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Occurrence and distribution of *Sacciolepis interrupta*, a potential problematic weed in the rice tracts of Kerala

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ABSTRACT

A survey was conducted in major rice tracts of Kerala *i.e.* Kole, Kuttanad and Palakkad during 2018 and 2019 to assess the distribution and occurrence of *Sacciolepis interrupta*. In Palakkad and Kole tract the highest density, frequency, abundance, relative density, relative frequency, and summed dominance ratio of *Sacciolepis* was recorded whereas, in Kuttanad tract it was *Echinochloa crusgalli* followed by *Sacciolepis*. Weed vegetation analysis indices were lowest in Palakkad compared to Kole and Kuttanad tract showing a high degree of domination of one species in Palakkad and larger diversity of weed species in other two tracts. The cluster analysis classified *Sacciolepis* types into 6 groups at 66.67% similarity level, and using principal component analysis these morphotypes were clustered into 3 groups A, B and C based on morphological characters. Association between *Sacciolepis* types and soil nutrient parameters indicated that Group A was abundant in less fertile saturated soils whereas group B and C were dominant in nutrient rich submerged soils of Kole and Kuttanad. The study concludes that *Sacciolepis interrupta* is a serious weed problem in direct seeded rice of Palakkad tract and is fast attaining the status of a dominant weed in other rice tracts also, thereby becoming a major menace in rice fields of Kerala.

INTRODUCTION

Direct-seeded rice is a method of rice cultivation in which cost of production is significantly reduced. However, yield reduction due to weeds is greater in direct-seeded rice (DSR) than in transplanted rice, and sometimes goes up to 50-90% (Rao *et al.* 2007). This is because the weed diversity is greater with a higher diversity index (Kim *et al.* 1992) and rice is subjected to a higher weed pressure. (Balasubramanian and Hill 2002, Tomita *et al.* 2003). The dominant category of weeds in DSR is contributed by grasses (Jayasuria *et al.* 2011). However, a common observation is the occurrence and dominance of new weeds in DSR, with variation in the number, relative densities and proportions, and a greatly altered scenario of competition between and within weed species. It was also observed that specific weeds were more competitive in DSR than in transplanted rice (Matloob *et al.* 2015), making them more difficult to control. In this context, the occurrence and spread of *Sacciolepis interrupta*, a tropical grass weed which mimics rice is of grave concern in the rice tracts of Kerala.

Sacciolepis interrupta was initially seen as a minor weed in the semi dry rice growing areas of Palakkad. However, extremely fast growth habit and multiple methods of propagation have led its gain the status of a major troublesome weed. It is also now reported in both wet-seeded and transplanted rice. A study by Renu (1999) concluded that competition from *Sacciolepis interrupta* alone could reduce the rice grain yield by 50%. The intensity of occurrence of *Sacciolepis interrupta* in Palakkad and other important rice growing tracts of the state, *viz.* Kole lands in Thrissur district and Kuttanad in Alleppey and Ernakulam districts, has not been assessed. Hence a study was conducted to assess the distribution and occurrence of *Sacciolepis interrupta* in the major rice growing tracts of Kerala.

MATERIALS AND METHODS

To study the distribution of *Sacciolepis*, a survey was conducted in three major rice growing tracts of Kerala *i.e.*, Kuttanad, Kole and Palakkad. In Kuttanad and Kole, the survey was conducted in December to March, and in Palakkad tract from April to May in the year 2017-18 and 2018-19, being the periods of most appropriate representation of majority of weed species in the respective tracts. For each rice tract, based on the dominance of the weeds, various indices on density of individual weeds and different characters of morphotypes were worked out. Sampling was done using quadrate of 0.5 x 0.5 m in the surveyed area with the quadrate being randomly placed in each location and total of 15 quadrates were sampled. Data of each year were pooled for each locality and average counts of different weeds were worked out. Weed phytosociological observations on density (d), relative density (RD), abundance (a), frequency (f), relative frequency (RF) and summed dominance ratio (SDR) or importance value index (IVI) of individual weeds were calculated as per methods suggested by Misra (1968) and Raju (1977).

Weed biodiversity in these rice tracts was studied using indices like species richness R (*i.e.*, the total number of species, which occurred in field), species diversity (H) measured by the Shannon-Wiener diversity index *i.e.* $H = Pi \log Pi$, in which Pi is the proportion of individual numbers of the i species to the total individual number of each species in the quadrates. Thus, $Pi = Ni/N$, of which N is the total individual number of each weed species and Ni is the individual number of the I species. Degree of community dominance, measured by the Simpson diversity index, D where $D = 1\text{-}Pi^2$ and community evenness was measured by the evenness index (Pielou index), J where $J = H/logR$.

Using Euclidean distance as similarity index, cluster analysis was done to differentiate between the eleven morphological characters of different morphotypes collected from the surveyed locations. For this analysis statistical package 'Minitab Version 19' was used and associated dendrogram was obtained. To find out the components which were important for clustering the *Sacciolepis* types, principal component analysis (PCA) was done with the same package. Soil analysis was also carried for each surveyed rice tract, to find out the association of dominance and occurrence of *Sacciolepis* morphotypes.

RESULTS AND DISCUSSION

In surveyed areas of Palakkad, a total of 15 species dominated and out of them, *Sacciolepis* recorded highest density, frequency, abundance, relative density, relative frequency and summed dominance ratio followed by *Leptochloa* sp. (**Table 1**).

In Kole tract, a total of 11 species were recorded in surveyed areas, and out of these *Sacciolepis* and weedy rice recorded highest density, frequency, abundance, relative density, relative frequency and summed dominance ratio (**Table 2**). This was in line with the report by Latha and Jaikumaran (2015), where a quantitative weed survey in the rice fields of Kole lands revealed a relative density of 2.46% of *Sacciolepis.*

Echinochloa crus-galli found to be the dominant weed in the surveyed areas of Kuttanad, with highest density, frequency, abundance, relative density, relative frequency and summed dominance ratio out of 12 species, followed by *Sacciolepis* and *Salvinia molesta* (**Table 3**).

Comparison of weed vegetation analysis indices in different rice tracts of Kerala showed the highest weed species richness (R) of 15 in Palakkad tract compared to other two tracts, showing the dominance of weeds, primarily *Sacciolepis,* under

Table 1. Distribution and dominance of weed species in surveyed areas of Palakkad tract

Species	Density (no./m^2)	Frequency (%)	Abundance (no./m^2)	RD (%)	RF (%)	SDR (%)
Echinochloa colona	1.9	70.0	2.7	5.9	9.0	7.4
Leptochloa chinensis	2.7	80.0	3.4	8.4	10.3	9.3
Fimbristylis miliacea	1.0	40.0	2.5	3.1	5.1	4.1
Eclipta alba	1.0	50.0	2.0	3.1	6.4	4.8
Ludwigia parviflora	1.8	70.0	2.6	5.6	9.0	7.3
Lindernia crustacea	0.4	20.0	2.0	1.2	2.6	1.9
Commelina diffusa	1.0	30.0	3.3	3.1	3.8	3.5
Cynotis axillaris	1.4	60.0	2.3	4.3	7.7	6.0
Leucas aspera	0.8	30.0	2.7	2.5	3.8	3.2
Scoparia dulcis	1.0	40.0	2.5	3.1	5.1	4.1
Isachne miliacea	1.8	60.0	3.0	5.6	7.7	6.6
Spilanthus calva	1.0	50.0	2.0	3.1	6.4	4.8
Sacciolepis interrupta	13.6	100.0	13.6	42.2	12.8	27.5
Schoenoplectus juncoides	1.5	40.0	3.8	4.7	5.1	4.9
Cyperus iria	1.3	40.0	3.3	4.0	5.1	4.6

dryland and direct seeded conditions. Higher values of diversity and evenness indices (>1), indicate that the weed species within the habitat were diverse and more equally distributed, but increase in dominance of one weed species would decrease the diversity of the habitat and also lower the values (Wilson *et al*., 2003). Simpson diversity (D), Shannon-Wiener diversity (H) and Evenness (J) indices were highest in Kuttanad and Kole, *i.e.*, 0.9, 2.3 and 0.95, and 0.8, 2.2 and 0.94, respectively, whereas in Palakkad tract it was 0.7, 1.5 and 0.57 respectively, showing a high degree of domination of one species in Palakkad tract and a larger diversity of weed species in other two tracts (**Figure 1**).

Morphotypes are a group of different types of individuals of the same species (Klingman and Oliver 1994). Growth stage, age, biotype or environment play a vital role in affecting the morphological appearance or a particular morphological traits of the same weed species (Booth *et al*. 2010). Based on morphological characters, fifteen types of *Sacciolepis interrupta* morphotypes were categorized from three surveyed rice tracts (**Table 4**).

Sacciolepis was classified into six groups by cluster analysis at 66.67% similarity level. Group 1 included 4 types *i.e.*, type 1, 8, 12 and 9. Group 2 included 4 types *i.e.*, 4, 10, 5 and 6. Type 11 and 2 occupied separate groups (Group 3 and Group 4 respectively). Group 5 included five types 3, 15, 7 and 13. Group 6 included type 14 (**Figure 2**).

Scree plot of principal component analysis (PCA) indicated that first two PCA corresponded to whole percentage variance in the data, as they possessed Eigen value of >1 (**Figure 3**). PC1 and PC2 together accounted for 81.7% of total variations of which PC1 accounted for 61.9% and PC2 accounted for 19.8%.

