: 23.69%, silt: 39.64% and clay: 37%). The climate of experimental site was sub-tropical in nature exhibiting high humidity and medium rainfall. The rice cv. *'Pusa 1509'* (120 days duration) was used as test material. The monthly mean maximum and minimum temperature during the crop growing period ranged from 29.2 - 35.4^{0}C and 12.2 - 23.2^{0}C, respectively. The rice seedlings were transplanted at 25×25 cm apart. The specification of the experimental weeders is mentioned in **Table 1**.

Table 1. Specification of cono and Mandava weeder

Cono weeder	Mandava weeder
Length : 2040 mm	Length: 1500 mm
Nominal width:194 mm	Width (handle): 460 mm
Working width: 125 mm	Nominal width: 150 mm
Height: 1120 mm	Working width: 120 mm
Width (handle): 500 mm	Height: 1000 mm
Type of handle: T-Type	Type of handle: T-Type
Number of rotors: 02	Number of rotors: 01
Weight: 6.1 kg	Weight: 5.1 kg
Unit Cost: ` 1200/-(approx.)	Unit Cost: ` 1000/- (approx.)

Different test parameters were evaluated with formulae given as below:

Theoretical field capacity Theoretical field capacity was calculated with standard formula as suggested by Mehta *et al.* (2005).

$$\text{Theoretical field capacity} = \frac{\text{Working width} \times \text{Speed}}{10} \text{................(1)}$$

Where, working width in m and speed in km/h

Effective field capacity: Effective field capacity is an average output of the weeder per hour and calculated from total area weeded in ha and the total work time (Mehta *et al.* 2005).

$$\text{Effective field capacvity} = \frac{\text{Area covered by weeder}}{\text{Total time taken} \times 10000} \text{........(2)}$$

Where, Area covered in m^2 and total time in hr

Field efficiency: It is the ratio of the effective field capacity to theoretical field capacity and expressed in percent (%) and it was calculated by using the formula as suggested by Mehta *et al.* (2005).

$$\text{Field efficiency (\%)} = \frac{\text{Effective field capacity}}{\text{Theoritica l field capacity}} \times 100\text{.......(3)}$$

***Corresponding author:** jsmishra31@gmail.com

$$\text{Field capacity} = \frac{W \times S}{10} \times \frac{E}{10} \text{............(4)}$$

Where, W= theoretical width of cut in m, S = speed of travel in km/h, E= field efficiency (%)

Weeding efficiency: Square loop (0.25 m^2) was randomly thrown to field and number of weeds including in loop was counted before and after weeding (Rangasamy *et al.*1993). Three sets of observations were taken and weeding efficiency was calculated as below.

$$\text{Weeding efficiency (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \text{.........(5)}$$

Where, W_1= number of weeds before weeding, W_2= number of weeds after weeding

Plant damage: It was calculated by counting the number of injured plants and total number of plants in sample plot and expressed in per cent (%) (Biswas and Yadav 2004).

$$P_d = \frac{A}{B} \times 100 \text{...................................(6)}$$

Where, Pd = Plant damage (%), A=Injured plant (no.), B = Total no. of plant in sample plot

The human energy co-efficient 1.96 MJ was considered as suggested by De *et al.* (2001)

Pushing force measurement: The force requirement of operation was determined in field using spring balance and three persons involved in test (**Figure 1).** Spring balance was fixed between pulling wire and one person pulled weeder, while another person recorded data of spring balance and third person just held handle of weeder along with line of action.

$$Draft = Pulling\ Force \times Cos\,\theta \text{ .... Eqn. (7)}$$

$$Pushing\ Force = \frac{Draft}{Cos\,\theta} \text{............................ Eqn. (8)}$$

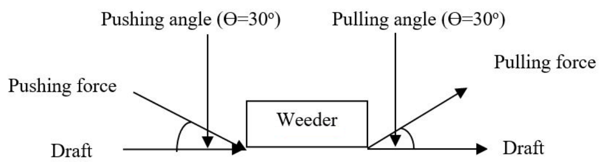

Figure 1. Pushing force measurement

Weed flora

Major weed associated with crop was grasses, broad-leaved weeds and sedges. Among grasses, *Echinochloa crus-galli* (L.), *Echinochloa colona* (L.) Link, *Eleusine india* (L.) Gaertn., *Leptocholoa chinensis* (L.) Nees, *Cynodon dactylon* (L.) Pers.; broad-leaved weeds (BLW) *Trianthema, portulacastrun* L., *Euphorbia hirta* L.; sedges *viz. Cyperus rotundus* L. and *Cyperus iria* L. were important weed flora during the experimentation. The relative dominance of BLWs, grasses and sedges was recorded as 84, 11 and 5%, respectively.

Field capacity of Mandava weeder was higher (0.0168 ha/hr) than cono-weeder (0.0149 ha/hr). The lower value of effective field capacity for cono-weeder was also reported by Shakya *et al.* (2016). The wide difference in the values of field capacity in both the weeders may be due to difference in width of cutting parts (blades) as well as forward speed. Mandava weeder facilitates worker by providing easy push and pull action to the implement as compared to cono-weeder. Field efficiency was higher with Mandava weeder (89%) as compared to cono-weeder (87%). Higher field efficiency of weeder was because of minimum time loss in turning and during operation (Shakya *et al.*2016). Weed density of 84 and 96/m^2 was recorded before weeding with the cono-weeder and Mandava weeder, respectively (**Table 2**). The maximum weeding efficiency was found with Mandava weeder (88%) as compared to cono-weeder (71%) which might be due to greater soil contact and soil inversion capacity of the weeder. The wide difference in the values of weeding efficiency in both weeders may be due to difference in shape of blades and depth of operation. The average value of plant damage factor for cono and Mandava weeder were obtained 7.58 and 6.17% respectively, which was 30% lower in developed cono-weeder reported by Shakya *et al.* (2016). Involvement of man power was examined with respect to weeder used in controlling weeds of rice under SRI and it was noted that Mandava weeder consumed the minimum man-days/ha (7.44).

Human energy: The highest human energy was consumed by cono-weeder (131.39 MJ/ha) as compared to Mandava weeder **(**116.65 MJ/ha). As, cono-weeder required the highest energy, it was not found to be economical in terms of eco-energetics (**Table 3**). But Mandava weeder was not only proved efficient in terms of eco-energetics but also useful in completing weeding in lesser time.

Pushing force measurement: Result showed that forces of 98°74' N and 68°64'N are required for 10

Table 2. Weed density (no./m^2) and weed control efficiency (WCE) as affected by two weeders

Weeder	Grasses (no no./m^2)	Broad-leaved weeds (no./m^2)	Sedges (no./m^2)	Weed count (no./m^2) before weeding	Weed count (no./m^2) after weeding	Weeding efficiency (WCE %)
Cono-weeder	71.0	9.24	4.20	84	24	71
Mandava weeder	80.64	10.56	4.80	96	12	88

and 30 mm water depth, respectively in cono-weeder, while in mandava-weeder; they were 89.38 N and 61.14 N, respectively (**Table 4**).

Ergonomics Evaluation: Ergonomic study was carried out with 5 male workers for weeding in SRI. Anthropometric rod and weighing balance were used to measure the physical characteristics and stop watch for recording time. Polar Heart Rate Monitor (RS-400, Finland) was used for recording heart rate of subject. To evaluate the weeding through ergonomic point of view, 5 workers in age group of 21 to 46 yrs were selected and average age as 33.8 yrs, body height of 167.8 cm and weight 66.60 kg, respectively (**Table 5**).

Physiological stress of weeding was determined on the basis of parameters *i.e.* heart rate during work and rest, energy expenditure and cardiac cost of work while performing activity (**Table 6**).

There was 10.4% increase in working efficiency with usage of the mandava weeder. The output recorded by Mandava weeder was 168 m^2/hr as compared to cono-weeder (149 m^2/hr). During weeding with cono and Mandava weeder, ÄHR was 27.6 and 24.4 beats/min, respectively. Energy expenditure was 8.57 kJ/s and cardiac cost 11.15 beats/m^2 for cono-weeder. However, in case of Mandava weeder it was found 7.68 kJ/s and 8.71 beats/m^2 of energy expenditure and cardiac cost, respectively. Manduva weeder saved 21.88% cardiac cost and increases efficiencd 10.38%.

Table 3. Human energy requirement for weeders in SRI rice field

Weeder	Human (Man-hr/ha)	Energy requirement (MJ/ha)
Cono weeder	67.04	131.39
Mandva weeder	59.52	116.65

Table 4. Pushing force vs. water levels in rice field

Water levels	Pushing force (N)	
	Cono-weeder	Mandava weeder
Dry	196.2	188.58
10 mm	98.74	89.38
30 mm	68.64	61.14

Table 5. Physical characteristics of selected male farmers (N=5)

Physical characteristic	Mean±SD
Age (yrs)	33.80±9.18
Height (cm)	167.80±3.96
Weight (kg)	66.60±4.28

Table 6. Performance of male farmers during field operation (N=5)

Particular	Cono-weeder	Mandava weeder
Average working heart rate (beats/min)	108.8±10.47	103.2±10.64
Average heart rate during rest (beats/min)	81.2±5.59	78.8±7.39
Δ HR (beats/min)	27.6	24.4
Output (m^2/hr)	149	168
Energy expenditure (kJ/s)	8.57	7.68
Cardiac cost (beats/m^2 area covered)	11.15	8.71
Reduction in drudgery (%)	-	10.38
Increase in efficiency (%)	-	21.88

SUMMARY

Two weeding tools were evaluated in SRI. Maximum weeding efficiency was recorded with mandava weeder as compared to cono-weeder. Mandava weeder consumed minimum man-days/ha. Therefore, mandava weeder may be promoted at farmer's fields in wider scale as it reduces energy use of small and marginal farming community of the Indo-Gangrtic Plains of the Eastern India.

ACKNOWLEDGEMENTS

The senior authors sincerely acknowledge to the 'Sir Jamsed Ji Tata Trusts' Mumbai for technical and financial support to conduct the present study.

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Indian Journal of Weed Science **49**(1): 85–87, 2017
DOI: 10.5958/0974-8164.2017.00021.1

Short communication

Weed management and nitrogen application for improved yield of mustard

Sontara Kalita*, S.L. Mundra, N.S. Solanki and Naresh Kumar Sharma
Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology Udaipur, Rajasthan 313 001

Received: 29 December 2016; Revised: 21 January 2017

Key words: Mustard, Pre-emergence herbicides, Weed management

Rapeseed and mustard is the second major oilseed crop after groundnut in India, accounting nearly 25-30% of total oilseeds production. As an irrigated crop in North-West India, Indian mustard suffers more from weed competition especially at the early stage of crop growth. Weeds caused yield reduction to the tune of 10-58% (Banga and Yadav 2001 and Malik *et al.* 2012) depending on the type, intensity and duration of competition. Uncontrolled weed reduced mustard yield by 68% as compared to weed free condition (Degra *et al.* 2011). Moreover, competition of weeds with crop plant causes severe nutrition deprivation in general (Roshdy *et al.* 2008) and nitrogenous fertilizer in particular on small, marginal and rocky areas of tribal dominated population. The most common practice of weed management in Indian mustard is manual weeding at 3-4 weeks after sowing. But, increasing wages, scarcity of labour at peak periods and high cost involvement compel to search other alternatives which are technically feasible and economically viable so that these measures can manage the weed below the economic threshold level and allow harnessing the yield potential of this crop. Optimum nitrogen dose enhances the yield by influencing a variety of growth and yield parameters and also provides lush green colour of the crop canopy and concurrently increasing the competitive ability of the crop. Considering these facts, a field experiment was carried out to find out the most effective weed management practice and nutrient level in Indian mustard.

Field experiment was conducted during *Rabi*, 2014-2015 on clay loam soil of Instructional farm, Rajasthan College of Agriculture, Udaipur, (Rajasthan). The soil of the experimental field was alkaline in reaction (pH 8.2), medium in available N (287.00 kg/ha) and P_2O_5 (20.51 kg/ha) and high in K_2O (286.88 kg/ha). The experiment involved 15 treatment combinations consisted of 5 weed management practices (pendimethalin 0.75 kg/ha as pre-emergence, oxadiargyl 0.09 kg/ha as pre-emergence, quizalofop-ethyl 0.05 kg/ha 25 days after sowing (DAS), hand weeding at 25 DAS and weedy check) and 3 nitrogen levels (45, 60 and 75 kg/ha). Indian mustard variety '*BIO-902*' ('Pusa Jaikissan') was sown with seed rate of 2.5 kg/ha on 2nd November 2014 at 30 x 10 cm spacing using package of practices available for Sub-Humid Southern Plain and Aravalli Hills'' of Rajasthan. Herbicides were sprayed with knapsack sprayer fitted with flat-fan nozzle using 500 liter of water/ha. The required doses of N for different treatments were applied both through urea and DAP after adjusting the quantity of nitrogen supplied by DAP for supplying 35 kg P_2O_5/ha. In each plot, weeds were counted category wise (monocot and dicot) from two predetermined randomly selected area of 0.25 m^2 using 0.5 x 0.5 m quadrate at 60 DAS and their average were subjected to square root transformation. At 90 DAS, weeds were removed and categorized as monocot and dicots and then were oven dried to obtain the weed biomass. Weed control efficiency at 90 DAS was calculated on the basis of weed biomass using the standard formula. Observations on other parameters were taken following standard procedure.