PC1 was related to all morphological characters except width of spikelets and PC2 was related to characters like plant height, panicle length, leaf

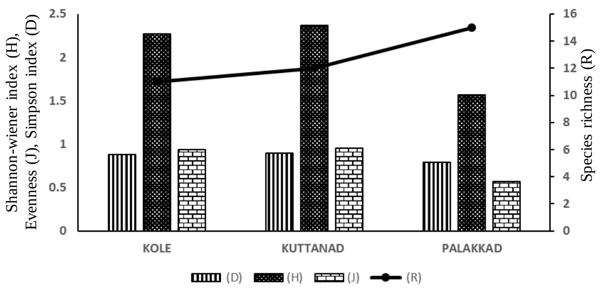

Figure 1. Weed vegetation analysis indices in different rice tracts of Kerala

Table 2. Distribution and dominance of weed species in surveyed areas of *Kole* tract

Species	Density (no./m^2)	Frequency (%)	Abundance (no./m^2)	RD (%)	RF (%)	SDR (%)
Echinochloa colona	2.7	70.0	3.9	10.6	9.2	9.9
Salvinia molesta	1.5	50.0	3.0	5.9	6.6	6.2
Monochoria vaginalis	1.5	70.0	2.1	5.9	9.2	7.6
Cyperus haspan	2.5	60.0	4.2	9.8	7.9	8.9
Sacciolepis interrupta	4.9	100.0	4.9	19.3	13.2	16.2
Leptochloa chinensis	3.3	70.0	4.7	13.0	9.2	11.1
Oryza rufipogon	3.6	90.0	4.0	14.2	11.8	13.0
Ludwigia parviflora	0.9	60.0	1.5	3.5	7.9	5.7
Limnocharis flava	0.9	50.0	1.8	3.5	6.6	5.1
Isachne miliacea	2.2	80.0	2.8	8.7	10.5	9.6
Kyllinga monocephala	1.4	60.0	2.3	5.5	7.9	6.7

Table 3. Distribution and dominance of weed species in surveyed areas of Kuttanad tract

Species	Density (no./m^2)	Frequency (%)	Abundance (no./m^2)	RD (%)	RF (%)	SDR (%)
Echinochloa crus-galli	3.0	73.3	4.1	15.8	15.5	15.6
Oryza rufipogon	1.4	46.7	3.0	7.4	7.2	7.3
Cyperus iria	1.5	80.0	1.8	7.7	7.6	7.6
Cyperus haspan	0.5	40.0	1.3	2.8	2.8	2.8
Salvinia molesta	2.7	73.3	3.7	14.4	14.1	14.2
Monochoria vaginalis	1.5	53.3	2.8	7.7	7.6	7.6
Fimbristylis miliacea	1.5	46.7	3.1	7.7	7.6	7.6
Leptochloa chinensis	1.5	66.7	2.3	8.1	7.9	8.0
Schneopletis juncoides	0.9	46.7	1.9	4.6	4.5	4.5
Alternathera sessilis	0.7	46.7	1.6	3.9	3.8	3.8
Digitaria ciliaris	1.1	40.0	2.7	5.6	5.5	5.6
Sacciolepis interrupta	2.7	66.7	4.1	14.4	14.1	14.2

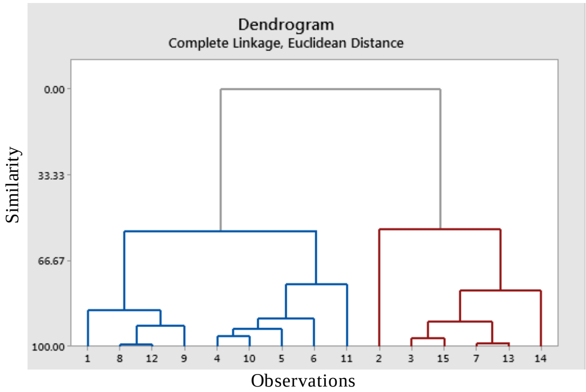

Figure 2. Dendrogram from hierarchical cluster analysis for dissimilarity among the 15 morphotypes of *Sacciolepis interrupta*

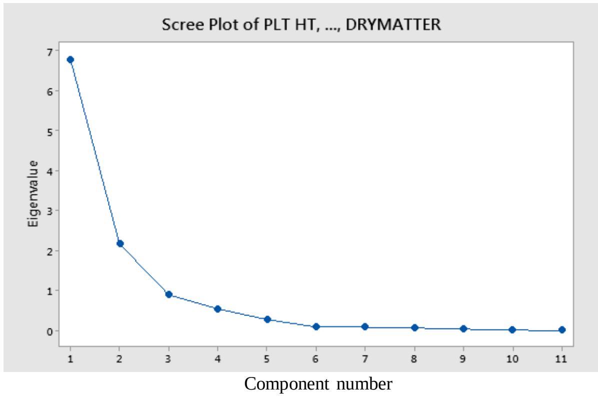

Figure 3. Scree plot showing the Eigen values in response to the morphological characters of *Sacciolepis interrupta*

Table 4. Distribution of *Sacciolepis interrupta* morphotypes in rice fields of surveyed areas

Location		Latitude (^{0}N)	Longitude (^{0}E)	*Sacciolepis* morphotypes	Code no.
Palakkad	Chithali 1	10°41'40.8"	76°35'23.4"	Green variegated	1
	Chithali 2	10°41'41.0"	76°35'00.1"	Green variegated	2 and 3
	Chithali 3	10°41'40.9"	76°35'01.7"	Green variegated	4
	Chithali 4	10°41'40.4"	76°35'02.0"	Green variegated	5
	Kavasseri	10°38'01.6"	76°31'07.2"	Green variegated	6
Kole lands	Pullazhi	10°31'32.1"	76°10'16.0"	Purple variegated	7
	Manakkody	10°29'08.5"	76°10'10.9"	Purple variegated	8 and 9
	Alappad	10°31'00.8"	76°13'25.1"	Purple variegated	10 and 11
Kuttanad		9°21'04.1"	76°28'10.0"	Green-purple variegated	12
	Veeyapuram	9°21'04.2"	76°28'10.2"	Green-purple variegated	13
		9°25'02.6"	76°29'32.2"	Green-purple variegated	13
	Kidangara	9°24'55.7"	76°29'37.6"	Green-purple variegated	14

length, leaf width and dry matter production/plant. PC1 was more positively contributed by six morphological characters in the order plant height, panicle length, length of spikelet, leaf length, leaf width, dry matter production/plant, number of tillers/ plant and number of panicles/plant. PC2 was more positively contributed by dry matter production/plant, panicle length, plant height, leaf length and leaf width (**Table 5**). The scree plot between PC1 and PC2, which together contributed more than 81% of total variation, showed that *Sacciolepis* included in different groups showed distinguishable variations in morphological characters.

The first component data is efficient in grouping and separating one group from others. Group A referred to the morphotypes from Palakkad having green coloured panicles, oblong spikelets, medium stature and narrow light green leaves (green variegated), Group B from Kole tract having purple coloured panicles, enlongated spikelets, tall stature and narrow dark green leaves (purple variegated) and Kuttanad tract ones were categorized into Group C having bicoloured green and purple panicles, oblong to bulged spikelets, short stature, profuse tillering and with broad dark green leaves (green-purple variegated).

Table 5. PCA values of morphological characters of *Sacciolepis interrupta*

Morphological observations	PC1	PC2
Plant height	0.367	0.115
No of tillers	0.274	-0.190
No. of panicles	0.162	-0.490
Panicle Length	0.362	0.124
No. of spikelets	0.166	-0.324
Seeds per plant	0.203	-0.549
Length of spikelets	0.362	-0.105
Width of spikelets	-0.244	-0.429
Leaf length	0.375	0.073
Leaf width	0.349	0.054
Drymatter production per plant	0.334	0.291

Majority of group B morphotypes were differentiated from group A by the first component, PC1, which is depicted on right hand side of scree plot, and group A on left hand side, and Group C is placed intermediary on the scree plot (**Figure 4**).

Table 6. Soil chemical properties and moisture level in rice tracts of Kerala

Rice tract	pH	Organic C (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Soil moisture level
Kole	5.5	1.9	229.6	11.7	168.6	Submerged
Palakkad	6.1	1.1	131.6	16.6	186.2	Saturated
Kuttanad	4.4	3.7	265.0	20.5	188.4	Submerged

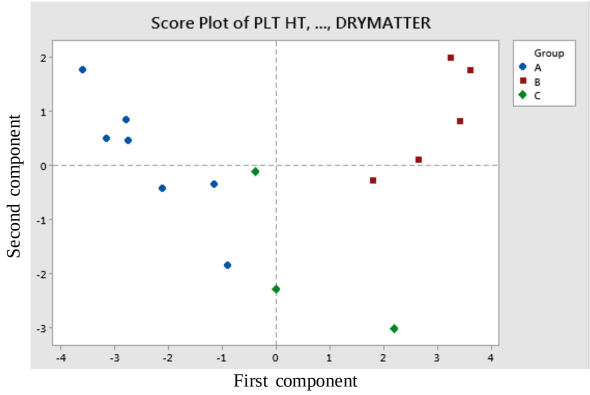

Figure 4. Scree plot of first two PC indicating the variability in morphological characters of *Sacciolepis interrupta*

Severe infestation of *Sacciolepis* group A was observed in saturated soils of Palakkad with near neutral pH, low organic carbon and low nutrient status. Group B dominated in acidic pH, medium organic carbon and submerged soils of Kole lands, and group C morphotypes were prominent in highly acidic and nutrient rich submerged soils of Kuttanad (**Table 6**).

The density and dominance indices clearly indicate the severity of *Sacciolepis interrupta* in the surveyed areas. Based on their morphology, *Sacciolepis interrupta* could be grouped into three groups A, B and C which might have evolved as an adaptation to the existing habitat, changing cultural practices and climatic conditions.

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Penoxsulam + butachlor: A new ready-mix herbicide for control of complex weed flora in transplanted rice

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ABSTRACT

A field experiment was conducted to evaluate the efficacy of penoxsulam 0.97%w/w (1.0%w/v) + butachlor 38.8% w/w (40% w/v) 41% SE applied as pre-emergence(0-7DAT) spray in standing water against complex weed flora in transplanted rice at CCS HAU Regional Research Station, Karnal during rainy (*Kharif*) seasons of 2015 and 2016. The crop was infested mainly with *Echinochloa crus-galli* (~15%), *Ammannia baccifera* (~70%), and *Cyperus difformis, Cyperus rotundus* and other sedges (~15 %). Penoxsulam + butachlor 41% SE at 820 g/ha being as good as weed free check provided almost complete control (98.1-98.5% WCE) of complex weed flora during both the years, and it was better than penoxsulam 22.5 g/ha (87-88%), butachlor 1500 g/ha (90%) and pretilachlor 1000 g/ha (91%). Penoxsulam + butachlor 820 g/ha resulted into the highest number of effective tillers and grain yield (5.43 t/ha in 2015 and 6.06 t/ha in 2016). It was superior to its lower doses (615 and 718 g/ha) and penoxsulam 22.5 g/ha during both the years, and butachlor 1500 g/ha during 2016. There was no crop phyto-toxicity of penoxsulam + butachlor 41% SE at 820 g/ha (X) and 1640 g/ha (2X). Weeds allowed to grow throughout the crop season reduced the grain yield to the extent of 27.3 and 32.9% during 2015 and 2016, respectively.

INTRODUCTION

Rice is the most important staple food crop of the world and Asia as well. It is grown over an area of about 44 mha in India with total production of 105 m tones, amounting to 40% of the total food grain in the country (Economic Survey 2015-16) supporting 600 million people. India is the second largest producer among the rice growing countries, but its productivity is still very low, and weed infestation is the major cause of yield reduction (27-68%) in transplanted rice (Singh *et al.* 2003, Yadav *et al.* 2009, Manhas *et al.* 2012, Duary *et al.* 2015, Yadav *et al.* 2018). *Echinochloa crus-galli* is the dominant weed in transplanted rice in north-western India. However, infestation of broad-leaf weeds and the sedges is also increasing nowadays. Butachlor, pretilachlor, anilofos and oxadiargyl are some of the most commonly sand mixed broadcast (in standing water) used pre-emergence herbicides in transplanted rice. Recently, bispyribac-sodium is also being used as post-emergence herbicide (Yadav *et al.* 2009). Penoxsulam 24% SC as early post-emergence herbicide applied 8-12 days after transplanting (DAT) is another quite effective herbicide against complex weed flora, specifically against the broad-leaf weeds and sedges. However, there are issues in spraying of this herbicide as early PoE due to standing water and small rice seedlings, thereby limiting its use in real field situations. Butachlor is quite effective against *Echinochloa* but slightly less efficacy against some of the broad-leaf weeds and sedges. Generally, single application of one herbicide does not provide satisfactory weed control throughout the crop season as some of the broad-leaf weeds and sedges are not controlled that effectively, and farmers are forced to apply either other sequential post-emergence herbicide(s) or follow manual weeding. This escalates the cost and energy for weed management. Farmers largely prefer to use pre-emergence herbicides in transplanted rice not only due to easiness in application but also to achieve effective weed management starting from at an early growth stage. Therefore, more convenient option would be single shot application of ready mix or tank mix combination of pre-emergence herbicide(s). Pretilachlor + pyrazosulfuron-ethyl (ready-mix) at

615 g/ha as pre-emergence has been reported very effective (91-96%) against complex weed flora in transplanted rice, with higher grain yield and B-C ratio (Yadav *et al.* 2018). Keeping these points in view, present study was conducted to evaluate the efficacy of a ready-mix combination of penoxsulam 0.97%w/w (1.0%w/v) + butachlor 38.8%w/w (40%w/v) 41% SE (Dow Agro Science) as pre-emergence (0-7 DAT) sprayed in standing water against complex weed flora in transplanted rice.

MATERIALS AND METHODS

Bio-efficacy studies

A field experiment was conducted at CCS HAU Regional Research Station, Karnal during *Kharif* seasons of 2015 and 2016 to evaluate the bio-efficacy of penoxsulam 0.97% w/w (1.0% w/v) + butachlor 38.8% w/w (40% w/v) 41% SE against complex weed flora in transplanted rice. The soil of the experimental filed was low in organic carbon available nitrogen, medium in available, phosphorus and potassium with slightly alkaline in reaction (pH 8.2). The treatments included penoxsulam+ butachlor 41% SE 615, 718 and 820 g/ha at 0-7 DAT, penoxsulam 24% SC 22.5 g/ha at 8-12 DAT, butachlor 50% EC 1500 g/ha at 0-3 DAT, pretilachlor 50% EC 1000 g/ha at 0-3 DAT along with weed free and weedy checks. The experiment was laid out in randomized block design with three replications. Transplanting of 35 days old seedlings of rice cultivar '*HKR 47*' was done on 10 July, 2015 and 12 July, 2016 at a spacing of 20 x 15 cm in a plot size of 6.5 x 2.4 m. Herbicides were applied by spray with knap-sack sprayer fitted with flat-fan nozzle using 300 liter water/ha. The soil was kept under saturated moisture conditions during spray, and field was re-irrigated after 24 hours of spray application. Data on weed count and weed dry weight were recorded at 60 days after transplanting (DAT), Yield and yield attributes at maturity crop was harvested on 24 October, 2015 and 22 October, 2016. Before statistical analysis, the data on density of weeds were subjected to square root $(\sqrt{x+1})$ transformation to improve the homogeneity of the variance. All the data were subjected to the analysis of variance (ANOVA) separately for each year. The significant treatment effect was judged with the help of 'F' test at the 5% level of significance. The 'OPSTAT' software of CCS Haryana Agricultural University, Hisar, India was used for statistical analysis (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

Weed flora

Weed flora composition of the experimental field during two years of investigation consisted of mainly grassy weed *Echinochloa crus-galli* (14.1-15.4%), broad-leaf weed *Ammannia baccifera* (69.2-71.8%) and around 15% sedges including *Cyperus difformis, Cyperus rotundus* and others.

Effect on density of weeds

All the herbicides reduced the density of *Echinochloa crus-galli*, *Ammannia baccifera* and all sedges significantly as compared to the untreated weedy check (**Table 1**). The density of grassy weed *Echinochloa crus-galli* at 60 DAT decreased with the corresponding increase in the dose of penoxsulam + butachlor (ready mix) during both the years (**Table 1**). Penoxsulam + butachlor at its higher dose (820 g/ha) reduced the density of *E. crus-galli* significantly more than its lower doses (615 and 718 g/ha) during

Table 1. Effect of different herbicidal treatments on density of weeds at 60 DAT in transplanted rice (*Kharif* 2015 and 2016)

Treatment	Dose (g/ha)	Density of weeds (no./m^2)*									
		Echinochloa crus-galli		*Ammannia baccifera*		*Cyperus difformis*		*Cyperus rotundus*		Total sedges	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Penoxsulam + butachlor 41% SE	615	2.20(4.0)	2.04(3.3)	5.62(30.7)	4.65(20.7)	1.49(1.3)	1.49(1.3)	1.73(2.0)	1.73(2.0)	2.07(3.3)	2.07(3.3)
Penoxsulam + butachlor 41% SE	718	2.07(3.3)	1.73(2.0)	5.32(27.3)	3.69(12.7)	1.24(0.7)	1.00(0)	1.49(1.3)	1.49(1.3)	1.66(2.0)	1.49(1.3)
Penoxsulam + butachlor 41% SE	820	1.24(0.7)	1.24(0.7)	3.60(12.0)	2.24(4.0)	1(0.0)	1.00(0)	1(0.0)	1.00(0)	1(0)	1.00(0)
Penoxsulam 24% SC	22.5	2.65(6.0)	1.66(2.0)	4.99(24.0)	3.31(10.0)	1.24(0.7)	1.00(0)	1.24(0.7)	1.00(0.0)	1.49(1.3)	1.00(0.0)
Butachlor 50% EC	1500	1.90(2.7)	1.49(1.3)	5.79(32.7)	4.49(19.3)	1.9(2.7)	1.73(2.0)	2.07(3.3)	1.90(2.7)	2.65(6.0)	2.37(4.7)
Pretilachlor 50% EC	1000	1.73(2.0)	1.24(0.7)	6.14(36.7)	4.57(20.0)	1.73(2.0)	1.73(2.0)	1.9(2.7)	1.66(2.0)	2.37(4.7)	2.20(4.0)
Weed free		1.00(0)	1.00(0)	1.00(0)	1.00(0)	1(0)	1.00(0)	1(0)	1.00(0)	1(0)	1.00(0)
Weedy check		4.58(20.0)	4.12(16.0)	10.14(102)	8.53(72.0)	2.37(4.7)	2.37(4.7)	2.51(5.3)	2.07(3.3)	3.31(10.0)	2.99(8.0)
LSD (p=0.05)		0.50	0.73	0.47	0.65	0.48	0.29	0.40	0.46	0.56	0.45

*The original figures in parentheses were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis both years, being at par with pretilachlor during the both years. It was better than penoxulam and butachlor during 2015 only. Penoxsulam + butachlor at 820 g/ha also reduced the density of *A. baccifera* significantly more than its lower doses, penoxulam, butachlor and pretilachlor during both years. Penoxsulam + butachlor at 820 g/ha being similar to penoxulam 22.5 g/ha was statistically similar to its lower dose of 718 g/ha only against C. *difformis*, but superior to its lower doses of butachlor and pretilachlor against all other sedges during both the years. Pretilachlor 750 g/ha + pyrazosulfuron 25 g/ha as tank mix application at 3 DAT and pretilachlor + pyrazosulfuron-ethyl (ready mix) at 615 g/ha have already been reported very effective in reducing the density of complex weed flora in transplanted rice by Teja *et al*. (2016) and Yadav *et al*. (2018).

Effect on dry weight of weeds

All the herbicides reduced the dry weight of grassy weeds, broad-leaf weeds, sedges and total weeds significantly as compared to the untreated weedy check (**Table 2**). Penoxsulam + butachlor at its higher dose (820 g/ha) being as good as weed free reduced the dry weight of grassy weeds, broad-leaf weeds, sedges and total weeds significantly compared to all other herbicidal treatments during both years. Weed control efficiency of penoxsulam + butachlor increased with increase in its dose from 615 g/ha (75.8-78.4%) to 718 g/ha (81.8-84.0%) and 820 g/ha (98.1-98.5%) during both the years (**Table 2**). Weed control of efficiency of penoxsulam + butachlor 820 g/ha was higher than penoxsulam 22.5 g/ha (87-88%), butachlor 1500 g/ha (90%) and pretilachlor 1000 g/ha (91%). Thus, based on two years data, 820 g/ha was realized the most optimum dose of penoxsulam + butachlor. Pre-emergence application of herbicides used in combination have been reported very effective against mixed weed flora in transplanted rice earlier also (Manhas *et al*. 2012, Kumar *et al*. 2014, Duary *et al*. 2015, Teja *et al*. 2015, Teja *et al*. 2016, Yadav *et al*. 2018).