Weed flora

Monocot and dicot weeds predominant in the experimental sites were *Cynodon dactylon, Cyperus rotundus, Phalaris minor, Asphodelus tenuifolius, Anagallis arvensis, Chenopodium murale, Chenopodium album, Convolvulus arvensis, Fumaria parviflora* and *Melilotus indica.*

Weed density, dry matter and weed control efficiency

In general, the weed density of dicot weed was dominating at the site of experimentation. All the weed management practices except density and dry matter of dicot weeds due to quizalofop-ethyl 0.05 kg/ha, significantly reduced density as well as dry matter of monocot, dicot and total weeds compared to weedy

***Corresponding author:** sontara.kalita101@gmail.com

Table 1. Effect of weed management and nitrogen levels on weed density, weed dry matter and weed control efficiency in Indian mustard

Treatment	Weed density/m² at 60 DAS			Weed dry matter (kg/ha) at 90 DAS			Weed control efficiency (%) at 90 DAS		
	Monocot	Dicot	Total	Monocot	Dicot	Total	Monocot	Dicot	Total
Weed management									
Pendimethalin 0.75 kg/ha	4.35(18.4)	7.03(48.9)	8.24(67.3)	78.8	238.6	317.4	58.4	48.7	51.7
Oxadiargyl 0.09 kg/ha	3.94(15.0)	6.99(48.5)	7.99(63.5)	55.1	162.5	217.5	70.9	65.4	67.0
Quizalofop-ethyl 0.05 kg/ha	4.87(23.2)	10.60(112.1)	11.65(135.3)	71.9	458.9	530.9	62.1	2.5	19.7
One hand weeding 25 DAS	3.60(12.5)	4.23(17.6)	5.52(30.1)	50.2	151.1	201.2	73.5	67.8	69.5
Weedy check	9.39(87.7)	10.97(120.0)	14.43(207.7)	190.5	470.8	661.3	-	-	-
LSD (p=0.05)	0.16	0.45	0.35	9.7	30.8	33.9	-	-	-
Nitrogen levels									
45 kg/ha	5.21(31.5)	7.80(67.0)	9.43(98.5)	83.4	278.6	362.0	52.5	35.8	40.7
60 kg/ha	5.30(31.8)	7.93(69.4)	9.57(101.3)	91.2	294.2	385.4	52.5	37.7	42.1
75 kg/ha	5.37(32.5)	8.02(70.1)	9.69(102.6)	93.3	316.3	409.6	54.0	37.1	42.0
LSD(p=0.05)	NS	NS	NS	7.5	23.8	26.3	-	-	-

Figures in parentheses are original values, while outside are transformed values ($\sqrt{x+0.5}$)

check. Among weed management treatments, one hand weeding treatment resulted in minimum density of monocot, dicot and total weeds at 60 DAS compared to rest of the treatments which was followed by oxadiargyl 0.09 kg/ha and pendimethalin 0.75 kg/ha (Table 1). However, one hand weeding and oxadiargyl 0.09 kg/ha treatments were at par in reducing weed dry matter at 90 DAS. Oxadiargyl effectively controlled density of *Phalaris minor*, sedges, *Melilotus indica* and *Chenopodium* spp. and this result was in the line of findings of Punia *et al.* (2006) and Kumar *et al.* (2012). The highest weed control efficiency at 90 DAS (69.5%) was recorded under one hand weeding treatment closely followed by oxadiargyl 0.09 kg/ha (67.01%) in this regard. Thus, both these treatments provided the crop better environment for luxuriant growth and later on the crop itself acted as smoother crop and curbed the growth of weeds beneath the crop coverage. Application 75 kg N/ha increased dry matter of monocot, dicot and total weeds at 90 DAS compared to 45 kg N/ha.

Yield parameters and yield

Among different weed management treatments, one hand weeding at 25 DAS and oxadiargyl 0.09 kg/ha were found statistically at par in recording different yield attributes such as siliqua/plant, seeds/siliqua and weight of 1000 seeds as well as stover and biological yield (Table 2). One hand weeding at 25 DAS recorded maximum seed, stover and biological yields of 2.24, 5.59 and 7.83 t/ha, respectively, which was found statistically at par with pre-emergence application of oxadiargyl 0.09 kg/ha (2.23, 5.46 and 7.70 t/ha, respectively). The higher yield attributes and yield under these two treatments were attributed to minimum weed infestation and thus resulting into an overall favourable conditions for crop growth due to better availability of light, water, space and nutrients to the plant. Maximum harvest index (29.03 %) was registered with oxadiargyl 0.09 kg/ha, which was statistically at par with one hand weeding at 25 DAS and pendimethalin 0.75 kg/ha with respective harvest index values as 28.5 and 27.8% (Table 2). It is evident from results that uncontrolled weeds reduced yield of mustard by 26.1 to 70.7% due to vigorous growth of weeds and thus hampered the crop growth. Seed yield of the crop increased with each level of nitrogen application from 45 kg/ha to 75 kg/ha and was the manifestation of increase in yield attributes *i.e.* number of siliqua/plant, number of seeds/siliqua and weight of 1000 seeds (Table 2). Alike seed yield, stover yield was also increased significantly with increasing dose of N up to 75 kg/ha (Table 2). This result could be confirmed with the finding of Dongarkar *et al.* (2005). Harvest index was not affected significantly with different levels of nitrogen. It was well emphasized that application of 75 kg N/ha markedly improved overall growth of the crop in terms of dry matter/plant by virtue of its impact on morphological and photosynthetic components. The improvement in these growth parameters resulted competitive ability of crop with unwanted plants. This reflects great availability of nutrients and metabolites for different biosynthesis process of growth and development of both vegetative (source) and reproductive (sink) part, which resulted into increase in different yield attributes and yield.

Table 2. Effect of weed management and nitrogen levels on yield attributes, yield and economics in Indian mustard

Treatment	Siliqua/ plant	Seeds/ siliqua	Weight of 1000-seed (g)	Seed yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	Harvest index (%)	Net returns ($x10^3$ `)	B-C ratio
Weed management									
Pendimethalin 0.75 kg/ha	251.06	13.95	5.46	1.85	4.84	6.69	27.76	52.86	2.45
Oxadiargyl 0.09 kg/ha	286.24	15.08	5.64	2.23	5.46	7.70	29.03	67.14	3.05
Quizalofop-ethyl 0.05 kg/ha	240.93	14.39	5.39	1.65	4.51	6.17	26.78	44.91	2.04
One hand weeding 25 DAS	291.91	15.22	5.82	2.24	5.59	7.83	28.49	65.76	2.76
Weedy check	213.05	13.81	4.99	1.31	4.00	5.31	24.65	33.66	1.68
LSD (p=0.05)	24.21	NS	0.19	0.21	0.51	0.67	1.75	-	-
Nitrogen levels									
45 kg/ha	233.33	13.76	5.34	1.61	4.35	5.96	26.86	43.26	1.97
60 kg/ha	257.28	14.64	5.43	1.89	4.94	6.83	27.52	54.00	2.46
75 kg/ha	279.31	15.07	5.60	2.08	5.35	7.43	27.65	61.33	2.75
LSD (p=0.05)	18.75	NS	0.15	0.16	0.39	0.52	NS	-	-

Economics

Economic evaluation of the treatments revealed maximum net returns and B-C ratio (` 67136/ha and 3.05, respectively) was recorded under pre-emergence application of oxadiargyl 0.09 kg/ha followed by one hand weeding 25 DAS (` 65757/ha and 2.76, respectively). Among the nitrogen levels maximum net returns (` 61333/ha) and B-C ratio (2.75) were recorded under application of 75 kg N/ha (Table 2) due to higher seed and stover yields with comparatively less additional cost of nitrogen under this treatment.

SUMMARY

Pre-emergence application of broad spectrum herbicide oxadiargyl 0.09 kg/ha in mustard recorded the highest net returns and B-C ratio with greater seed yield comparable to one hand weeding. It was found that oxadiargyl 0.09 kg/ha is the alternative option of costly hand weeding practice in gaining higher yield in mustard. Among the N treatments, application of 75 kg N/ha recorded the maximum net returns (` 61333/ha) and B-C ratio (2.75) with higher seed yield.

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Indian Journal of Weed Science **49**(1): 88–89, 2017
DOI: 10.5958/0974-8164.2017.00022.3

Short communication

Effect of herbicides on weeds, grain yield and soil health in wheat

Raj Kumar*, R.S. Singh, Jaidev and Manoj Kumar
Narendra Deva University Agriculture &Technology, Kumarganj, Faizabad, Utter Pradesh 224 229

Received: 24 January 2017; Revised: 11 March 2017

Key words: Herbicides, soil health, microbial population, wheat, weeds and yield

The productivity wheat (*Triticum aestivum* L.) in eastern Uttar Pradesh is very low due to the continuous adoption of cereal-cereal (rice-wheat) cropping system, poor weed management, poor soil health and imbalance fertilizer use. Weed reduce wheat yield up to 60% if not controlled at the critical stages of crop (Angiras *et al.* 2008). Chemical weed control is a preferred practice due to unavailability of labour and high labour costs. Also there is lesser feasibility of mechanical or manual weeding in wheat. There is a need to evaluate such molecules of herbicides, which are safe to soil health. The effect of herbicide application on soil health (microbial environment) is a great concern as it may affect the microbial growth (Kumar *et al.* 2014). Continued application of large quantities of herbicides may bring about lasting changes in soil micro flora, and affecting its fertility level, respectively (Rangaswami and Bagyaraj 2004). Keeping all these view, the present investigation was carried out to find out herbicidal effect on soil health and yield of wheat.

The field experiment was conducted during *Rabi* 2014-15 at Narendra Deva University Agriculture & Technology, Kumarganj, Faizabad (UP). The soil of the experimental field was silt loam having pH 8.1, EC 0.23 dSm, organic carbon 3.1 g/kg, available N 120 kg/ha, available P 16.5 kg/ha, available K 247 kg/ha, bacteria 37.14 cfu/g, fungi 11.38 cfu/g and actinomycetes 8.19 cfu/g respectively. The experiment was laid out in a randomized block design with three replications having 12 treatments, *viz*. isoproturon 1.0 kg/ha, sulfosulfuron 0.025 kg/ha, metribuzin 0.2 kg/ha, clodinafop 0.06 kg/ha, pendimethalin + metribuzin (1.0+0.175 kg/ha), pendimethalin + sulfosulfuron (1.0+0.018 kg/ha), sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha), pinoxaden + metsulfuron (0.06 + 0.004 kg/ha), mesosulfuron + idosulfuron (0.012 + 0.0024 kg/ha), clodinafop + metsulfuron (0.06 + 0.004 kg/ha), two hand weeding and unweeded control. Wheat variety '*PBW-502*' was sown on 9th December 2014 in rows at 20 cm apart using seed rate at 125 kg/ha. Recommended dose of fertilizers 120:60:60 kg N:P;K/ha and herbicides were applied as per treatments. Growth, yield and weed density were recorded after harvesting the crop. Rhizospheric soil sample were collected randomly from the top layers of the soil depth (0-15 cm) from each plot for soil health studies by using standard methods.

***Corresponding author:** rkpnduat@gmail.com

Effect on weed density and yield of crop

Among different herbicides, application of pendimethalin + metribuzin 1.0 + 0.175 kg/ha followed by pendimethalin + sulfosulfuron 1.0 + 0.018 kg/ha were found better on plant height (62.40 and 61.30 cm) and grain yield [4.24 and 4.16 t/ha] of wheat. However minimum weed density (50.29/m) was also recorded in the same treatment. This may be due to effective control of weeds under this treatment.

Different weed control treatments increased N, P and K uptake over unweeded control (**Table 1**). Among different weed control measures, maximum uptake of N (102.41 kg/ha), P (23.73 kg/ha) and K (130.20 kg/ha) was recorded under T_5. It might be due to the fact that herbicides reduced crop-weed competition and enhanced the availability of nutrients (Singh *et al.* 2015).

Weed control measures did not affect the physical, chemical and microbial properties of soil significantly after harvesting the crop (**Table 2**). However, the microbial population (bacteria, fungi and actinomycetes) at 50 DAS were affected due to application of herbicides. But after harvest of the crop, there was no toxic effect on microbial population. This was mainly due to degradation of herbicides by micro-organism and degraded products serves as a carbon and energy sources due to which at harvest stage microbial population tended to improve. Among different weed control management, two hand weeding recorded maximum microbial population. This might be due to effect of aeration and sunlight into the soil with intercultural operation. Tiwari *et al.* (2012) and Priya *et al.* (2015) also reported the similar results.