Effect on crop

There was no significant effect of herbicidal treatments on plant height and panicle length of the crop during both the years (**Table 3**). Penoxsulam + butachlor 820 g/ha resulted into highest number of effective tillers (486-488/m^2) and grain yield (5.43 t/ha in 2015 and 6.06 t/ha in 2016) among all the herbicidal treatments, which were at par with weed free check. Grain yield under penoxsulam + butachlor

Table 2. Effect of different herbicidal treatments on dry weight of weeds at 60 DAT in transplanted rice (*Kharif* 2015 and 2016)

Treatment	Dose (g/ha)	Dry weight of weeds (g/m^2)								Weed control efficiency (%)	
		Grassy weeds		Broad-leaf weeds		Sedges		Total weeds			
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Penoxsulam + butachlor 41% SE	615	17.0	12.1	6.0	4.3	1.9	2.1	24.8	18.5	75.8	78.4
Penoxsulam + butachlor 41% SE	718	13.4	9.8	4.6	2.9	0.8	1.0	18.7	13.7	81.8	84.0
Penoxsulam + butachlor 41% SE	820	1.2	1.3	0.8	0.0	0.0	0.0	2.0	1.3	98.1	98.5
Penoxsulam 24% SC	22.5	9.8	8.8	2.1	1.3	1.2	0.0	13.1	10.1	87.2	88.2
Butachlor 50% EC	1500	3.9	3.0	3.2	3.0	3.2	2.8	10.3	8.8	90.0	89.7
Pretilachlor 50% EC	1000	3.0	2.0	3.3	2.7	2.9	2.7	9.2	7.4	91.0	91.3
Weed free		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
Weedy check		86.0	71.8	10.7	8.4	6.0	5.3	102.6	85.5	0.0	0.0
LSD (p=0.05)		4.4	4.0	1.6	1.5	0.9	0.4	4.9	3.9		

Table 3. Effect of different herbicidal treatments on yield and yield attributes of transplanted rice (*Kharif* 2015 and 2016)

Treatment	Dose (g/ha)	Plant height (cm)		Effective tillers (no./m^2)		Panicle length (cm)		Grain yield (t/ha)	
		2015	2016	2015	2016	2015	2016	2015	2016
Penoxsulam + butachlor 41% SE	615	109.7	113.0	408	454	21.7	22.6	4.80	5.46
Penoxsulam + butachlor 41% SE	718	110.3	112.9	440	462	21.9	23.1	5.01	5.61
Penoxsulam + butachlor 41% SE	820	110.1	114.2	486	488	22.3	23.7	5.43	6.06
Penoxsulam 24% SC	22.5	110.7	113.9	454	474	21.9	23.3	5.13	5.85
Butachlor 50% EC	1500	111.3	114.3	468	478	21.9	22.8	5.23	5.92
Pretilachlor 50% EC	1000	110.3	113.8	470	488	22.1	22.9	5.28	5.95
Weed free		110.9	113.6	497	489	22.1	23.5	5.48	6.17
Weedy check		111.8	112.9	339	329	21.6	22.4	3.99	4.13
LSD (p=0.05)		NS	NS	26	28	NS	NS	0.21	0.14

820 g/ha was superior to its lower doses and penoxsulam 22.5 g/ha during both the years, and butachlor 1500 g/ha during 2016. In comparison to weedy check during 2015, penoxsulam + butachlor 820 g/ha, penoxsulam 22.5 g/ha, butachlor 1500 g/ha and pretilachlor 1000 g/ha increased the grain yield of rice to the extent of 36.3, 28.7, 31.2 and 32.4%, respectively. Whereas, the corresponding figures during 2016 were 46.6, 41.5, 43.1 and 44.0%, respectively. Effective management of complex weeds consequently resulting into higher yields of transplanted rice due to combined application of herbicides has been realized earlier also (Kumar *et al*. 2014, Duary *et al*. 2015, Teja *et al*. 2015, Yadav *et al*. 2018). Weeds allowed to grow throughout the crop season reduced the grain yield to the extent of 27.3 and 32.9% during 2015 and 2016, respectively.

Based on two years field experimentation, it might be concluded that penoxsulam 0.97% w/w (1.0% w/v) + butachlor 38.8% w/w (40% w/v) 41% SE 820 g/ha applied as spray in 300 L water/ha at 0-7 DAT under saturated moist field conditions (re-irrigation 24 hours after spray) provided effective control of complex weed flora in transplanted rice with improved grain yields.

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Weed management in rice established by different methods

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ABSTRACT

The field experiment was conducted at Agronomy Department Farm, College of Agriculture, Dapoli, during *Kharif* (rainy) seasons 2016 and 2017 to study the effect of established by different methods of rice establishment on weeds. The field experiment was laid out in a strip plot design comprising of twenty five treatment combinations replicated thrice. The horizontal strips comprised five rice establishment methods, *viz.* sowing of dry seeds by drum seeder at onset of monsoon , sowing of sprouted seeds (*Rahu*) by drum seeder in puddled field, broadcasting of sprouted seeds (*Rahu)* in puddled field, system of rice intensification (SRI) method and conventional transplanting. The vertical strips consisted five weed management practices, *viz.* need based two hand weedings at 20/30 and 40/60 DAS/DAT, pre-emergence application of oxadiargyl 80 WP 100 g/ha + 1 hand weeding at 20/30 DAS/DAT, pre-emergence application of oxadiargyl 80 WP 100 g/ha + 1 hand weeding at 40/60 DAS/DAT, pre-emergence application of oxadiargyl 80 WP 100 g/ha + post-emergence application of Almix 20 WP 4 g/ha and unweeded control. SRI method with two hand weedings carried out at 20 and 40 DAT recorded highest grain and straw yield of rice and lowest weed density and dry weight of weeds as compared to remaining treatment combinations during both the seasons.

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple food crop of the world, feeding more than half of its population every day. Globally it is cultivated in an area of 161.28 million hectares with an annual production of 715.75 million tonnes (Anonymous, 2016a). In Asia, about 90% of the rice is produced and consumed as a staple food.

In India, rice is the most important and extensively grown food grain crop, occupying an area of 44.11 million hectares with production of 105.48 million tonnes. However, the productivity of India (2.39 t/ha) is lower than the world average yields (4.4 t/ha) and is much behind than the rice productivity of Egypt, Japan and China (Anonymous, 2016b). Rice is also an important cereal food crop of Maharashtra, which contributes 3.6% of area and 2.8% of production of rice at national level.

Rice is grown either by direct seeding or by transplanting. In Konkan region, rice is mostly grown by transplanting method. Weed infestation and weed competition are more in direct-seeded rice as compared to transplanted rice, because the land is exposed till the initial seedling establishment in direct-seeded rice. Crop establishment and weed management techniques are critical in rice farming.

The System of Rice Intensification (SRI), a technique for rice culture, is being practiced in almost 22 countries. The proponents of SRI have claimed substantial increases in rice yields, sometimes as high as 3 to 4 times, with the consequent increase in the productivity of land, water and capital (Uphoff, 2002). SRI increases rice yield over the conventional method of cultivation by 32% and net returns by 67%, while decreases labour input by 8% in West Bengal, India (Sinha and Talati 2007). Besides, it enhances soil health with reduction in input use such as seeds, water, labours, *etc*. Krishna *et al.* (2008) reported an enhanced tillering, early flowering, higher yield and better grain quality in SRI practices compared to conventional methods. The traditional system of transplanting gives the crop a 14 to 21 day growth advantage over the weeds. The transplanting also enables rice to capture space earlier. This is because the young rice plants have leverage over germinating weeds due to shading and earlier establishment of root system. The immediate flooding after transplanting limits the establishment of many weeds. Similarly, in direct seeded method, the use of high seed rates could reduce weed infestation to a large extent. Therefore, the rice cultivation trend has been increasingly shifting to direct-seeding as labour prices become higher. So, keeping this point in the view present investigation conducted during rainy (*Kharif*) season of 2016 and 2017 with following objectives:

1. To find out suitable rice establishment method that can be an alternative for cost involving manual transplanting method.
2. To find out effective weed management practices for *Kharif* rice.
3. To study the interaction effects between establishment methods and weed management practices on growth and yield of *Kharif* rice.

MATERIALS AND METHODS

The field experiment was conducted at College of Agriculture, Dapoli Dist. Ratnagiri is situated at 17-0.45' N latitude and 730.1' E longitude having altitude of 250 meters above the mean sea level during *Kharif* 2016 and 2017. The soil of the experimental plot was sandy clay loam in texture, low in available nitrogen (216.12 kg/ha), phosphorus (9.22 kg/ha) and potassium (205.75 kg/ha), moderately high in organic carbon (0.94%) and slightly acidic in reaction (5.80). The meteorological data revealed that the weather was, congenial for the growth and development of *Kharif* rice without incidence of any major pests or diseases during both the years.

The field experiment was laid out in a strip plot design comprising of twenty five treatment combinations replicated thrice. The horizontal strips comprised five rice establishment methods, *viz.* sowing of dry seeds by drum seeder at onset of monsoon, sowing of sprouted seeds (*Rahu*) by drum seeder in puddled field, broadcasting of sprouted seeds (*Rahu)* in puddled field, System of Rice Intensification (SRI) method and conventional transplanting. The vertical strips consisted five weed management practices, *viz.* need based two hand weedings at 20/30 and 40/60 DAS/DAT, pre-emergence application of oxadiargyl 80 WP 100 g/ha + 1 hand weeding at 20/30 DAS/DAT, pre-emergence application of oxadiargyl 80 WP 100 g/ha + 1 hand weeding at 40/60 DAS/DAT, pre-emergence application of oxadiargyl 80 WP 100 g/ha + post-emergence application of almix 20 WP 4 g/ha and unweeded control . The gross plot size was 4.50 m x 3.60 m and truthful seed of long bold seeded early rice variety, '*Ratnagiri-1*' was used in the present investigation.

The sowing of dry seeds by drum seeder was done at onset of monsoon as per the treatments. The nursery for conventional transplanting and SRI method was put on the same day of sowing of dry seeds by drum seeder. Similarly, seeds were kept for soaking in water on the same day of nursery sowing for sowing of sprouted seeds (*Rahu*) by drum seeder and broadcasting sprouted seeds in puddled field. Two days sprouted seeds were sown in the puddled field by drum seeder and broadcasting as per the treatments. In SRI and conventional transplanting methods 12 and 21 days old seedlings were transplanted, respectively in puddled field as per the treatments. FYM (7.5 t/ha), half N and full dose of P_2O_5 and K_2O was applied as basal dose and remaining half dose of N was applied at tillering and panicle initiation stages in equal splits. The other usual common packages of practices were followed time to time and periodical growth and weed observations were recorded at an interval of 30 days. The pre- and post-emergence herbicides are oxadiargyl and almix is applied at 2 to 3 and 20 to 25 DAS/DAT. Crop was harvested at physiological maturity and data on yield attributes and yield were recorded.

RESULTS AND DISCUSSION

Effect of establishment methods on density and dry weight of weeds

The following dominant weeds observed in the *Kharif* rice crop:

Botanical name	Family	Common name
A) Grassy weeds		
Echinochloa colona	Poaceae	Pakhad
Echinochloa glabrescens	Poaceae	Pakhad
Ischaemum globosa	Poaceae	Dhur
B) Sedges		
Cyperus iria	Cyperaceae	Lavala
Cyperus difformis	Cyperaceae	Lavala
C) Broad-leaved weeds		
Celosia argentea	Amaranthaceae	Cocks comb
Mimosa pudica	Leguminaceae	Lajaloo
Alternanthera sessilis	Amaranthaceae	Reshim kata
Ageratum conyzoides	Asteraceae	Osadi
Ludwigia octovalvis	Onagraceae	Kadu Chinch

The sowing of dry seeds by drum seeder at onset of monsoon (**Table 1** and **2**) recorded significantly maximum weed density and dry weight of weeds (3.04 and 3.07 t/ha) as compared to rest of the rice establishment methods during both the years of experimentation. Further, the other rice establishment methods, *viz.* SRI method (2.36 and 2.43 t/ha), conventional transplanting (2.39 and 2.46 t/ha), sowing of sprouted seeds by drum seeder (2.44 and 2.53 t/ha) and broadcasting of sprouted seeds on puddled field (2.48 and 2.56 t/ha) remained at par with each other and recorded significantly minimum weed intensity and dry weight of weeds during both the years of study.

Effect of different weed management practices on density, dry weight of weeds, weed index and weed control efficiency

Weed management practices recorded significantly (**Table 1** and **2**) lower weed density and dry weight of weeds as compared to unweeded control (3.92 and 4.05 t/ha) during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT

Table 1. Mean number of grassy, sedges and broad-leaved weeds/m^2 as influenced by different treatments during *Kharif* 2016 and 2017

Treatment	Weed density/m^2 Grassy weeds		Sedges		Broad-leaved weeds	
	2016	2017	2016	2017	2016	2017
Establishment method						
Sowing of dry seeds by drum seeder	7.15 (56.7)	7.17 (56.9)	6.91 (51.5)	6.95 (51.9)	4.98 (26.8)	5.00 (26.9)
Sowing of sprouted seeds by drum seeder	4.99 (26.8)	5.00 (26.9)	4.84 (25.0)	4.96 (25.9)	3.64 (13.8)	3.65 (13.9)
Broadcasting of sprouted seeds	5.00 (26.8)	5.01 (26.9)	4.85 (25.0)	4.94 (25.7)	3.65 (13.9)	3.66 (13.9)
SRI method	4.90 (25.7)	4.89 (25.6)	4.84 (24.9)	4.90 (25.4)	3.64 (13.8)	3.64 (13.8)
Conventional transplanting	4.92 (25.8)	4.92(25.7)	4.83 (24.9)	4.92 (25.7)	3.60 (13.5)	3.63 (13.7)
LSD (p=0.05)	0.57	0.55	0.27	0.37	0.14	0.08
Weed management practice						
Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	4.60 (21.9)	4.60 (22.0)	4.56 (21.6)	4.56 (21.6)	3.63 (12.9)	3.62 (12.9)
Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	4.02 (15.9)	4.03 (15.9)	3.88 (14.9)	4.09 (16.5)	2.93 (8.2)	2.94 (8.3)
Oxadiargyl (PE) + Almix (POE)	6.52 (43.2)	6.51 (43.1)	6.24 (39.5)	6.25 (39.6)	4.40 (19.8)	4.42 (20.0)
Two hand weeding	3.82 (14.4)	3.83 (14.5)	3.87 (14.8)	4.07 (16.3)	2.77 (7.3)	2.78 (7.3)
Unweeded control	8.00 (66.3)	8.01 (66.5)	7.71 (60.5)	7.72 (60.6)	5.80 (33.6)	5.81 (33.7)
LSD (p=0.05)	0.51	0.50	0.36	0.40	0.15	0.13
Interaction effect						
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
General mean	5.39 (32.3)	5.40 (32.4)	5.25 (30.3)	5.33 (30.9)	3.90 (16.3)	3.92 (16.4)

Note: Transformed values (Y=$\sqrt{x+0.5}$); Figures in parentheses are means of original values

Table 2. Total dry weight of weeds (t/ha) at harvest, weed index (%) and weed control efficiency (%) as influenced by different treatments during *Kharif* 2016 and 2017

Treatment	Dry weight of weeds (t/ha)		Weed index (%)		Weed control efficiency (%)	
	2016	2017	2016	2017	2016	2017
Establishment method						
Sowing of dry seeds by drum seeder	3.04 (9.9)	3.07 (10.1)				
Sowing of sprouted seeds by drum seeder	2.44 (5.9)	2.53 (6.4)				
Broadcasting of sprouted seeds	2.48 (6.1)	2.56 (6.5)				
SRI method	2.36 (5.4)	2.43 (5.8)				
Conventional transplanting	2.39 (5.6)	2.46 (6.0)				
LSD (p=0.05)	0.04	0.08				
Weed management practice						
Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	2.27 (4.7)	2.32 (4.9)	2.66	3.30	67.65	68.34
Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	2.03 (3.6)	2.09 (3.9)	4.82	5.52	74.90	75.11
Oxadiargyl (PE) + Almix (POE)	2.48 (5.7)	2.54 (6.0)	8.92	9.21	61.32	61.93
Two hand weeding	2.01 (3.6)	2.06 (3.7)	-	-	75.57	75.92
Unweeded control	3.92 (15.2)	4.05 (16.2)	11.77	13.37	-	-
LSD (p=0.05)	0.05	0.09				
Interaction effect						
LSD (p=0.05)	NS	NS				
General mean	2.54 (6.57)	2.61 (6.96)				

Note: Transformed values (Y=$\sqrt{x+0.5}$); Figures in parentheses are means of original values

(2.01 and 2.06 t/ha) and oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (2.03 and 2.09 t/ha) produced significantly lower density and weed biomass than oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (2.27 and 2.32 t/ha) and pre- and post-emergence application of oxadiargyl + Almix (2.48 and 2.54 t/ha) during both the years.

Lowest weed index was recorded under oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (2.66 and 3.30) *fb* oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (4.82 and 5.52), pre- and post-emergence application of oxadiargyl + Almix (8.92 and 9.21) and the highest weed index was recorded under unweeded control (11.77 and 13.37) during both the years of study. Two hand weeding at 20/30 and 40/60 DAS/DAT (75.57 and 75.92%) recorded the highest weed control efficiency *fb* oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (74.90 and 75.11%), oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (67.65 and 68.34%) and the lowest weed control efficiency was recorded under pre- and post-emergence application of oxadiargyl + Almix (61.32 and 61.93%) during both the years.

Table 3. Number of panicles/m^2, length of panicle (cm) and weight/ panicle (g) of rice as influenced by different treatments during *Kharif* 2016 and 2017

Treatment	No. of panicles/m^2		Length of panicle (cm)		Weight/ panicle (g)	
	2016	2017	2016	2017	2016	2017
Establishment methods						
Sowing of dry seeds by drum seeder	271.93	270.40	20.08	20.00	3.06	3.03
Sowing of sprouted seeds by drum seeder	281.60	280.53	21.41	21.29	3.38	3.23
Broadcasting of sprouted seeds	275.47	274.53	21.21	21.08	3.29	3.17
SRI method	280.87	281.40	23.61	23.61	3.57	3.48
Conventional transplanting	286.13	285.13	23.05	23.01	3.49	3.38
LSD (p=0.05)	1.06	1.03	0.83	0.71	0.06	0.07
Weed management practices						
Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	282.40	281.67	22.57	22.51	3.49	3.39
Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	279.53	279.00	22.08	21.86	3.39	3.27
Oxadiargyl (PE) + Almix (POE)	276.60	275.93	21.10	21.09	3.21	3.11
Two hand weedings	284.13	283.60	23.68	23.65	3.63	3.52
Unweeded control	273.33	271.80	19.92	19.89	3.06	2.99
LSD (p=0.05)	0.55	0.77	0.63	0.77	0.07	0.04
Interaction effect						
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
General mean	279.20	278.40	21.87	21.80	3.36	3.26

Table 4. Grain and straw yield of rice as influenced by different treatments during *Kharif* 2016, 2017 and in pooled data

Treatment	Grain yield (t/ha)			Straw yield (t/ha)		
	2016	2017	Pooled	2016	2017	Pooled
Establishment methods						
Sowing of dry seeds by drum seeder	3.75	3.58	3.67	5.36	5.22	5.29
Sowing of sprouted seeds by drum seeder	3.95	3.86	3.91	6.01	5.86	5.94
Broadcasting of sprouted seeds	3.86	3.77	3.82	5.72	5.58	5.65
SRI method	4.38	4.26	4.32	6.37	6.22	6.29
Conventional transplanting	4.28	4.17	4.22	6.25	6.11	6.18
LSD (p=0.05)	0.11	0.20	0.13	0.40	0.36	0.37
Weed management practices						
Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	4.18	4.06	4.12	6.08	5.96	6.02
Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	4.09	3.97	4.03	5.99	5.85	5.92
Oxadiargyl (PE) + Almix (POE)	3.91	3.81	3.86	5.81	5.69	5.75
Two hand weedings	4.29	4.20	4.24	6.22	6.11	6.16
Unweeded control	3.77	3.60	3.69	5.60	5.39	5.49
LSD (p=0.05)	0.15	0.17	0.13	0.23	0.21	0.22
Interaction effect						
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
General mean	4.05	3.93	3.99	5.94	5.80	5.87

Effect of establishment methods on yield and yield attributes: The yield and yield attributes of rice was significantly (**Table 3** and **4**) higher when it was grown by transplanting the seedlings by SRI method or conventional transplanting as compared to sowing of either dry or sprouted seeds. System of Rice Intensification method produced maximum and significantly higher grain yield and yield attributes of rice as compared to rest of the rice establishment methods during both the years as well as in pooled data. Sowing of sprouted seeds by drum seeder on puddled field recorded significantly higher grain yield and yield attributes of rice as compared to broadcasting of sprouted seeds on puddled field and sowing of dry seeds by drum seeder during individual years and in pooled data.

Effect of different weed management practices on yield and yield attributes: Among weed management practices, two hand weedings at 20/30 and 40/60 DAS/DAT significantly increased the yield and yield attributes of rice as compared to integration of oxadiargyl (PE) with 1 HW either at 20/30 DAS/DAT or 40/60 DAS/DAT during both the years and in pooled analysis. Application of oxadiargyl (PE) along with 1 HW at 20/30 DAS/DAT recorded significantly higher grain yield over the integration of oxadiargyl (PE) and 1 HW at 40/60 DAS/DAT as well as pre and post emergence application of oxadiargyl and Almix, respectively. Unweeded control recorded significantly lowest yield and yield attributes of rice as compared to other weed management practices during both the years as well as in pooled data.