Table 1. Herbicidal effect on plant height, no. of tillers, weed density, grain yield, B:C ratio and nutrient uptake of wheat.

Treatment	Plant height (cm)	No. of tillers/ plant	Weed density at 60 DAS (m^2)	Grain yield (t/ha)	B-C ratio	Nutrient uptake (kg/ha)		
						N	P	K
Isoproturon 1.0 kg/ha	56.90	4.65	(92.42) 9.67	3.23	1.41	76.46	16.85	101.1
Iulfosulfuron 0.025 kg/ha	57.40	5.10	(92.38) 9.66	4.47	1.55	82.50	17.99	106.0
Metribuzin 0.2 kg/ha	57.10	4.92	(111.66) 10.66	3.34	1.47	77.61	16.97	102 3
Clodinafop 0.06 kg/ha	56.20	4.50	(97.66) 9.93	3.31	1.39	77.58	16.78	100.8
Pendimethalin + metribuzin (1.0 + 0.175 kg/ha)	62.40	5.92	(50.29) 7.16	4.24	1.95	102.41	23.73	130.2
Pendimethalin + sulfosulfuron (1.0 + 0.018 kg/ha)	61.30	5.80	(56.93) 7.61	4.16	1.93	98.35	22.87	128.1
Sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha)	60.10	5.75	(65.30) 8.14	3.97	1.84	93.03	21.40	121.5
Pinoxaden + metsulfuron (0.06 + 0.004 kg/ha)	60.20	5.72	(76.74) 8.82	3.84	1.76	89.12	20.27	118.3
Mesosulfuron + idosulfuron (0.012 + 0.0024 kg/ha)	58.70	5.50	81.68) 9.09	3.80	1.69	89.93	19.71	116.8
Clodinafop + smetsulfuron (0.06 + 0.004 kg/ha)	58.10	5.34	(82.27) 9.13	3.78	1.67	89.62	19.60	115.9
Two hand weeding	63.50	6.06	(0.00)1.00	4.47	1.83	107.48	25.48	134.1
Unweeded control	55.70	4.20	(199.4)14.15	2.86	1.20	64.67	14.30	90.6
LSD (p=0.05)	3.95	1.14	-	.385	-	1.55	0.80	2.2

Table 2. Herbicidal effect on physical properties of soil, nutrient available and microbial population of wheat

Treatment	Physical properties of soil (After harvest)				Available nutrient (kg/ha) (After harvest)			Microbial population (gm soil)					
								Bacterial (cfu x 10^7)		Fungi (cfu x 10^4)		Actinomycetes (cfu x 10^4)	
	Bulk density (g/cm^3)	pH	EC (dSm)	O C (g/kg)	N	P	K	50 DAS	After harvest	50 DAS	After harvest	50 DAS	After harvest
Isoproturon 1.0 kg/ha	1.33	8.05	0.23	3.2	126.7	17.2	234.1	22.5	27.7	4.5	7.8	4.1	6.2
Iulfosulfuron 0.025 kg/ha	1.31	8.10	0.24	3.4	128.6	17.9	236.5	23.6	28.4	5.2	8.5	4.2	6.3
Metribuzin 0.2 kg/ha	1.32	8.05	0.21	3.1	127.8	17.2	235.6	23.4	28.2	4.9	8.2	4.1	6.2
Clodinafop 0.06 kg/ha	1.33	8.05	0.23	3.2	125.9	16.8	233.4	21.5	26.0	4.2	7.1	3.9	6.0
Pendimethalin + metribuzin (1.0 + 0.175 kg/ha)	1.28	8.20	0.22	3.5	134.0	19.0	242.8	29.8	34.6	7.2	10.5	5.7	7.8
Pendimethalin + sulfosulfuron (1.0 + 0.018 kg/ha)	1.28	8.20	0.23	3.5	133.9	18.9	241,5	29.5	34.5	6.4	9.5	5.4	7.5
Sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha)	1.29	8.10	0.24	3.4	132.4	18.7	240.0	28.2	34.2	6.2	9.5	5.1	7.2
Pinoxaden + metsulfuron (0.06 + 0.004 kg/ha)	1.30	8.05	0.25	3.2	131.7	18.6	239.5	26.4	32.5	5.7	9.0	4.9	7.0
Mesosulfuron + idosulfuron (0.012 + 0.0024 kg/ha)	1.30	8.05	0.21	3.3	131.1	18.3	238.7	25.5	32.0	5.4	8.7	4.7	6.8
Clodinafop + smetsulfuron (0.06 + 0.004 kg/ha)	1.31	8.10	0.22	3.3	129.8	18.2	237.1	24.1	30.2	5.1	8.5	4.4	6.5
Two hand weeding	1.27	8.00	0.25	3.6	135.2	19.2	244.5	43.5	45.9	11.5	11.7	8.3	8.7
Unweeded control	1.34	8.10	0.22	3.2	124.5	16.7	232.2	39.8	41.2	11.2	11.4	8.1	8.2
LSD (p=0.05)	NS	NS	NS	NS	2.3	1.4	1.9	1.34	0.90	1.01	0.96	0.69	0.82

SUMMARY

Application of pendimethalin + metribuzin 1.0 + 0.175 kg/ha was found most suitable for increasing growth, yield, nutrient uptake and economics. However, two hand weeding was found most effective for improving soil health. Microbial population was found affected at 50 DAS it was gain increased by the harvest time. hand weeding recorded maximum population.

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Indian Journal of Weed Science **49**(1): 90–92, 2017
DOI: 10.5958/0974-8164.2017.00023.5

Short communication

Weed management to improve productivity and nutrient uptake of *Rabi* maize

Pradeep Ram, G. Sreenivas, P. Leela Rani* and A. Madhavi
Department of Agronomy, College of Agriculture,Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad 500 030

Received: 4 January 2017; Revised: 15 February 2017

Key words: Crop, Herbicides, Mulches, Nutrient uptake, *Rabi* maize, Weeds, Weed management

In Indian agriculture, maize assumes a special significance on account of its utilization as food, feed and fodder besides several industrial uses. There are many socio-economic, physical and biological factors limiting the productivity of maize crop. Among the biotic production constraints, weeds play important role. Nature of weed problem in *Rabi* maize is quite different from that of the rainy season maize. Heavy application of fertilizers coupled with frequent irrigation favours the profuse growth of weeds in maize which compete with the crop for soil moisture, nutrients and space during the initial slow growth resulting in decline in productivity. Yield reduction from 33-90% has been reported in *Rabi* maize (Dalley *et al*. 2006). Approximately 65 - 80% of the plant total N is taken up by maize before silking, (Rajcan and Tollenaar 1999). After silking, less assimilates are supplied to roots as the kernels become the major sink for photo assimilates. In weedy check treatment, 14% reduction in yield was noticed when compared to weed free condition. Weed control can increase fertilizer use efficiency of the crop with checking wasteful removal of nutrients by weeds (Samant *et al*. 2015). Keeping this in view, present investigation was undertaken to study weed growth, yield and nutrient uptake in maize under varied sustainable weed management practice during winter season under irrigated conditions.

Experiment was conducted during *Rabi*, 2014-15 at College farm, Rajendranagar, Hyderabad, with eight sustainable weed management practices in randomized block design, replicated thrice (**Table 1**). Plant samples of crop and weeds were collected at the time of harvest from each plot. These were oven dried, ground into powder and chemically analyzed for N, P and K content as per recommended procedure as suggested by Subbiah and Asija (1956) for N, Olsen *et al*. (1954) for P and Jackson (1973) for K. The nitrogen, phosphorus and potassium uptake by crop and weeds was calculated by multiplying per cent content in the tissue with their respective dry matter values and expressed as kg/ha.

***Corresponding author:** leelagro@gmail.com

Weed flora

The floristic composition of the experimental site at physiological maturity stage was dominated by *Trianthema. portulacastrum, Trichodesma indicum, Parthenium hysterophorus, Melilotus alba, Digera arvensis, Dactyloctenium aegyptium, Cyperus rotundus, Cynodon dactylon, Commelina benghalensis Chenopodium album, Amaranthus polygamus* and *Eragrostis cilianensis.*

Effect on dry matter and yield

Reduced weed dry matter was noticed significantly in farmers practice (HW at 20 and 40 DAS), which was comparable with black and white polythene mulch (25 µm thickness UV resistant). Weed management practices brought about significant effect on crop dry matter (**Table 1**). Application of black polythene mulch showed significant increase in crop dry matter at physiological maturity stage. This was not differed significantly with white polythene mulch, farmers practice (HW at 20 and 40 DAS) and pre-emergence (PE) application of atrazine 1.0 kg/ha *fb* 2,4-D sodium salt 1.0 kg/ha at 30 DAS treatment. In polythene mulch treatment, weeds seeds might have failed to germinate due to lack of light and rise in temperature and also due to increase in minimum temperature required for normal growth and vigorous growth of the maize plants as reflected in plant height which caused an early crop canopy development and ultimately helped in smothering the weed flora. The higher dry matter in polythene mulch might be due to reflection of PAR into plant canopy, increased photosynthesis and biomass accumulation (Loy *et al*. 1998).

Nutrient uptake was found higher in treatments which produced higher biomass. Irrespective of the treatments, highest N, P and K removal was noticed with black polythene mulch, which was at par with white polythene mulch and farmers practice for grain nitrogen, whereas for grain P and K, higher removal was observed with black polythene mulch and was comparable with white polythene mulch and were followed by farmers practice and pre-emergence application of atrazin 1 kg/ha *fb* 2,4-D sodium salt 1.0 kg/ha at 30 DAS (**Table 2**). Increased stover NPK uptake was recorded with black and white polythene mulch and was at par with stover N uptake of farmers practice, stover P uptake of farmers practice and pre-emergence application of atrazine 1.0 kg/ha *fb* 2,4-D sodium salt 1.0 kg/ha at 30 DAS treatment. But, K stover uptake in mulch treatments was significantly superior over rest of the treatments. The higher removal of these nutrients by black and white polythene mulch was due to vigorous growth with adequate supply of these nutrients resulting in higher biological yield coupled with their effective transfer to the ultimate sink *i.e.* grains thus leading to numerically higher *Rabi* maize grain nutrient contents of N, P and K (Kaur *et al.* 2014). Among weed management practices, highest N, P and K removal from grain and stover of *Rabi* maize was observed from farmers practice (hand weeding twice at 20 and 40 DAS) and pre-emergence application of atrazine 1.0 kg/ha *fb* 2, 4- D sodium salt 1.0 kg/ha at 30 DAS. This could be attributed to higher weed control efficiency resulting in more favourable environment for growth and development of crop apparently due to the lesser weed competition. The results were in conformity with findings of Kour *et al.* (2014) in winter maize.

At harvest, higher NPK uptake of whole plant was recorded with black and white polythene mulch and was not differed significantly with N uptake and was comparable with farmers practice (hand weeding twice at 20 and 40 DAS). Even though whole plant P uptake was significantly superior in mulch treatments over other treatments, but it was at par with K nutrient uptake observed with farmers practice (hand weeding twice at 20 and 40 DAS) and pre-emergence application of atrazine 1.0 kg/ha *fb* 2,4-D sodium salt 1.0 kg/ha at 30 DAS (**Table 3**). This was due to efficient control of the complex weed flora due to which nutrient availability for crop increased, which helped to increase in higher dry matter accumulation in crops. The lowest nutrient uptake was recorded with weedy check. Results conformed the findings of Shrinivas *et al.* (2014).In farmers practice and other sustainable weed

Table 1. Effect of weed management on weed dry matter of crop and weeds grain yield of maize during *Rabi* 2014-15

Treatment	Weed dry matter (g/m)	Crop dry matter (g/plant)	Grain yield (t/ha)
Farmers practice (HW at 20 and 40 DAS)	4.86 (22.67)	451	7.07
Atrazine 1.0 kg/ha as PE *fb* 2, 4- D sodium salt 1.0 kg/ha at 30 DAS	9.71 (93.33)	445	6.91
Live mulch (vegetable cowpea)	6.55 (42.00)	250	4.26
Brown manuring (desiccation of cowpea live mulch at 50% flowering with 2, 4-D sodium salt 1.0 kg/ha)	6.80 (45.67)	327	3.86
Black polythene mulch (25 µm thickness UV resistant)	5.80 (32.67)	489	7.66
White polythene mulch (25 µm thickness UV resistant)	6.08 (36.00)	466	7.56
High density planting (planting on either side of the ridge) + halosulfuron methyl 67.5 g/ha at 20 DAS	7.02(53.00)	271	5.34
Weedy check (no weed control)	10.45(108.33)	232	3.85
LSD (p=0.05)	1.69	45.13	0.77

Figure in parentheses are original values transformed to $\sqrt{x+0.5}$; PE - Pre-emergence

Table 2. Effect of weed management on nutrient uptake by grain and stover of maize during *Rabi* 2014-15

Treatment	N (kg/ha)		P_2O_5 (kg/ha)		K_2O (kg/ha)	
	Grain	Stover	Grain	Stover	Grain	Stover
Farmers practice (HW at 20 and 40 DAS)	71	61	23	14	31	84
Atrazine 1.0 kg/ha as PE *fb* 2,4-D sodium salt 1.0 kg/ha at 30 DAS	68	47	22	13	27	79
Live mulch (vegetable cowpea)	44	40	14	11	16	70
Brown manuring (desiccation of cowpea live mulch at 50% flowering with 2,4-D sodium salt 1.0 kg/ha)	39	49	13	10	14	68
Black polythene mulch (25 µm thickness UV resistant)	79	58	28	14	34	99
White polythene mulch (25 µm thickness UV resistant)	79	58	28	14	33	95
High density planting (planting on either side of the ridge) and application of halosulfuron methyl 67.5 g/ha at 20 DAS	47	49	17	10	19	63
Weedy check (no weed control)	37	41	12	10	15	65
LSD (p=0.05)	3.52	3.43	1.34	0.78	1.15	4.19

Table 3. Effect of weed management practices on total nutrient uptake by crop and weeds at harvest in maize during *Rabi* 2014 15

Treatment	Crop (kg/ha)			Weeds (kg/ha)		
	N	P_2O5	K_2O	N	P_2O5	K_2O
Farmers practice (HW at 20 and 40 DAS)	132	37	115	3	0	4
Atrazine 1.0 kg/ha as PE *fb* 2,4-D sodium salt 1.0 kg/ha at 30 DAS	115	35	106	13	2	15
Live mulch (vegetable cowpea)	84	25	86	6	1	6
Brown manuring (desiccation of cowpea live mulch at 50% flowering with 2, 4-D sodium salt 1.0 kg/ha)	87	23	83	6	1	7
Black polythene mulch (25 µm thickness UV resistant)	137	41	133	5	1	6
White polythene mulch (25 µm thickness UV resistant)	137	42	129	5	1	6
High density planting (planting on either side of the ridge) and application of halosulfuron methyl 67.5 g/ha at 20 DAS	96	27	82	6	1	6
Weedy check (no weed control)	78	21	81	16	2	17
LSD (p=0.05)	16.73	4.81	12.64	0.92	0.19	1.14

management practices, weeds showed minimum nutrient depletion compared to pre-emergence application of atrazine 1.0 kg/ha and weedy check owing to function of concentration of nutrients and total weed biomass (Sinha *et al.* 2005).

Significantly more grain yield obtained under black polythene mulch, which was comparable with grain yield of white polythene mulch, farmers practice (HW at 20 and 40 DAS) and pre-emergence application of atrazine 1.0 kg/ha *fb* 2, 4- D sodium salt 1.0 kg/ha at 30 DAS. (**Table 1**). According to Tollenaar and Lee (2006) increase in maize grain yield under polythene mulches was mainly attributed to an increase in biomass production, especially during the reproductive stage. Thus it can be summerised that, sustainable weed management practices of application of either black or white polythene mulch of 25 µm thickness UV resistant is effective to get season long weed control with reduced weed drymatter and increased productivity in *Rabi* maize

SUMMARY

Present investigation was undertaken to study weed growth, yield and nutrient uptake in maize under varied weed management practice during winter season under irrigated conditions. Reduced weed dry matter was noticed significantly in farmers practice (HW at 20 and 40 DAS), which was comparable with black and white polythene mulch (25 µm thickness UV resistant). Application of black polythene mulch showed significant increase in crop dry matter at physiological maturity stage. highest N, P and K removal was noticed with black polythene mulch and was at par with white polythene mulch and farmers practice for grain nitrogen, whereas for grain P and K, higher removal was observed with black polythene mulch. Significantly more grain yield was obtained under black polythene mulch, which was comparable with grain yield of white polythene mulch, farmers practice (HW at 20 and 40 DAS) and pre-emergence application of atrazine 1.0 kg/ha *fb* 2, 4- D sodium salt 1.0 kg/ha at 30 DAS.

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Indian Journal of Weed Science **49**(1): 93–94, 2017
DOI: 10.5958/0974-8164.2017.00024.7

Short communication

Integrated weed management in chickpea

Alka Singh and Namrata Jain*
College of Agriculture, Tikamgarh, Madhya Pradesh 472 001

Received: 29 January 2017; Revised: 1 March 2017

Key words: Alachlor, Hand hoeing, Pendimethalin, Straw mulch, Weed mulch

Chickpea (*Cicer arietinum* L.) is the predominant crop among pulses in Madhya Pradesh occupying an area of 2722.36 thousand hectares with production of 3321.09 thousand tonnes and productivity 1.22 t/ha. Infestation of weeds is one of the major causes of poor productivity of chickpea. It is a poor competitor of weeds because of slow growth rate and limited leaf area development at early stages. Kumar *et al.* (2014) reported that presence of weeds throughout crop season reduced the seed yield of chickpea up to 68%. The predominant methods of weed control by mechanical hoeing and manual weeding over extensive scale have been declined because of shifting the agricultural labourers to industries for better and assured wages. The current trend and future development of intensive agriculture are likely to seek the help of chemicals as an effective weed control measures and replace the conventional method of weed control. Unfortunately till now, majority of the farmers are quite ignorant about the use of herbicides in chickpea. Mulching is also a good option to conserve moisture and reduce weeds. Mulch is used to cover soil surface around the plants to create congenial condition for the growth, reduce salinity and weeds (Bhardwaj 2013). The present experiment was aimed to find out the effective weed management practices for weed management in chickpea.

Experiment was conducted at Research Farm of College of Agriculture, Tikamgarh (M.P.) during *Rabi* season of 2015-16. The soil of the experimental field was clay loam in texture, medium in available nitrogen and potassium, high in available phosphorus with a pH of 7.3. The experiment was laid out in a randomized block design. The treatments comprised of pre-emergence pendimethalin 1.0 kg/ha, pendimethalin + hand weeding at 30 DAS, pendimethalin + hand hoeing at 30 DAS, alachlor 1.0 kg/ha, alachlor + hand weeding at 30 DAS, alachlor + hand hoeing at 30 DAS, straw mulch, weed mulch, weedy check and hand weeding twice at 20 and 40 DAS. Herbicidal spray solution was prepared by mixing the required quantity of herbicide as per the recommended dose in water 500 liters/ha. In straw mulch treatment, paddy straw was spread uniformly after the germination with the rate of 5 t/ha, whereas in weed mulch plots, the uprooted weeds of nearby area was spread uniformly on the soil surface about 4-5 cm after the germination. Chickpea variety '*JG-315*' was sown on 01 November 2015 using seed rate of 80 kg/ha. A basal dose of 20:60:20 N:P_2O_5:K_2O kg/ha was applied at the time of sowing. The observation on weed intensity and weed dry weight was recorded at 40 days after sowing with the help of quadrate of 1 metre square. Data on total weed intensity and dry weight were subjected to square root transformation ($\sqrt{x+0.5}$).

***Corresponding author:** j_namrata1@rediffmail.com

Weed flora

The prevalence of monocot weeds were found with relative density of 68.2% as compared to dicot weeds (24.2%). Among the monocots, *Cyperus rotundus* had the highest relative density (33.1%) followed by *Cynodon dactylon* (27.8%), while among dicots, *Launea pinnatifolia* registered the highest relative density of 13.3% followed by *Chenopodim album* (6.0%) and *Anagallis arvensis* (4.8%).

Weed growth

All the herbicidal treatments reduced the weed intensity and dry weight as compared to weedy check. Hand weeding twice was most effective and recorded minimum weed density and weed dry weight followed by pendimethalin at 1.0 kg/ha + hand weeding. Application of pendimethalin at 1.0 kg/ha + hand weeding and hand hoeing at 30 DAS and alachlor at 1.0 kg/ha + hand weeding and hand hoeing at 30 DAS recorded the lower weed intensity than their alone application. Kumar *et al.* (2010) also revealed that application of pendimethalin with one hand weeding significantly reduced the total weed density in chickpea. Hand weeding superseded over all the treatments and attained minimum weed biomass with highest weed control efficiency of 97.2% followed by pendimethalin 1.0 kg/ha + hand weeding at 30 DAS (92.9%), pendimethalin 1.0 kg/ha + hand hoeing at 30 DAS (90.4%) and alachlor + hand weeding (86.1%). Reduction in weed biomass

Table 1. Effect of different treatments on weed intensity, weed dry weight, weed control efficiency, yield attributes, seed yield (t/ha) and economics of chickpea

Treatment	Weed intensity	Weed dry weight (g/m^2)	Weed control efficiency	No. of pods/ plant	No. of seeds/ pods	Seed weight/ pod (g)	Test weight (g)	Seed yield (t/ha)	Net monetary return ($x10^3$ `/ha)	B:C Ratio
Pendimethalin 1.0 kg/ha as pre-emergence	6.78(45.7)	6.60(43.2)	73.51	77.00	2.33	0.25	17.43	1.57	47.34	2.98
Pendimethalin 1.0 kg/ha + hand weeding at 30 DAS	5.24(27.0)	3.25(10.1)	92.90	85.00	2.67	0.30	18.38	2.07	64.51	3.41
Pendimethalin 1.0 kg/ha + hand hoeing at 30 DAS	5.77(32.8)	4.23(17.5)	90.42	83.00	2.33	0.29	18.32	1.94	62.31	3.36
Alachlor 1.0 kg/ha as pre-emergence	7.41(54.4)	7.11(50.1)	60.41	70.67	2.67	0.24	17.30	1.51	45.77	3.00
Alachlor 1.0 kg/ha + hand weeding at 30 DAS	6.34(39.7)	3.88(14.5)	86.06	80.33	2.33	0.28	17.60	1.91	58.75	3.22
Alachlor 1.0 kg/ha + hand hoeing at 30 DAS	6.79(45.7)	4.39(18.8)	82.42	78.00	2.33	0.26	17.52	1.74	53.07	3.08
Straw mulch	7.79(60.2)	7.63(57.7)	53.83	63.00	2.00	0.23	17.20	1.19	31.71	1.95
Weed mulch	8.36(69.4)	8.33(68.9)	38.49	60.33	2.00	0.22	17.10	1.05	23.10	1.20
weedy check (control)	11.33(128)	12.8(164)	0.00	52.33	1.67	0.18	16.90	0.71	14.33	1.00
Two hand weeding at 20 and 40 DAS	3.98(15.3)	2.50(5.7)	97.19	88.33	2.67	0.32	18.59	2.38	75.74	3.73
LSD (P=0.05)	0.39	0.49		6.74	0.86	0.03	0.17	0.063		

Values in parentheses are original transformed to $\sqrt{x+0.5}$

and increased weed control efficiency under pre emergence application and alachlor followed by mechanical methods was due to complete removal of weeds at critical period of crop weed competition. The findings of Singh and Singh (2000) also revealed the effectiveness of integrated approach of pendimethain + one hand weeding in reducing the weed biomass and increase in weed control efficiency of chickpea.

Yield attributes and economics

Yield attributing characters, *viz*. number of pods per plant, number of seeds per pod and test weight attained significantly higher values under two hand weeding followed by pre-emergence pendimethalin 1.0 kg/ha + hand weeding at 30 DAS (Table 1). Two hand weeding gave significantly higher yield attributes than rest of the treatments. Among the herbicidal treatments, pendimethalin + hand weeding at 30 DAS recorded significantly higher yield attributes than other herbicidal treatments. The results were in close conformity with Pedde *et al.* (2013). Straw mulch and weed mulch registered significantly lower yield attributing characters but was significantly higher than the weedy check.

Seed yield was significantly higher under all the weed control practices over weedy check. Two hand weeding at 20 and 40 DAS recorded the highest yield (2.38 t/ha) followed by pendimethalin 1.0 kg/ha + hand weeding at 30 DAS (2.07 t/ha). Pre-emergence application of pendimethalin 1.0 kg/ha and alachlor 1.0 kg/ha produced significantly higher seed yield over straw mulch and weed mulch.

The highest net monetary returns (` 75739/ha) was obtained with two hand weeding followed by pendimethalin + hand weeding and pendimethalin + hand hoeing. Benefit cost ratio was the highest under two hand weeding (3.73) followed by pendimethalin + hand weeding (3.41) and pendimethalin + hand hoeing (3.36) whereas it was the lowest under weedy check (1.00). Gore *et al*. (2015) also reported that application of pendimethalin 0.75 kg/ha + one hand weeding produced higher yield and gave highest net monetary returns and B:C ratio and found most effective and economical in controlling weeds and increasing the yield of chickpea.