Weeds are the major constraint in rice production systems. From the results of the present investigation, it was concluded that when rice crop was established by SRI method with two hand weedings carried out at 20 and 40 DAT reorded highest grain and straw yield of *Kharif* rice and lowest weed density and dry weight of weeds as compared to remaining treatment combinations during both the seasons. There is also a need to study weed biology and ecology in different rice ecosystems.

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Role of submergence tolerant rice cultivar and herbicides in managing invasive alien weeds

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ABSTRACT

The present investigation was conducted to evolve a suitable weed management practice for invasive alien weeds in transplanted rice at *Annamalai University* Experimental Farm, Annamalainagar, during samba seasons of consecutive years (2015 and 2016). The experiments were laid out in a split plot design with the conventional rice and submergence tolerant rice varieties compared in main plot. Weed management practices, *viz.* unweeded control, twice hand weeding (at 30 and 45 DAT), butachlor 1.5 kg/ha, bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha and oxadiargyl 0.07 kg/ha were compared in sub treatments. The results indicated that submergence tolerance as a biological or genetic trait in crops helped suppressing invasive alien weeds like *Leptochloa chinensis* and *Marsilea quadrifolia*, offering biotic resistance to invasion by alien weeds and when integrated with weed control measures. Hence, weed control in submergence tolerant rice with the application of bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha could be suggested as an efficient weed control programme for monsoon transplanted rice crop.

INTRODUCTION

Rice cultivation in wetlands are characterised by transplanted mode of cultivation with standing water and crop growing seasons coinciding with monsoon rains. Frequently, excess rainfall during monsoon results in flash floods that lead to complete submergence of the crop. Traditional and popular rice varieties are prone for their susceptibility to complete submergence. Accordingly, submergence tolerant rice varieties are introduced and are being increasingly cultivated as they withstand complete submergence up to ten days. They do not suffer any yield loss compared to conventional varieties (Manzoor *et al.* 2018). Frequent occurrence of flash floods in these rice growing delta regions have resulted in the disappearance of predominant native or naturalised rice weeds like *Echinochloa colona* and *Spenoclea zylanica*, leaving open niches that tend to invite invasion by alien weeds such as *Leptochloa chinensis* and *Marsilea quadrifolia.*

Annamalai University introduced a new submergence tolerant paddy variety "*Sigappi*", developed by incorporating the Sub-1 gene (submergence tolerant gene) in the traditional '*CR 1009*' paddy variety. While retaining the characteristics of the traditional variety, the new one also withstand total submergence for 10 days and yet capable of giving 70 to 80 per cent of the normal yield in 145-150 days (Manzoor *et al.* 2018). This variety is now picking up in Cauvery delta region, the rice granary of Tamil Nadu, which is prone to many natural calamities like uncertain monsoon rains, periodical floods *etc.*

Phytosociological survey of floristic composition of weeds in this region revealed the recent invasion of the wetland rice fields by alien invasive weeds *Leptochloa chinensis* and *Marsilea quadrifolia*. These two weed species dominated over the native weed such as *Echinochloa colona*. and others by virtue of their amphibious adaptation to alternating flooded and residual soil moisture conditions prevalent during recent years in this region (Yaduraju and Kathiresan 2003, Kathiresan 2005, Kathiresan and Gulbert 2016). Alteration in the precipitation and evaporation pattern, more number of wet years annual rainfall excess by ten per cent or more resulting in frequent inundation or flooding resulted in invasion of rice fields of Cauvery river delta in India (Kathiresan 2006, Kathiresan 2009).

Herbicides have become the major weed management tool in rice crop. Hence, the present investigation was conducted to compare the magnitude infestation and competition by invasive alien weeds *Marsilea quadrifolia* and *Leptochloa* *chinensis*, its impact on grain yield of submergence tolerant rice variety and to evaluate weed control by using herbicides in rice prone to complete submergence.

MATERIALS AND METHODS

Field experiments were conducted during *samba (Kharif)* seasons of consecutive years (2015 and 2016) at Annamalai university experimental farm, Department of Agronomy, Annamalainager, Tamil Nadu. The soil was clayey loam with a pH of 7.09. The available nitrogen, phosphorus and potassium content in the soil were 227.4, 19.7 and 342.5 kg/ha respectively. The experiment was laid out in split plot design with three replications. The main plot treatments comprised conventional and sub-mergence tolerant rice varieties namely *BPT* (5204) and *Siggapi* (*CR1009 sub1*). The weed management practices were compared as sub-plots. They included two hand weedings, butachlor 1.5 kg/ha, bensufuron-methyl 0.6 + pretilachlor 6% GR 10 kg/ha and oxadiargyl 0.07 kg/ha. The weed flora was allowed to grow without any disturbance throughout the crop duration in the unweeded control. Hand pulling of weeds was done once at 30 DAT and again at 45 DAT in twice hand weeded plots. In herbicide treatments, the herbicides were sprayed by using knapsack sprayer fitted with flood jet deflector nozzle using 600 L/ha water. Butachlor formulation used was 50% EC 1.25 kg/ha, granular bensulfuron methyl 0.06 + pretilachlor 0.6 kg/ha was mixed with 50 kg sand/ha and they were applied on 4th day after transplanting, oxadiargyl 80% WP was sprayed 0.07kg/ha on 3rd day after transplanting. A thin film of water was maintained at the time of herbicide application.

The crop was manured with 150 kg N, 50 kg P and 50 kg K_2/ha, with half dose of N (75 kg/ha) and full dose of phosphorus (60 kg/ha) and potassium (50 kg/ha) as basal before transplanting. The remaining half nitrogen (75 kg/ha) was top dressed in two equal splits at tillering and panicle initiation stages. Thirty days old seedlings were transplanted in the main field with a spacing of 20x15 cm. The plants were exposed to submergence with water depth of 50 cm after 10 days of transplanting during the field experimentations for seven days and there after normal water depth of 10 cm was maintained.

All other agronomic and plant protection measures were adopted as per the recommended packages. The data on weed density (30 and 60 DAT) and weed dry weight (60 DAT) were recorded with the help of a quadrat of 0.25 m^2. Weed control index of each treatment plot was calculated by using the following formula suggested by Misra and Tosh (1979) and recorded in percentage.

$$WCI = \frac{a-b}{a} \times 100$$

Where,

a= weed biomass in unweeded control plot
b= weed biomass in treatment plot

Economics of production for the cropping systems were also computed and recorded. The experimental data were statistically analyzed following analysis of variance and least significant difference was worked out at 5% probability level.

RESULTS AND DISCUSSION

Effect on weeds

The weed flora was dominated by *Leptochloa chinensis* and *Marsilea quadrifolia*. Other weeds like *Cyprus rotundus*, *Bergia capensis*, *Eclipta alba*, *Acalypha indica*, and *Echinocloa colona*, were also present but were sporadic in frequency and negligible in occurrence. Among the conventional and submergence tolerant rice varieties tried submergence tolerant rice variety was found to be superior by recording the least population of weeds. This was because of better vegetative growth and canopy coverage during the vegetative phases of the crop growth that suppressed the establishment of *Leptochloa chinensis* and *Marsilea quadrifolia.* The competitive edge is attributable to the physiology of submergence tolerance in the variety *Sigappi* that surpassed the hydrophytic adaptation of the both the invasive alien species. This finding is supported by the earlier reports of Reddy *et al.* (2012).

Weed management practices influenced the weed population greatly. All the weed management treatments resulted in control of weed population. Among the weed control measures compared, the application of bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha were significantly superior to the other treatments. Bensulfuron-methyl 0.06 + pretilachlor 0.6 Kg/ha offeredeffective control of annual grasses and broad leaf weeds (*Leptochloa chinensis and Marsilea quadrifolia)* (**Table 1**). This finding is supported by the earlier reports of Anbhazhagan and Kathiresan (2008), Kathiresan and Ramah (2000).

Submergence tolerant rice variety was superior over the conventional variety, in reducing the weed dry matter of 30.0 and 55.2 kg/ha during both seasons. On the other hand, conventional rice varieties encouraged a higher weed dry matter of 60.8 and 70.5 kg/ha during both the seasons. Among the weed control treatments application of bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha recorded the least weed dry matter of 10.64 and 15.91 kg/ha during both the seasons. Unweeded control registered the highest weed dry matter of 123.4 and 175.7 kg/ha during both the seasons. The interaction effects between rice varieties and weed management were also significant. The least weed dry matter production was observed with submergence tolerant rice variety along with the application of bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha (5.85 kg/ha). Unweeded control in conventional variety recorded the highest dry matter production.

Among the conventional and submergence tolerant rice varieties tried '*Sigappi*' excelled with the highest weed control index of 67.51 and 66.67% during both the seasons. Conventional variety recorded the lowest weed control index of 63.84 and 62.65% during both the seasons. Among the weed control treatments, application of bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha recorded the highest weed control index of 94.9 and 91.03% during both the seasons. The interaction effects between rice varieties and weed management were also significant (Gnanavel and Kathiresan 2002) (**Table 2**).

Crop growth, yield attributes and yield

Among the varieties, the submergence tolerant '*Siggappi*' recorded the highest crop dry matter production, panicle/m^2 as compared to conventional variety because of it's ability to overcome the stress due to complete submergence for seven days with 50 cm water column during the period that extended 10 days after transplanting. The conventional variety was not able to recover from the stress and suffered comparative yield reduction, besides the stress from weed competition. All the weed control treatments recorded significantly more number of panicles/ m^2 as compared conventional variety (**Table 3**). Submergence tolerant rice variety exhibited higher yields of 4.09 and 4.54 t /ha during both seasons, respectively. (**Table 3**) This finding is supported by Yamano *et al.* (2013).

Economics of weed control

Economics worked out also favoured the integration of submergence tolerant rice variety with the application of bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha, towards achieving a wholistic weed control and profitable production of rice. The highest gross income of ` 1,15,241 and ` 1,17,231 during both seasons, net income of ` 82, 971 and ` 83,510 during both seasons and BCR of ` 2.57 and ` 2.51 during both seasons, (**Table 4**). These are in line with the earlier reports of Reddy *et al.* (2012), Singh *et al.*(1999) and Rachna Sharma and Upadyay (2002).