SUMMARY

Hand weeding twice was most effective and recorded minimum weed density and weed dry weight followed by pendimethalin at 1.0 kg/ha + hand weeding and pendimethalin at 1.0 kg/ha + hand hoeing. Two hand weeding at 20 and 40 DAS recorded the highest yield (2.38 t/ha) followed by pendimethalin 1.0 kg/ha + hand weeding at 30 DAS (2.07 t/ha). Pre-emergence application of pendimethalin 1.0 kg/ha and alachlor 1.0 kg/ha produced significantly higher seed yield over straw mulch and weed mulch. The highest net monetary returns (` 75739/ha) was obtained with two hand weedings followed by pendimethalin + hand weeding and pendimethalin + hand hoeing.

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Indian Journal of Weed Science **49**(1): 95–97, 2017
DOI: 10.5958/0974-8164.2017.00025.9

Short communication

Crop geometry and weed management effect on weed dynamics in soybean

B.S. Nagre, A.B. Kamble*, N.J. Danawale and M.B. Dhonde
Department of Agronomy, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar 413 722

Received: 14 December 2016; Revised: 2 February 2017

Key words: Crop geometry, Economics, Herbicide, Soybean, Weed management

Soybean (*Glycine Max*. L. Merrill.) grown in rainy season faces severe weed competition. Weed competition in soybean at early stage of crop growth is critical, as it causes yield losses up to 35 to 50% (Tiwari and Kurchania 1990). The incessant rains do not permit timely inter-cultivations and manual control of weeds on account of high cost and labour shortage during need of weeding. There is a need for alternative methods for reducing the weed load during crop weed competition period of first 30-45 days. Therefore, present investigation was conducted to see the effect of crop geometry and weed management practices on growth and yield of soybean.

Experiment was conducted at Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar (Maharashtra) during *Kharif* (rainy) season, 2015. The experiment was laid out in factorial randomized block design consisted of two factors, first crop geometry, *viz.* 45 x 5 and 30 x 10 cm and second factor was weed management practices *viz*. pendimethalin as pre-emergence (PE) 0.75 kg/ha *fb* one hand weeding at 30 DAS (days after sowing), pendimethalin as PE 0.75 kg/ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS, one hoeing at 15 DAS *fb* hand weeding at 30 DAS, weedy check and weed free check. The soybean variety used was '*KDS-344*' (*Phule Agrani)*. The gross and net plot size were 6.0 x 5.4 and 5.6 x 4.5 m, respectively. The soil of experimental site was silty clay in texture, medium in available nitrogen (204 kg/ha), phosphorous (18 kg/ha) and very high in potassium (548 kg/ha) with pH of 8.18 and electrical conductivity of 0.16 ds/m. The recommended fertilizer dose (75:50:00 N, P_2O_5 and K_2O kg/ha) was applied as basal through urea and single super phosphate at the time of sowing. Growth and yield parameters of soybean crop, total weed density (no./m), weed dry matter (g/m) were periodically recorded by following standard methodology, Weed control efficiency (%), weed index (%), herbicide efficiency index (%) and crop resistance index (%) were calculated by using standard. The herbicide pendimethalin 38.7% CS was used as pre-emergence while imazethapyr 10% SL, propaquizafop 10% EC were applied as post-emergence by using 500 litre spray volume through knapsack spray pump fitted with flat fan nozzle.

***Corresponding author:** drarunkamble@gmail.com

Weed density and biomass

Crop geometry of 45 x 5 cm spacing recorded significantly lowest total weed density (3.55, 3.21 and 3.22 (no./m^2) at 28, 56 DAS and at harvest, respectively) as compared to 30 x 10 cm spacing (**Table 1**). This might be due to wider rows and closer plants hence significantly reduced weed population because increased competition from higher density of crop plants resulted in suppression of weeds. These results were in close conformity with the finding of Bishnoi and Mays (2002). Among the weed management practices, pendimethalin PE 0.75 kg/ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS recorded significantly lowest weed density while pendimethalin PE 0.75 kg/ha *fb* one hand weeding at 30 DAS recorded lowest weed density at 56 DAS and at Harvest. This might be due to application of pre-emergence herbicide, which effectively hindered the germination of weed seeds while application of post-emergence tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS or hand weeding at 30 DAS effectively controlled latter emerged weeds. These results were in close conformity with Jadhav *et al.* (2013).

Soybean dibbled at geometry of 45 x 5 cm recorded significantly the lowest weed dry matter at harvest (5.28 g/m^2) as compared to 30 x 10 cm spacing (**Table 1**). It might be due to increased competition from higher density of crop plants resulted in reducing weed density and thereby reduced biomass of weed (g/m^2). These results were in close conformity with the finding of Bishnoi and Mays (2002). Among the weed management treatments, pendimethalin PE 0.75 kg/ha *fb* one hand weeding at 30 DAS registered significantly lowest weed biomass at harvest (4.04 g/m^2) as compared to the rest of the treatments.

Weed control efficiency

Crop geometry 45 × 5 cm spacing recorded significantly higher weed control efficiency (74%) at harvest as compared to 30 × 10 cm spacing. Pendimethalin 0.75 kg/ha *fb* one hand weeding at 30 DAS and pendimethalin 0.75 kg/ha *fb* tank mix application of imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS recorded highest weed control efficiency of 89 and 88%, respectively at harvest (**Table 1**).

Weed index and herbicide efficiency index

Crop geometry of 45 x 5 cm spacing recorded numerically lowest weed index (11.7%) and highest herbicide efficiency index value (1.3) as compared to 30 x 10 cm spacing (12.1 and 0.5, respectively). This might be due to less crop-weed competition during the growing period of the crop resulted in better yield. Among the weed management practices pendimethalin 0.750 kg/ ha *fb* one hand weeding at 30 DAS (3.86) and pendimethalin 0.75 kg/ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS (3.96) recorded the lowest weed index indicating minimum yield loss due to weeds compared to weed free check. The herbicide efficiency index value was numerically highest in pendimethalin 0.75 kg/ha *fb* one hand weeding at 30 DAS (2.04) followed by pendimethalin 0.75 kg/ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS (1.43) (**Table 1**). The minimum value of weed index with pendimethalin 0.75 kg/ha *fb* one hand weeding at 30 DAS indicated less yield losses due to weeds because of less crop-weed competition during the growing period of the crop resulted in better yield. These results are close conformity with the finding of Nainwal *et al.* (2010).

Crop resistance index

Crop geometry of 45 x 5 cm spacing recorded significantly highest crop resistance index value (9.6) as compared to 30 x 10 cm spacing (6.7). Among the integrated weed management treatments, pendimethalin 0.75 kg/ha *fb* one hand weeding at 30 DAS recorded significantly highest crop resistance index (15.2) followed by the pendimethalin 0.750 kg/ ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS (12.9) (**Table 1**).

Grain and straw yield

Crop geometry of 45×5 cm recorded significantly highest soybean grain yield (2.08 t/ha) and straw yield (2.85 t/ha) as compared to 30 × 10 cm spacing (1.83 t/ha) and (2.23 t/ha), respectively (**Table 2**). Results suggested that in wider spacing, lowest weed competition due to suppression of weeds and more interception of sun light by crop increased photosynthetic activities resulted in better

Table 1. Effect of crop geometry and weed management practices on weed dynamics

Treatment	Total weed count (no./m^2)			Weed dry matter (g/m^2) at harvest	WCE (%) at harvest	Weed index at harvest	Herbicide efficiency index at harvest	Crop resistance index at harvest
	28 DAS	56 DAS	At harvest					
Crop geometry								
30 x 10 cm	3.76 (20.06)	3.45 (17.79)	3.46 (17.99)	5.63 (49.91)	71.08	12.1	0.53	6.70
45 x 5 cm	3.55 (18.65)	3.21 (16.38)	3.22 (16.59)	5.28 (46.25)	73.85	11.6	1.27	9.58
LSD (p=0.05)	0.15	0.19	0.19	0.07	0.58	NS	0.01	0.61
Weed management								
Pendimethalin PE 0.75 kg/ha *fb* one hand weeding at 30 DAS	3.89 (14.66)	2.44 (5.49)	2.44 (5.49)	4.04 (15.85)	89.42	3.9	2.04	15.24
Pendimethalin PE 0.75 kg/ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS	1.67 (2.33)	2.59 (6.32)	2.59 (6.32)	4.39 (18.88)	87.69	4.0	1.43	12.89
One hoeing at 15 DAS *fb* hand weeding at 30 DAS	3.96 (15.32)	2.74 (7.15)	2.74 (7.15)	4.47 (19.60)	85.21	9.0	1.03	11.56
Weedy check	8.06 (64.48)	8.18 (66.48)	8.24 (67.48)	13.66 (186.1)	0.00	42.7	0.0	1.0
Weed free check	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	100.0	0.0	0.0	0.0
LSD (p=0.05)	0.24	0.30	0.30	0.10	0.92	1.9	0.01	0.97

Original values are in parentheses transformed to $\sqrt{x + 0.5}$; PE= Pre-emergence

Table 2. Effect of crop geometry and weed management on plant growth and yield and economics of soybean

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (x10^3 `/ha)	Net returns (x10^3 `/ha)	B : C Ratio
Crop geometry					
30 x 10 cm	1.83	2.23	38.39	30.41	1.81
45 x 5 cm	2.08	2.85	40.18	38.20	1.96
LSD (p=0.05)	0.03	0.03	-		
Weed management					
Pendimethalin PE 0.75 kg/ha *fb* one hand weeding at 30 DAS	2.17	2.71	37.65	43.85	2.16
Pendimethalin PE 0.75 kg/ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS as POE	2.15	2.71	36.65	44.36	2.21
One hoeing at 15 DAS *fb* hand weeding at 30 DAS	2.00	2.45	37.83	37.55	1.99
Weedy check	1.26	2.19	31.33	16.40	1.52
Weed free check	2.19	2.71	52.99	29.36	1.55
LSD (p=0.05)	0.04	0.05	-		

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

utilization of nutrients, light, moisture and space by soybean crop for growth and development which reflected its effect into reproductive growth of soybean crop in terms of yield. These results are close conformity with the findings of Pandya *et al.* (2005). Weed free check treatment recorded significantly highest soybean grain yield (2.2 t/ha) and straw yield (2.7 t/ha), but it was at par with pendimethalin 0.75 kg/ha *fb* one hand weeding at 30 DAS (2.2 t/ha) and (2.7 t/ha), respectively. These results were in close conformity with the findings Habimana *et al.* (2013).

Economics

Crop geometry 45 x 5 cm spacing recorded highest net monetary returns (` 38205/ha) and B:C Ratio (1.96) as compared to 30 × 10 cm crop geometry (` 30411/ha) and (1.81), respectively (**Table 2**). This might be due to higher grain and straw yield. Pendimethalin 0.75 kg/ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS recorded significantly highest net monetary returns (` 44362/ha) and B: C Ratio (2.21) but was at par with pendimethalin 0.75 kg/ha *fb* one hand weeding at 30 DAS (` 43858/ha) and (2.16). These results are close conformity with the findings of Sankaranarayanan (2002).

It was concluded that geometry of 45 x 5 cm spacing as well as both weed management practices, *viz.* pendimethalin PE 0.75 kg/ha *fb* one hand weeding at 30 DAS and pendimethalin PE 0.75 kg/ha *fb* tank mix imazethapyr + propaquizafop (80 + 60 g/ha) at 25 DAS recorded significantly lowest total weed count, weed dry matter and weed index while higher WCE, herbicide efficiency index, crop resistance index and higher soybean grain, straw yield, net returns and B:C ratio.

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Indian Journal of Weed Science **49**(1): 98–99, 2017
DOI: 10.5958/0974-8164.2017.00026.0

Short communication

Chemical control of weeds in dry-seeded rice

Tej Pratap*, V. Pratap Singh and Rekha
G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand 263 145

Received: 21 December 2016; Revised: 2 February 2017

Keywords: Dry seeded rice, Herbicides combination, Weed biomass, Weed control efficiency, Grain yield

Rice (*Oryza sativa* L.) is the principal crop of India cultivated in an area of 43.95 million hactares annually with a production of 106.65 million tonnes, with an average productivity of 2.4 t/ha (Ministry of Agriculture 2015). The conventional system of rice production *i.e* transplanting under puddled conditions is mainly followed by farmers. However, it is water, labour and energy intensive. Therefore, to assure sustainability of rice production, more resource efficient alternative methods of rice cultivation are needed. The dry seeded rice (DSR) technology being water, labour, energy efficient and having eco-friendly characteristics, received much attention as a potential alternative to transplanting under puddle conditions (Kumar and Ladha 2011). However, weed control is major limitation for the success of DSR as compared to transplanted rice (Chauhan and Yadav 2013). In DSR, weeds emerge simultaneously with crop seedlings and grow more quickly in moist soil than in puddled transplanted rice, resulting in severe competition for resources to the crop. Therefore, weeds present in the field are the main biological constraint to the success of DSR and failure to control weeds result in yield losses ranging from 50 to 90% (Chauhan and Opena 2012). Therefore, an experiment was conducted to study the sequential application of pre- and post-emergence herbicides and their combination along with hand weeding for weed control in dry seeded rice.

A field experiment was conducted at N.E.Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology Pantnagar, Uttarakhand during *Kharif* seasons of 2012 and 2013 to evaluate the efficacy of herbicides alone or in combination to control the weed flora in dry-seeded rice. The experiment consisted of ten treatments was laid out in randomized block design with three replications.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. Rice variety '*Narendra-359*' was sown at a row spacing of 20 cm on June 22, 2012 and June 14, 2013.The crop was raised with recommended package of practices. Pre-emergence herbicides were applied within 3 days of sowing using 750 liter water/ha whereas post–emergence herbicides were applied at 20 days of sowing by using a knapsack sprayer fitted with flat fan nozzle using water volume of 500 liter per hectare.The observations on density and weed biomass were taken at 60 DAS. Weed biomass was recorded and expressed in g/m^2. The data on weed density and weed biomass 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 was presented as t/ha.

***Corresponding author:** drtpsingh2010@gmail.com

Weed flora

The dominant weeds were *Echinochloa colona* and *Leptochloa chinensis* in grassy, *Ammania baccifera* and *Caesulia axillaris* in broad-leaved weeds and *Cyperus rotundus* among sedges.

Weed density, dry weight, weed control efficiency

The density of weeds was significantly influenced by weed control treatments in both the years at 60 DAS (**Table 1**). All herbicides reduced the growth of weeds compared to those observed in control. Among the herbicidal treatments total weed density was significantly reduced in pendimethalin1000 g/ha *fb* bispyribac-Na 25 g/ha + one hand weeding at 45 DAS, which was found statistically similar to pendimethalin 1000 g/ha + one hand weeding at 30 DAS and pyrazosulfuron 20 g/ha *fb* bispyribac-Na 25 g/ha, bispyribac-Na 20 g/ha + ready mix of chlorimuron-ethyl + metsulfuron-methyl 4 g/ha and bispyribac-Na 25 g/ha than other herbicidal treatments.

Table 1. Effect of weed management on total weed density, total weed dry weight, weed control efficiency at 60 DAS, yield attributes and grain yield of dry-seeded rice (pooled data of 2012 and 2013)

Treatment	Total weed density (no./m^2)	Total weed biomass (g/m^2)	Weed control efficiency (%)	No. of panicles /m^2	No. of grains /Panicle	Grain yield (t/ha)
Bispyribac-Na (25 g/ha)	7.9 (62.3)	7.4 (54.6)	82.4	222	146	3.6
Pendimethalin *fb* bispyribac-Na (1000 *fb* 25 g/ha)	11.0 (122.1)	4.1 (16.8)	94.6	274	170	5.3
Oxadiargyl *fb* bispyribac-Na (100 *fb* 25 g/ha)	9.5 (90.0)	5.1 (26.1)	91.6	269	159	5.2
Pyrazosulfuron *fb* bispyribac-Na (20 *fb* 25 g/ha)	7.7 (58.6)	6.4 (40.5)	87.0	238	158	4.1
Pendimethalin *fb* bispyribac-Na + hand weeding (45 DAS) (1000 *fb* 25 g/ha)	5.6 (31.7)	3.5 (12.0)	96.0	291	192	5.7
Pendimethalin + hand weeding (30 DAS) (1000 g/ha)	6.0 (35.3)	5.4 (29.5)	90.5	261	158	4.9
Bispyribac-Na + CME + MSM (20 + 4 g/ha)	7.6 (57.3)	7.0 (49.7)	84.0	210	145	3.6
Mechanical weeding (cono weeder) (20, 40 and 60 DAS)	6.2 (38.0)	11.5 (131.4)	57.7	193	137	3.4
Hand weeding (20, 40 and 60 DAS)	4.2 (17.3)	3.6 (12.7)	95.9	284	175	5.5
Weedy check	16.0 (247.7)	17.6 (310.6)	-	183	130	1.3
LSD (p=0.05)	2.5	2.0		51.1	28.5	0.32

Values within parentheses are original. Data are subjected to square root transformation $(\sqrt{x+1})$, CME+MSM- chlorimuron-ethyl + metsulfuron-methyl

Weed control treatments brought about significant variation in the total weed biomass at 60 DAS during both the years.The lowest weed biomass was recorded with pendimethalin 1000 g/ha *fb* bispyribac-Na 25 g/ha + one hand weeding at 45 DAS, which was significantly at par with thrice hand weeding at 20,40 and 60 DAS, pendimethalin1000 g/ ha *fb* bispyribac - Na 25g/ha, oxadiargyl 100 g/ha *fb* bispyribac 25 g/ha and pendimethalin 1000 g/ha + one hand weeding at 30 DAS as compared to other herbicidal treatments. Among the herbicidal treatments, maximum weed control efficiency was recorded with pendimethalin 1000 g/ha *fb* bispyribac-Na 25 g/ha + one hand weeding at 45 DAS (96.0%) followed by pendimethalin 1000 g/ha *fb* bispyribac-Na 25g/ha, oxadiargyl 100 g/ha *fb* bispyribac 25 g/ha and pendimethalin 1000 g/ha + one hand weeding at 30 DAS than rest of the herbicidal treatments.

Yield

All the weed control treatments resulted in significantly more panicles/m^2 and number of grains/ panicle as compared to weedy check. Application of pendimethalin 1000 g/ha *fb* bispyribac-Na 25 g/ha + one hand weeding at 45 DAS resulted in highest value of panicles/m^2 and number of grains/panicle over rest of the treatments (**Table 1**). The highest grain yield (5.7 t/ha) was recorded with pendimethalin 1000 g/ha *fb* bispyribac-Na 25g/ha + one hand weeding at 45 DAS, which was statistically at par with thrice hand weeding at 20, 40 and 60 DAS as compared to rest of the herbicidal treatments.Uncontrolled weeds in weedy check plots caused on an average 76.1% reduction in grain yield when compared with pendimethalin1000 g/ha *fb* bispyribac-Na 25 g/ha + one hand weeding at 45 DAS mainly due to highest density and weed biomass. Similar results were also reported by Bhat *et al.* (2013).

SUMMARY

Application of pendimethalin 1000 g/ha as pre-emergence *fb* bispyribac-sodium 25 g/ha as post-emergence + one hand weeding at 45 DAS was found most effective in controlling weeds resulted in higher weed control efficiency and grain yield.

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Indian Journal of Weed Science 49(1): 100–101, 2017
DOI: 10.5958/0974-8164.2017.00027.2

Short communication

Leaching behavior of oxyfluorfen in FYM amended and un-amended sandy clay loam soil

Asha Arora*
AICRP on Weed Management, RVSKVV, College of Agriculture, Gwalior, Madhya Pradesh 474 002

Received: 22 January 2017; Revised: 9 March 2017

Key words: Bioassay, FYM, Leaching, Oxyfluorfen

Herbicides are most successful weed control technology ever developed as they are selective, fairly easy to apply and offer flexibility in application time. Herbicides have come as big boon to farmers in areas where labour is limited and wages are high. But along with many advantages, there are some inadvertent disadvantages like shift in weed flora, herbicide resistance and herbicide residues in food chain and ground water. The potential of herbicides in contaminating the ground water have gained considerable attention in recent years.

Oxyfluorfen (Chloro-1-(3-ethoxy-4-nitrophe-noxy)-4-(trifloromethyl) benzene), belonging to diphenyl ether group, is a selective pre- and post-emergence herbicide used to control many annual broad-leaf and grassy weeds in vegetables, fruits, cotton, ornamentals and on non-crop areas. It acts by destroying cell membranes and causing rapid desiccation of the plant. Adsorption of pesticides by soils, that influence the movement of herbicides, has frequently been found to be correlated with organic matter and clay contents. The soil of northern Madhya Pradesh is low in organic matter. Therefore the present study was undertaken to study the mobility of oxyfluorfen in FYM amended and un-amended sandy clay loam soil of Gwalior (Madhya Pradesh).

Soil (0-15 cm depth) was collected from surrounding area of Research farm, College of Agriculture, Gwalior. The soil collection site was never treated with any herbicide. The soil was sandy clay loam in texture with sand 55.2%, silt 19.4% and clay 25.4%. The portion of soil was amended with FYM 20 t/ha, moistened with water and kept for 15 days, air dried and passed through a 2 mm sieve. The experiment was done at ambient temperature in a completely randomized design with three replications. Polyvinyl chloride (PVC) columns (10 cm internal diameter and 60 cm long) were cut vertically into two and joined together using adhesive tape. Muslin cloth was tied to one end to hold the soil. PVC columns were filled with soil (6 kg/column) and packed by gentle tapping the columns. The surface of each column was then covered with sand (3 cm) to maintain uniformity of the column surface during water application. One day before the herbicide application, 500 ml water was added from the top to pre condition soil. Oxyfluorfen was added directly to column after dilution with 10 ml water at doses equivalent to 230 and 460 g/ha. Sufficient quantity of water (200 ml per day) was added to encourage movement of herbicide. A set of columns was used without herbicide for comparison. At the end of the trial, (7 days) adhesive tape was cut and the column was split. The presence of herbicides at different soil depths was determined through bioassay using maize as sensitive crop by following the standard procedure. Plant height, fresh weight and dry weight of maize plant as affected by oxyfluorfen were recorded on 21 days after sowing (**Table 1**).

*__Corresponding author:__ ashaaroragwl@gmail.com

Leaching behaviour

The pH of the soil was 7.9 and 7.8, electrical conductivity 0.11 and 0.14 dS/m, and organic carbon 0.20 and 0.33% for non-amended soil and FYM amended soil, respectively. The leaching of oxyfluorfen was affected by concentration of herbicide as well as amendment of FYM as depicted by the growth of maize plant at different depth. Plant height and fresh weight of maize were reduced up to 30-35 cm and 35-40 cm at 230 and 460 g/ha oxyfluorfen, respectively in un-amended soil. In soil amended with FYM the oxyfluorfen leached down to 20-25 cm at 230 g/ha and 30-35 cm at 460 g/ha dose as evident by decrease in maize growth (**Table 1**). The presence of organic matter constitutes an impediment for oxyfluorfen movement because of its high adsorption capacity (Sondhia 2008). Ram Prakash *et al.* (2015) recorded 10 and 15 cm leaching of oxyflourfen in black and red soil of Hyderabad, respectively. Gustafson (1995) revealed that mobility of herbicide in soil is inversely related to its degree of

Table 1. Effect of oxyfluorfen on growth of maize at different depths in FYM amended and un-amended soil

Soil depth (cm)	230 g/ha						460 g/ha					
	Un-amended soil			FYM amended soil			Un-amended soil			FYM amended soil		
	Plant height (cm)	Fresh wt. (g/plant)	Dry wt. (mg/pl.)	Plant height (cm)	Fresh wt. (g/pl.)	Dry wt. (mg/pl.)	Plant height (cm)	Fresh wt. (g/pl.)	Dry wt. (mg/pl.)	Plant height (cm)	Fresh wt. (g/pl.)	Dry wt. (mg/pl.)
0 - 5	20.78	0.773	89	17.74	0.600	67	18.39	0.710	83	17.22	0.613	82
5 -10	20.77	0.717	78	17.91	0.659	77	18.78	0.611	73	16.23	0.604	76
10-15	22.24	0.823	83	17.25	0.648	68	17.52	0.732	83	17.07	0.636	63
15-20	21.66	0.809	78	18.54	0.793	88	21.22	0.766	83	17.05	0.737	67
20-25	23.72	0.840	86	17.44	0.748	80	21.75	0.707	88	20.22	0.830	68
25-30	24.27	0.961	99	28.11	1.250	133	21.11	0.836	97	24.66	0.746	81
30-35	26.55	1.121	124	27.22	1.275	109	26.00	0.926	104	25.22	0.865	109
35-40	31.44	1.533	160	29.72	1.203	128	26.33	0.903	107	27.16	1.118	131
40-45	30.24	1.474	165	28.99	1.056	133	28.00	1.287	122	30.22	1.056	125
45-50	30.66	1.519	135	30.50	1.210	123	30.22	1.286	111	31.26	1.210	136
Control	29.83	1.301	122	26.92	1.249	108	29.83	1.301	122	26.92	1.249	108

sorption to soil surface. The leaching of oxyfluorfen in amended soil up to less depth as compared to un-amended soil may be due to higher organic matter in amended soil resulting in higher absorptive capacity of the soil constituents for herbicide. Sondhia (2008) reported that oxyfluorfen may move up to 90 cm in soil profile under continuous and high rainfall conditions (850 mm natural rainfall) and thus may have potential to contaminate ground water. Janaki *et al.* (2012) reported that oxyfluorfen at recommended and double recommended level leached up to 60 cm in different textured soil, while Mishra *et al*. (2012) recorded leaching of this herbicide up to 15 cm only irrespective of concentrations in sandy clay loam soil. Yen *et al.* (2003) reported that oxyfluorfen was not very mobile in soil and may not contaminate ground water under normal conditions. But in soil of extremely low organic carbon content and coarse texture, oxyfluorfen has the potential to contaminate groundwater less than 3 m deep (Ying and Williams 2000).