Table 1. Effect of treatments on individual weed density at 60 days after transplanting

Treatment	*Cyprus rotundus*		*Bergia capensis*		*Eclipta alba*		*Acalypha indica*		*Echinocloa colona*		*Leptochloachinensis*		*Marsilea quadrifolia*	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
BPT (5204)	2.05 (3.73)	1.95 (3.34)	1.90 (3.13)	1.76 (3.1)	1.70 (2.60)	1.12 (1.26)	1.58 (2.00)	1.41 (2.01)	1.64 (2.20)	1.41 (2.01)	5.25 (27.1)	6.54 (42.3)	3.58 (12.3)	3.29 (10.4)
Siggapi	2.37 (5.16)	1.11 (1.25)	1.72 (2.46)	2.04 (3.70)	1.95 (3.33)	1.52 (1.83)	1.62 (2.13)	1.82 (2.83)	1.70 (2.40)	1.82 (2.83)	2.04 (3.7)	3.60 (12.5)	2.85 (7.7)	1.98 (3.4)
LSD (p=0.05)	-	-	-	-	-	-	-	-	-	-	3.21	0.87	0.73	0.44
Unweeded control	2.37 (5.16)	2.06 (4.26)	2.19 (4.33)	1.35 (1.83)	2.30 (4.83)	1.20 (1.46)	2.08 (3.83)	1.44 (2.10)	2.30 (4.83)	1.44 (2.10)	6.83 (46.2)	7.51 (55.9)	1.15 (0.8)	4.12 (16.5)
Twice hand weeding	2.12 (4.00)	1.50 (2.26)	1.52 (1.83)	1.82 (3.33)	1.91 (3.16)	1.22 (1.50)	1.78 (2.67)	1.29 (1.67)	1.87 (3.00)	1.29 (1.67)	4.92 (23.7)	3.07 (8.93)	2.41 (5.3)	1.88 (3.0)
Butachlor 1.25 kg/ha	2.08 (3.83)	1.72 (2.48)	1.47 (1.67)	2.06 (4.25)	1.91 (3.16)	2.08 (4.33)	1.41 (1.50)	1.62 (2.13)	1.35 (1.33)	1.62 (2.13)	1.87 (3.00	6.23 (38.4)	3.02 (8.7)	3.19 (9.7)
Bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha	1.95 (3.33)	0.89 (0.89)	1.95 (3.33)	0.91 (0.83)	1.47 (1.67)	0.71 (0.00)	1.35 (1.33)	1.31 (1.73)	1.22 (1.00)	1.31 (1.73)	1.22 (1.0)	2.07 (3.8)	2.97 (8.3)	1.26 (1.1)
Oxadiargyl 0.07 kg/ha	1.82 (2.83)	2.06 (4.26)	1.82 (2.83)	1.82 (2.83)	1.58 (2.00)	1.41 (2.00)	1.22 (1.00)	1.41 (1.50)	1.35 (1.33)	1.41 (1.50)	1.87 (3.0)	5.52 (30.1)	2.48 (5.7)	2.16 (4.2)
LSD (p=0.05)	-	-	-	-	-	-	-	-	-	-	0.65	2.33	0.56	0.58

(Values in parentheses are original values and those outside are square root transformations); - NS

Table 2. Effect of treatments on total weed density, weed dry weight and weed control indexat 60 days after transplanting

Treatment	Weed density (no./m^2)		Weed dry weight (kg/ha)		WCI (%)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Main treatment						
BPT (5204)	6.91(47.3)	7.43(54.8)	7.83(60.8)	8.42(70.5)	53.03(63.8)	7.94(62.6)
Siggappi	5.88(34.2)	5.48(29.5)	5.97(30.0)	7.92(55.2)	55.24(67.5)	8.19(66.7)
LSD (p=0.05)	0.65	1.56	0.32	5.5	3.82	1.20
Sub treatment						
Unweeded control	8.93(79.3)	8.97(80.0)	5.31(123.4)	13.75(175.7)	0.70(0)	0.70(0)
Twice hand weeding	6.40(40.5)	4.69(21.5)	7.05(49.8)	5.47(24.8)	65.28(82.5)	9.40(87.9)
Butachlor 1.25 kg/ha	4.69(21.5)	7.45(55.1)	5.40(24.0)	7.16(51.4)	62.85(79.2)	8.93(70.7)
Bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha	3.36(10.8)	2.72(6.9)	3.76(10.6)	4.48(15.9)	76.94(94.9)	9.56(91.0)
Oxadiargyl 0.07 kg/ha	4.21(17.2)	6.91(47.3)	5.32(23.3)	7.33(46.7)	59.90(74.9)	8.61(73.6)
LSD (p=0.05)	1.34	3.32	0.45	5.16	5.57	4.20
Interaction						
LSD (p=0.05)	0.14	4.30	0.64	8.17	3.0	5.42
LSD (p=0.05)	2.2	4.70	0.64	7.31	0.25	5.95

Values in parentheses are original values and those outside are square root transformations

Table 3. Effect of treatments on yield parameters at harvest

Treatment	Crop dry matter production at harvest (t/ha)		Panicle/m^2		Grain yield (t/ha)		Straw yield (t/ha)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Main treatment								
BPT (5204)	4.99	7.38	6.23	6.15	2.32	2.88	4.15	4.19
Siggappi	10.99	10.86	6.70	7.19	4.09	4.54	6.12	5.94
LSD (p=0.05)	6.65	0.15	0.50	1.12	2.13	0.70	2.35	0.95
Sub treatment								
Unweeded control	4.03	7.07	4.24	4.84	2.80	2.80	4.60	4.25
Twice hand weeding	10.58	10.46	7.52	7.91	3.51	4.27	5.37	5.65
Butachlor 1.25 kg/ha	6.85	8.61	6.56	6.09	3.00	3.50	5.01	4.96
Bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha	11.33	10.35	7.26	7.86	3.58	4.26	5.55	5.53
Oxadiargyl 0.07 kg/ha	7.16	9.11	6.30	6.67	3.10	3.73	5.15	5.18
LSD (p=0.05)	2.17	0.53	0.30	0.27	0.08	0.12	0.5	0.18
Interaction								
LSD (p=0.05)	5.90	0.69	2.91	1.13	1.40	0.70	1.57	0.95
LSD (p=0.05)	2.68	0.76	2.50	0.38	0.04	0.18	0.50	0.26

Table 4. Effect of treatments on economics

Treatment	Cost of cultivation (x10^3 `/ha)		Gross income (x10^3 `/ha)		Net income (x10^3 `/ha)		Benefit cost ratio	
	1st Season	2st Season	1st Season	2st Season	1st Season	2st Season	1st Season	2st Season
BPT (5204)								
Unweeded control	32.00	32.12	57.75	59.05	25.75	26.93	0.80	0.83
Twice hand weeding	34.43	34.52	75.30	83.05	40.87	48.53	1.18	1.40
Butachlor 1.25 kg/ha	32.44	32.59	61.30	65.29	28.86	32.70	0.88	1.00
Bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha	32.15	34.01	74.00	82.19	41.86	48.82	1.30	1.46
Oxadiargyl 0.07 kg/ha	32.63	33.05	66.00	78.39	33.37	45.34	1.02	1.37
Siggapi								
Unweeded control	31.20	32.70	72.43	73.47	41.23	40.77	1.32	1.24
Twice hand weeding	33.16	33.72	115.29	117.23	82.13	83.51	2.47	2.48
Butachlor 1.25 kg/ha	34.25	34.27	77.69	117.29	83.44	83.02	2.43	2.42
Bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha	32.27	33.72	115.24	118.45	82.97	84.73	2.57	2.51
Oxadiargyl 0.07 kg/ha	32.05	35.31	109.45	119.67	77.40	84.36	2.41	2.38

The results indicated that submergence tolerance as a biological or genetic trait in crops helped suppressing invasive alien weeds like *Leptochloa chinensis* and *Marsileaquadrifolia*, offering biotic resistance to invasion by alien weeds and when integrated with weed control measures were efficient in suppressing these alien weeds.

Hence, weed control using submergence tolerant rice along with the application of bensulfuron-methyl 0.06 + pretilachlor 0.6 kg/ha could be suggested as an efficient weed control programme, for monsoon transplanted rice crop.

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Impact of diversification of rice-wheat cropping system on weed dynamics under irrigated condition of eastern Uttar Pradesh

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ABSTRACT

Effects of ten diversified rice based cropping sequences on weed dynamics were evaluated at Banaras Hindu University, Varanasi (Uttar Pradesh) in different season during 2016-17 and 2017-18. The results revealed that density of *Cyperus* spp., *Cynodon dactylon* and *Digitaria sanguinalis* was significantly lowest in rice-potato-greengram sequence but it remained at par with rice-berseem-cowpea fodder, rice-cabbage-cowpea fodder and rice-potato-cowpea fodder during second year in rainy season. Dry weight of *Digitaria sanguinalis* was significantly lowest under rice-potato-greengram sequence. During winter season, significantly lower density and dry weight of *Medicago denticulata, Chenopodium album* as well as total weeds were recorded in mustard (rice-mustard-cowpea fodder), though it was found similar with mustard (rice-mustard-sudan grass fodder), potato (rice-potato-greengram and rice-potato-cowpea fodder) and wheat (rice-wheat, rice-wheat-greengram and rice-wheat-cowpea fodder). While, density of *Cynodon dactylon* was markedly lower in wheat (rice-wheat) it was on a par with mustard (rice-mustard-sudan grass fodder), potato (rice-potato-green gram, rice-potato-cowpea fodder) and wheat (rice-wheat-greengram, rice-wheat-cowpea fodder). During summer season, cowpea grown in rice-cabbage-cowpea fodder recorded significantly lower density as well as dry weight of *Cyperus rotundus, Cynodon dactylon* as well as total weeds. Grain yield of rice was significantly higher in rice-berseem-cowpea fodder. During winter season, berseem in rice-berseem-cowpea fodder sequence out yielded all the other crops. However, in summer, sudan grass in rice-mustard-sudan grass fodder produced the highest green fodder yield.

INTRODUCTION

Rice-wheat cropping system is one of the world's largest agricultural production systems, covering an area of 26 mha extend over the Indo-Gangetic Plains (IGP) in South Asia. In India, rice-wheat system occupies around 10.5 mha area and produces almost 50% of the total food consumed in the country (Dhillon *et al.* 2010).