SUMMARY

Leaching behavior of oxyfluorfen herbicide was evaluated under laboratory conditions in FYM amended (20 t/ha) and un-amended sandy clay loam soil. Oxyfluorfen at recommended and double the recommended level was applied in soil in PVC columns (10 cm diameter and 60 cm long). After seven days, the presence of herbicides at different soil depths was determined through bioassay by using maize as sensitive crop. The study revealed that oxyfluorfen leaches up to 30 to 40 cm in sandy clay loam soil and the leaching decreases to 20 to 35 cm by amendment of FYM indicating that organic carbon content is an important factor that influence the leaching of oxyfluorfen.

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Indian Journal of Weed Science **49**(1): 102–104, 2017
DOI: 10.5958/0974-8164.2017.00028.4

Short communication

Effect of cadmium uptake on growth and physiology of water lettuce

Mayank Varun*, Clement O. Ogunkunle[1], C. Sarathambal[2], Manoj S. Paul, Bhumesh Kumar[3]
Department of Botany, St. John's College, Agra, Uttar Pradesh 282 002

Received: 9 February 2017; Revised: 17 March 2017

Key words: Cadmium, Heavy metal, *Pistia stratiotes*, Phytoremediation, Uptake

Cadmium (Cd) is a major pollutant metal that is extremely toxic to organisms. Cadmium contamination occurs through the use of phosphate fertilizers and sludge, and inputs from mining and smelting industries (McGrath *et al*. 2001). Daily consumption of Cd-contaminated foods poses a risk to human health (Shukla *et al*. 2007). In Japan, Cd-contaminated rice caused Itai-itai disease near the Jinzu River basin in the middle of the 20th century. Even in recent years; rice is the major source of Cd intake of people in Japan (Watanabe *et al*. 2000). Cadmium is not an essential nutrient and at high concentration inhibits plant growth (Aery and Rana 2003). It has also been reported that even at relatively low concentrations, it alters plant metabolism (Van Assche and Clijsters 1990). The ability of aquatic macrophytes to uptake nutrients directly from water bodies and to assimilate them into their body is the greatest benefit of phytoremediation (Galal and Shehata 2014). Several aquatic plants effective in heavy metal uptake have been identified world over (Khankhane *et al.* 2014).

Pistia stratiotes L. is an aquatic plant. It grows abundantly in stagnant ponds, lakes and water bodies. The toxic effect of Cd has amply been documented both in the laboratory and under natural conditions in aquatic plants. Thus there was great need to assess toxic potential of Cd in *P. stratiotes* under such conditions. This study presents the toxicity and bioaccumulation potential of Cd in *P. stratiotes*.

Uniform plant of *Pistia stratiotes* were collected from ponds and brought to laboratory. Plants were cultured in 3% Hoagland's nutrient solution (pH 5.7) in laboratory under controlled conditions, illuminated with a light intensity of 45 µmoles $m^2/s^1/$ at 12 h/12 h light and dark cycle, under the temperature of 27 + 2 ºC. Each jar was amended with cadmium in increasing concentrations of 0.5, 1, 2.5, 5, and, 10 mg/L. Jar without any Cd treatment was used as control. $CdCl_2.4H_2O$ was preferred due to its stability and high solubility. pH of the solutions was adjusted to 5.7. The experiment was set up in triplicate for each concentration and test duration. Plant samples from each container were separately harvested after 3, 6, 9, 12, and 15 days to analyze for biomass productivity and total chlorophyll content.

Chlorophyll content of each plant was estimated according to Arnon (1949). Fresh leaves (40 mg) were soaked in 10 ml of 80% acetone and kept in a bottle covered with black carbon paper to prevent the entry of light and kept in a refrigerator for 4-5 days. The bottle was sealed to prevent evaporation of acetone. Care was taken to ensure that leaves of same age were taken from each treated plant. The absorbance of pigment extract was measured at both 663 nm and 645 nm on spectrophotometer. For biomass study, plant samples were kept in an oven at 80 ºC for 48 hr till a constant weight is obtained. The dry weight of plants for each metal concentration and exposure time was expressed as percentage decrease of biomass relative to controls.

Roots and leaves were analyzed by dry ash method where the samples were ashed in a muffle furnace and 0.5 g cooled ash was dissolved in HNO_3 and boiled for 20 min on a hot plate. The filtrate in each case was analyzed for Cd content by atomic absorption spectrophotometer (Analyst100, Perkin Elmer, USA), using an air-acetylene flame. Statistical evaluation of the data has been made by Pearson's correlation coefficient at a significance level of $p < 0.05$ and $p < 0.01$ with SPSS 16.0 statistics software. Factorial analysis of variance (ANOVA) was employed to test variance among readings. To isolate which group (s) differed from the others Fisher's LSD test was employed as a multiple comparison procedure.

***Corresponding author:** 30mayank@gmail.com
[1]Environmental Biology Unit, Department of Plant Biology, University of Ilorin, Nigeria 240 003
[2]ICAR - Indian Institute of Spices Research, Kozhikode, Kerala 673 012
[3]ICAR - Directorate of Weed Research, Jabalpur, Madhya Pradesh 482 004

Effect on biomass of weed

A significant reduction of biomass **(Figure 1)** was observed with the exposure time and increased metal concentration ($p<0.05$). The highest biomass (100%) was found in the control, while the lowest was found at 10 mg/L Cd (41.2%). The toxicity symptom in the form of chlorosis was observed in the leaves. The toxicity symptoms increased with increasing concentration and exposure time. Chlorosis started from the margin of leaves and extending towards the inner portion of the blades. By 15 day, leaves became brown and easily separated from other parts. However, no morphological changes were observed in the roots. Poskuta *et al.* (1987) who reported chlorosis because of a localized H_2O_2 production, oxidative stress and cell death in *Pisum sativum* exposed to Cd.

Effect on chlorophyll content

Total chlorophyll content of control slightly increased with increasing exposure time. The total chlorophyll contents in treated plants were significantly decreased (**Figure 2**) from that of control ($p<0.05$). Highest total chlorophyll content (2.8 mg/g) was observed in the control, and the lowest was observed at 10 mg/l Cd (0.78 mg/g) after 15 days. Comparatively, at the highest concentration of both metals, the total chlorophyll content of plants treated with Cd was significantly lower than that of Pb treated plants ($p<0.05$). Cadmium is an effective inhibitor of photosynthesis (Vassilev *et al.* 2005). The presence of Cd in the growth medium decreases the growth of soybean and chickpea plants (Hasan *et al.* 2007).

Cadmium uptake

A steady increase in Cd uptake and accumulation was observed for all treatments at all testing days (**Table 1**). The metal contents significantly increased when the exposure time and metal concentration were increased ($p<0.05$). By 15 days, the Cd contents in the roots and leaves increased to the maximum levels of 21, 118.4, 688.4, 912, and 1308 and 4.56, 19.3, 157.1, 208.1, and 543.3 µg/g dry wt at Cd concentrations at 0.5, 1, 2.5, 5, and 10 mg/L, respectively. The accumulation of Cd was more in roots as compared to the shoots. Translocation of metal from root to leaves also increased with increasing metal concentration and exposure period. The highest Cd content (1851.3 µg/g dry wt.) was found in plants exposed to 10 mg/L Cd. Another toxicity symptom observed as the result of Cd exposure was decreased in biomass of *P. stratiotes* when the exposure time and metal concentration were increased. Cd was found to inhibit growth in many aquatic plants such as *Lemna* (Mohan and Hosetti 1997), *Eichhornia* (Zhu *et al.* 1999). Accumulation of particular type of metal is a selective

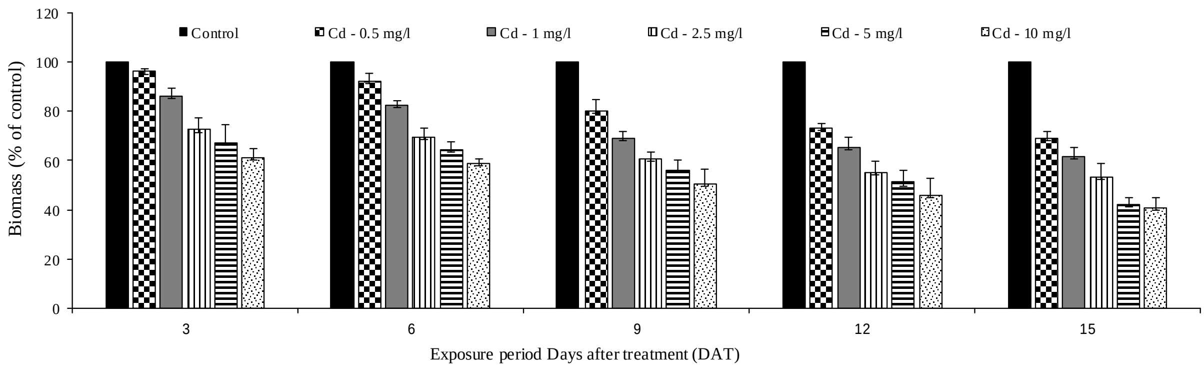

Fig. 1. Effects of Cd on biomass productivity (% control) of *P. stratiotes* at different concentrations and exposure period

Table 1. Cadmium uptake and accumulation (µg/g) in *P. stratiotes* (roots/leaves) at different days

Cd (mg/l)	Cadmium content in *P. stratiotes* (µg/g dry wt.)									
	3 DAT		6 DAT		9 DAT		12 DAT		15 DAT	
	Root	Leaf	Root	Leaf	Root	Leaf	Root	Leaf	Root	Leaf
0.5	1.68±0.6	0.63±0.2	6.12±1.7	1.68±0.7	8.26±2.3	2.18±0.8	19.2±2.1	2.52±0.5	21±1.9	4.56±1.4
1	41.7±2.1	7.74±1.4	85.3±8.3	9.24±1.8	106.6±8.2	12.3±1.7	116.3±11.7	17.5±16.1	118.4±11.7	19.3±2.6
2.5	265.6±6.2	104.2±7.6	490.2±17.2	114.8±27.1	612.7±18.7	117.1±17.2	655.2±2.2	128.1±21.1	688.4±28.2	157.1±21.2
5	352±12.3	138.1±13.2	649.6±38.2	152.2±17.2	812.1±10.3	153.7±26.1	868.3±21.6	169.8±9.7	912.2±11.5	208.1±19.1
10	613.7±9.3	178.4±18.2	664.5±14.8	232.4±28.2	830.6±9.5	237.4±11.8	1224±43.2	248.9±27.2	1308±41.7	543.3±26.3
Control	-	-	-	-	-	-	-	-	-	-

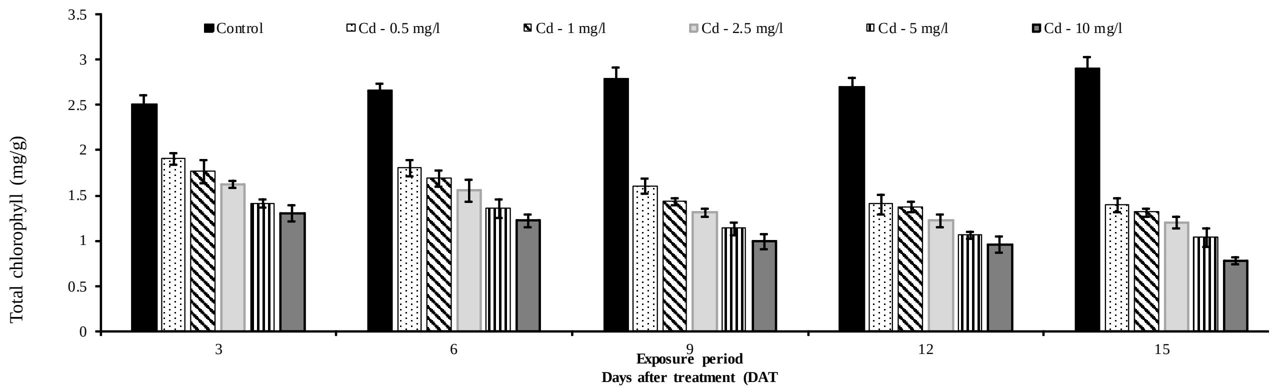

Fig. 2. Total chlorophyll content of *P. stratiotes* (mg/g) at different concentrations and exposure period

process that may vary from plant to plant. Metal concentrations were reported to be higher in the roots in most studies.

It was concluded that *P. stratiotes* was found to tolerate Cd concentrations up to 10 mg/kg, which confirms the ability of this plant to establish and grow well in Cd-contaminated water and accumulate substantial amount of Cd. Therefore, *P. stratiotes* is a promising plant for Cd accumulation and it can be employed for phytoremediation.

ACKNOWLEDGMENT

The financial help of University Grants Commission (No. F./PDFSS-2014-15-SC-UTT-8854) is gratefully acknowledged.

SUMMARY

This study was aimed to determine the cadmium uptake and accumulation potential of *Pistia stratiotes* for phytoremediation of cadmium contaminated water bodies. Plants were grown in Hogland's medium spiked with 0, 0.5, 1, 2.5, 5 and 10 mg/L Cd, individually. Plant samples (roots and leaves) were analyzed for Cd content at 3, 6, 9, 12, and 15 days after treatment. A steady increase in Cd accumulation with increasing metal concentration and exposure period was observed for all treatments. The toxicity symptoms of Cd showed chlorosis on leaves. A significant reduction in the relative growth, biomass productivity and total chlorophyll content with the exposure time and concentration was observed. Accumulation of cadmium was more in roots (1308 µg/g) as compared to shoots (543.3 µg/g). Statistically significant difference ($p \leq 0.001$) in mean metal content in root and shoot at successive days of study was recorded.

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Indian Journal of Weed Science **49**(1): 105–107, 2017
DOI: 10.5958/0974-8164.2017.00029.6

Short communication

Chemical control of duck weed and its effect on water quality and residue

Sushilkumar* and Shobha Sondhia
ICAR-Directorate of Weed Research, Maharajpur, Jabalpur, Madhya Pradesh 482 004

Received: 11 December 2016; Revised: 4 February 2017

Key words: Chemical control, Duckweed Glyphosate, Herbicides, Paraquat, Metsulfuron-methyl, Water quality

Aquatic plants are necessary in aquatic ecosystem for survival of various aquatic lives (fish, crustacean *etc*.) to satisfy their respiration need. Aquatic vegetation helps in reducing the pollution load of water bodies by absorbing several pollutants. But excessive growth of these plants may cause several problems also that are mainly related to hindering transportation, water supply, lowering in water quality, fishing, energy production besides proliferation of disease. *Lemna minor* L. commonly called duck weed refers to a group of lentil shaped, free floating plants of the family Lemnaceae, which forms green carpet on the water surface. Duckweed is commonly used for toxicity testing of pollutants in waste waters (Soukupova and Beklova 2010). Duckweed plants are fast growing and widely distributed. They are easy to culture and to test. Some reports suggest that duckweed plants are tolerant to environmental toxicity (Verma 2007**)**. *Lemna minor* represents a high growth rate and have been used for removal of heavy metals from polluted water bodies (Maine *et al.* 2001, Cardwell *et al.* 2002). In spite of beneficial aspects, it creates severe problems in respiration by clogging gills of fishes during fish culture. Small stagnated water bodies are favorite habitats of *L. minor*. Control of this weed by conventional manual and mechanical methods is most laborious, uneconomical and not suited for large water bodies, whereas biological control method has many limitations like lack of suitable natural enemies, culturing of agents, host specificity *etc*. Hence the chemical method appears quite suitable and cost effective to control duckweed. Although, no label claim is acclaimed for control of *Lemna minor* in India, application of oxadiargyl 450 mg/liter of water was found effective for controlling *L. minor* without showing any sign of harm to non-target organisms (Mandal and Nag 2014). Present study was conducted to evaluate most commonly used herbicides to control *L. minor* in wataer bodies in relation to its residue persistence and water quality.

***Corresponding author:** sknrcws@gmail.com

Experiment was carried out at ICAR-Directorate of Weed Research, Jabalpur during summer season of 2009 in 0.63 m^2 water tank. A 25 cm soil layer was maintained in the bottom of the water tank. FYM was added in the soil to increase soil fertility. Culture of *Lemna minor* was added in the tank. It was allowed to establish well for one month to form a mat over the water surface. The experiment was laid out in complete randomized design with three replications and consisted of 10 treatments, *viz*. paraquat 0.25, 0.50, 1.0 kg/ha, glyphosate 0.50, 1.0, 1.5 kg/ha and metsufuron-methyl (MSM) 0,008, 0.012, 0.016 kg/ha with unsprayed control. Spraying of herbicides was done on mat of *L. minor* with the help of knapsack sprayer fitted with flat fat nozzle using water 500 L/ha. Water samples were taken from treated and untreated water tanks before treatment and at 0, 1, 15 and 30 and 60 days after application. Water samples were filtered prior to extraction.

Metsulfuron-methyl residues were determined by high performance liquid chromatographic method using photodiode array detector. The method makes use of Phenomenex C–18 (ODS) column (250 x 4.6 mm) and acetonitrile: water (70 : 30 v/v) as mobile phase at a flow rate of 2 ml/min (Juhler *et al. 2001;* Sondhia 2009**).** Using these conditions, metsulfuron–methyl was eluted at Rt 2.08 minutes at wavelength of 220 nm. Water sample were extracted thrice by shaking in a horizontal shaker with 100 ml of dichloromethane for 2 hours. After extraction with dichloromethane, samples were subjected to florisil cleanup and passed through anhydrous sodium sulphate and makeup final volume in 5 ml (Bhattacherjee and Dureja 1998, Sondhia 2009). The recovery ranged of this method was between 63.4 to 85.6% in water.

Paraquat residues in water samples were determined by spectrophotometer following method of Sondhia and Gogoi 2005). Water samples were filtered (50 ml) through Whatman No.1filter paper. Pipetted 10 ml of water sample in to a test tube and added two ml of 0.2% sodium dithionite and mixed the solution by gently inverting the tube once or twice. The solution was placed in a 1.0 cm cell and recorded the absorbance at 396 nm **(**Kuntom *et al*. 1999**).**

For glyphosate residue determination, trifluroacetic acid (2 ml) and trifluroacetic anhydride (2 ml) were added to the residual material and refluxed in a water bath for 8 hours at 50-60 ^{0}C. Constituted final residue in 2 ml of methanol. Residues were subjected to cleanup by chromatographic column packed with 5 g of activated silica gel in between two layer of 2 g sodium sulphate. The sample was transferred to column and eluted with 50 ml of methanol. Elutes were collected and concentrated to 2 ml in a rotary vacuum evaporator and analyzed using photodiode array detector coupled with HPLC. A phenomenex C–18 (ODS) column (250 x 4.6 mm) and methanol: water (80 : 20 v/v) as mobile phase at a flow rate of 0.5 ml/min was used (Sondhia and Gogoi 2005**).** Using these conditions, glyphosate was eluted at Rt 2.3 at 215 nm. Recovery ranged between 60.2 to 78.5.6 in water. The physico-chemical analysis of water i.e. pH, DO, alkalinity etc. were measured as the methods developed by APHA, 2005 with appreciable degree of accuracy.

Effect of herbicides on weed

Application of paraquat 0.50 kg/ha, glyphosate 1.0 kg/ha and metsulfuron-methyl 0.008 kg/ha resulted in 100% control of *L. minor* in 15, 30 and 30 days, respectively. Paraquat (0.25 kg/ha) and glyphosate (0.5 kg/ha) reduced the growth of *L. minor* by 15th day but did not control the weed completely up to 30 days. The weed reoccupied the whole tank due to regrowth. Metsulfuron-methyl did not show effectiveness in all doses till 15 days but killed all the weed mat by 30 days in all the doses. Paraquat (0.5 and 1.0 kg/ha) controlled the maximum weed in seven days but completely cleared the water in 15 days. Glyphosate and metsullfuraon-methyl showed such effect in 25 to 30 days (**Table 1**).

Table 1. Control of duckweed (%), days after spray (DAS) of herbicides

Herbicide	Dose (kg/ha)	*Lemna minor* control efficiency (%) 7 DAS	15 DAS	30 DAS
Metsulfiron-methyl	0.008	40	60	100
	0.012	45	65	100
	0.016	45	70	100
Glyphosate	0.50	50	65	80
	1.00	50	80	100
	1.50	60	80	100
Paraquat	0.25	50	60	80
	0.50	90	100	-
	1.00	90	100	-

Effect on water quality

Water quality parameters like pH and dissolved oxygen were influenced with various treatment (**Table 2**). All treatments influenced the pH of treated water and also affected dissolved oxygen content. The pH of the water treated with paraquat, glyphosate and metsulfuron-methyl was slightly reduced after one day of spray, however, it was restored in due course. Before spray of herbicides, initial dissolved oxygen was low (4.0- 4.7) in all the tanks. Dissolved oxygen was decreased at 7, 15, 30 days in paraquat, metsulfuron-methyl and glyphosate treated tanks, respectively. This reduction in DO was observed when the weed was in decomposing process due to the effect of herbicides. Similar findings on the effect of herbicides on reduced water quality and fish mortality have been reported by Olaleye *et al.* (1993). Kannan and Kathiresan (2002) also observed reduction in pH and DO by paraquat (0.90 kg/ha), 2,4-D (1.00 kg/ha) and glyphosate (2.20 kg/ha) compared to the untreated control.

Table 2. Effect of herbicides on pH and dissolved oxygen after spray

Herbicide	Dose	pH Initial	pH 1 DAS	pH 15 DAS	pH 30 DAS	DO (ppm) Initial	DO 7 DAS	DO 15 DAS	DO 30 DAS
Metsulfiron-methyl	0.008	7.3	7.0	7.6	7.3	4.0	4.1	3.9	6.2
	0.012	7.2	6.9	7.5	7.2	4.3	4.2	348	6.9
	0.016	7.1	7.3	7.6	7.0	4.2	4.5	3.9	6.8
Glyphosate	0.5	7.2	6.9	7.0	6.6	4.3	4.3	4.2	6.6
	1.00	7.3	6.8	7.2	6.6	4.5	4.7	3.8	6.9
	1.50	7.3	7.0	6.8	6.5	4.5	4.1	3.9	6.8
Paraquat	0.25	7.5	7.2	7.3	7.0	4.4	4.2	6.5	7.2
	0.50	7.4	7.1	7.2	6.9	4.6	3.6	6.6	7.0
	1.00	7.4	7.1	7.0	6.8	4.3	3.8	6.4	6.7
	Control	7.3	7.2	7.2	7.1	4.7	6.7	6.8	6.6
LSD (p=0.05)	-	0.17	0.19	0.17	0.16	0.17	0.20	0.17	0.18

Residues of paraquat were found 0.11, 0.15 and 0.39 ppm at 0.25, 0.50 and 1.0 kg/ha applied dose at 0 day, which reduced to 0.001, 0.003 and 0.006 ppm, respectively at 60 DAS. Residue of MSM in higher dose (0.016 kg/ha) ranged from 0.56 at 0 day to 0.070 ppb at 60 DAS, but it could not be detected in lower dose at 0.008 kg/ha at 60 DAS. Glyphosate residues in higher dose (1.5 kg/ha) were ranged from 0.14 at 0 day to 0.017 ppm at 60 DAS, but it could be detected upto 60 DAS. Similar findings have also been reported by Sanyal (2006**).** Their study revealed that the half-lives of metsulfuron-methyl and chlorimuron-methyl ranged from 10.75 to 13.94 days irrespective of soils and doses applied. Field trials with rice, wheat and soybean also revealed that these two herbicides could safely be recommended for application as no residues were detected in the harvest samples.

Table 3. Detection of herbicides residues in water

Herbicide	Dose (kg/ha)	Herbicide residues* (days after spray)				
		0 DAS	1 DAS	15 DAS	30 DAS	60 DAS
Metsulfiron-methyl	0.008	0.330	0.230	0.110	0.039	ND
	0.012	0.550	0.390	0.120	0.081	0.05
	0.016	0.560	0.410	0.180	0.090	0.07
Glyphosate	0.5	0.035	0.024	0.017	0.013	0.004
	1.00	0.055	0.044	0.029	0.022	0.011
	1.50	0.140	0.120	0.083	0.057	0.017
Paraquat	0.25	0.110	0.800	0.300	0.090	0.001
	0.50	0.150	0.120	0.050	0.010	0.003
	1.00	0.390	0.31	0.150	0.110	0.006
LSD (p=0.05)	-	0.016	0.059	0.084	0.064	0.010

* Unit – All units in ppm except metsulfuron-methyl which are expressed in ppb

SUMMARY

An experiment was conducted to evaluate chemical control of duckweed (*Lemna minor*) and its effect on water quality and herbicide residue. Paraquat, glyphosate and metsulfuron-methyl (MSM) were applied in different doses on *Lemna minor* mat in water tank. Paraquat 0.5 kg/ha resulted in 100% control of *Lemna minor* in 15 days while metsulfuron-methyl (MSM) and glyphosate resulted 100% control in 30 days. Water quality in relation to dissolve oxygen and pH were affected by all treatments as compared to the untreated control. Low pH was found in all treated water tanks compared to untreated control. Residues of paraquat in water were 0.11 to 0.39 ppm at 0.25 to 1.0 kg/ha application rate at 0 day, which was reduced to 0.001 to 0.006 ppm at 60 days after application (DAA). Residues of MSM in higher dose (0.016 kg/ha) ranged from 0.56 at 0 day to 0.070 ppm at 60 DAA, but it could not be detected in lower dose at 0.008 kg/ha at 60 DAA. Glyphosate residue in higher dose (1.5 kg/ha) ranged from 0.14 ppm at 0 day to 0.017 ppm at 60 DAA.

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