Diverse weed flora and excessive weed pressure is an important constraints in the way to sustainability and production potential of this system (Bhatt *et al.* 2016). Weeds are self-perpetuating and appear simultaneously with crop plants creating severe competition with the main plants for light, water and nutrients and in turn decrease overall land productivity of the system as a whole hence weeds are the main factor responsible for the yield declines in any ecosystem (Chauhan and Johnson, 2011). Due to intensive tillage in rice–wheat sequence and monoculture, increased problem of weeds are becoming serious year after year. The extent of yield reduction of rice due to weeds has been estimated up to 95% in India (Naresh *et al*, 2011), 33-80% in Pakistan (Khaliq *et al.* 2012) and 71-96% in the Philippines (Chauhan and Johnson, 2011). However, weeds accounts for more than 48% loss of potential wheat yield (Govindra *et al.* 2002; Fahad *et al.* 2015). The continuous practice of the same system over the years had an adverse effect on soil conditions (Bhatt *et al.* 2016) and increased the population of grassy weeds in both the crops. The existences of weeds in cropped lands are largely influenced by crop rotation and management practices (Mishra *et al.* 2019).

Diversification of rice-wheat system with inclusion of berseem has exhausted the seed bank of *Phalaris minor* (Tripathi and Singh 2008, Singh *et al.* 2019; Sethi *et al.* 2019). Legumes with leafy growth, succulent foliage have ability to suppress weeds and reduce weed population in succeeding season (Ali *et al.* 2012). Different rotations that include crops with different life cycles lead to additional benefits of reducing the weed seed bank. Hence, a crop diversification including legumes, oilseeds and vegetables has the potential to decreases the problems of weeds in rice-wheat systems. However, with diversification of the system, the behavior of weeds in different season as function of preceding crops may change. Therefore, a necessity was felt to study the weed dynamics in different season as influenced by diversification of rice-wheat system.

MATERIALS AND METHODS

A field experiment on diversification of rice-wheat system was conducted under AICRP on Integrated farming systems during 2016-17 and 2017-18 at the Agricultural Research Farm, Banaras Hindu University, Varanasi (U. P.). Varanasi is situated at an altitude of 74.4 meters above mean sea level and located between 25°15′173″ North latitude and 82°59′273″ East longitude. The impact of different cropping sequences on the weed dynamics during rainy, winter and summer season were studied. The soil of the experimental field was sandy loam (*Inceptisol*) in texture, low in organic carbon (0.41%) and available nitrogen (194.7 kg/ha), medium in phosphorus (21.7 kg/ha) and potassium (215.7 kg/ha) with slightly alkaline soil reaction (pH 7.9). The experiment was laid out in randomized block design with three replications on fixed plots with ten rice-based cropping system, *viz.* rice-wheat, rice-wheat-greengram, rice-potato-greengram, rice-wheat-cowpea (fodder), rice-potato-cowpea (fodder), rice-berseem-maize (fodder), rice-berseem-cowpea (fodder), rice-mustard-sudan grass (fodder), rice-mustard-cowpea (fodder), rice-cabbage-cowpea (fodder). All the crops were grown with recommended package of practices under irrigated condition. In rainy season, rice was sown in nursery at 16-06-2016 and 17-06-2017 during first and second year, respectively and then transplanted in the main field at 10-07-2016 and 09-07-2017. In subsequent winter season, crops were sown at optimum sowing time in the month of November, if required with pre sown irrigation. On maturity, wheat and mustard crops were harvested between 3rd week of March to 1st week of April. Whereas, potato tubers were dug out at maturity and cabbage heads were harvested at full developed stage when heads attained about 1-1.5 kg weight in the month of February. However, first cutting of berseem was done at 55-60 DAS and subsequent cutting were at 25-30 days intervals. The summer crops were sown in succession after harvesting of winter crops during both the year of experimentation. Greengram was plucked two times in rice-potato-greengram sequence but only one picking was possible in rice-wheat-greengram sequence and the remaining left over plant material was incorporated into the soil.

The recommended dose of nutrients (rice-120:60:60, wheat- 120:60:60, mustard- 120:60:60, potato-120:60:80, cabbage- 150:75:75, berseem (F) - 25:60:60, greengram- 22:56:40, cowpea (F) - 22:56:40, maize (F)- 120:60:40 and sudan grass (F)- 120:60:40 kg/ha N, P_2O_5 and K_2O) was applied to each crop except rice (50% nutrient through FYM + 50 % nutrients through fertilizers) by using inorganic sources. The half of the nitrogen requirement of the rice in each sequence was given through farm yard manure (FYM). However, with respect to phosphorus and potassium application through fertilizer was adjusted on equivalent basis as per their application as FYM. Well decomposed FYM available in the IFS model at Agricultural Research Farm was used. The desired quantity of FYM was calculated on the basis of nitrogen content and moisture percentage. The whole quantity of P_2O_5 and K_2O along with half of the nitrogen was applied as basal application through FYM, DAP and MOP in rice and urea, DAP and MOP in the remaining crop. The remaining half quantity of nitrogen was top dressed in the form of urea in one or two equal splits at recommended stages of crops. For various crops in the cropping sequences the important weed species emerged in rainy, winter and summer crops were recorded and grouped into species wise and total weeds were worked out at 25 DAT/DAS. Data on weed population (no./m^2) and their dry weight (g/m^2) were recorded at 25 DAT/DAS with the help of quadrate and subjected to square root transformation for statistical analysis and only significant data are presented in Tables.

RESULTS AND DISCUSSION

In rice crop, during rainy season, 10 different species of weeds were identified and composition of dominant weeds such as *Sagittaria guayanensis, Cyperus* spp. *Echinochloa* spp., *Digitaria sanguinalis* and *Cynodon dactylon* were 39.1, 24.7, 24.5, 6.8, 4.7 and 31.4, 25.9, 25.6, 8.4, 8.5, respectively during 2016-17 and 2017-18 (**Table 1**). During winter season; dominant weed flora were of

Medicago denticulata, Chenopodium album, Cyperus rotundus, Cynodon dactylon and other weeds were 75.1, 10.7, 7.7, 3.5, 2.8 and 74.5, 4.8, 13.5, 4.6, 2.4% respectively, during 2016-17 and 2017-18 (**Table 1**). Similarly during summer season, dominant weed flora were of *Cyperus rotundus*, *Cynodon dactylon* and other weeds were 34.2, 36.1, 29.7 and 33.1, 29.2, 37.8% respectively, during 2016-17 and 2017-18 (**Table 1**).

Table 1. Weed flora composition (%) of dominant weed during rainy, winter and summer season at 25 day after transplanting/ days after sowing of crops

Weeds	2016-17	2017-18
Rainy season		
Sagitaria guyanensis	39.06	31.44
Cyperus spp.	24.74	25.97
Echinochloa spp.	24.55	25.62
Digitaria sanguinalis	6.88	8.40
Cynodon dactylon	4.77	8.57
Winter season		
Medicago denticulate	75.11	74.57
Chenopodium album	10.73	4.83
Cyperus rotundus	7.76	13.57
Cynodon dactylon	3.54	4.60
Other weeds	2.87	2.43
Summer season		
Cyperus rotundus	34.22	33.05
Cynodon dactylon	36.12	29.17
Other weeds	29.66	37.77

Effect of cropping sequences on weed dynamics of rainy season

Weed population in different rice based cropping sequences varied during second year while, during first year, variations in different treatments was found to be non significant. In general, diversification of rice-wheat cropping sequence caused reduction in weed population as well as weed dry matter production. The density of *Cyperus* spp., *Cynodon dactylon* and *Digitaria sanguinalis* were significantly the lowest in rice-potato-greengram but it remained at par with rice-berseem-cowpea, rice-cabbage-cowpea and rice-potato-cowpea during second year of experiment (**Table 2**). This might be attributed due to intensification of sequences with legumes, which suppressed weed population during summer season and reduced the density of this perennial weed density in succeeding rice crop. The results were in conformity with Singh *et al.* (2008), who reported that weed infestation in various diversified rice-wheat cropping systems was less than that in rice-wheat system. Similarly, Ali *et al.* (2008) stated that inclusion of legumes in the existing rice-wheat cropping sequence suppresses the weed due to leafy and high vegetative cover throughout the cropping season.

Similar to weed density, the weed dry weight of most of the species did not differ significantly under different cropping sequence except dry weight of *Digitaria sanguinalis*, which was significantly lowest under rice-potato-greengram though remained statistically similar with rice-wheat-cowpea, rice-potato-cowpea, rice-berseem-cowpea, rice-mustard-cowpea and rice-cabbage-cowpea in order (**Table 2**). However, it was the highest in rice-wheat sequence during second year of study. The better performance of these sequences was mainly due to maximum coverage of ground area during summer season. Singh *et al.* (2008) reported that diversification of rice-wheat system through inclusion of green gram, cowpea fodder or *Sesbania* for green manuring in summer resulted significantly lowest population of grasses and sedges as well as weed dry matter production.

Effect of cropping sequences on weed dynamics in winter season

Density and dry weight of different species of weeds during winter season was markedly influenced by varying cropping system (**Table 3**). Significantly lower population of *Medicago denticulata*, *Chenopodium album* as well as total weed population were recorded in mustard (rice-mustard-cowpea fodder) though it was found similar with mustard (rice-mustard-sudan grass fodder), potato (rice-potato-greengram and rice-potato-cowpea fodder) and wheat (rice-wheat, rice-wheat-greengram and rice-wheat-cowpea fodder) whereas, density of *Cynodon dactylon* was markedly lower in wheat (rice-wheat). However, it was also statistically comparable with mustard (rice-mustard-sudan grass fodder, rice-mustard-cowpea fodder), potato (rice-potato-greengram and rice-potato-cowpea fodder) and wheat (rice-wheat-greengram and rice-wheat-cowpea fodder) proved distinct superior over cabbage grown (rice-cabbage-cowpea fodder) during both the year of experimentation. The lower density of weeds in these sequences might be due to establishment method of these crops which inhibited emergence of weeds under these sequences as compared to berseem and cabbage. However, comparatively higher population of all weeds were observed in cabbage (rice-cabbage-cowpea fodder) followed by berseem (rice-berseem-maize fodder and rice-berseem-cowpea fodder) sequences which could be ascribed due to establishment method of these crops, which pose favorable condition for weed

Table 2. Effect of different cropping sequences on weed density (no./m²) and weed dry wt. (g/m²) at 25 DAT of rice in rainy season

Treatment	Weed density(no./m²)								Weed dry wt. (g/m²)			
	Cyperus spp.		*Digitaria sanguinalis*		*Cynodon dactylon*		Total weeds		*Digitaria sanguinalis*		Total weeds	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Rice-wheat	1.64	2.19	1.16	1.44	1.04	1.42	3.53	3.97	0.753	0.812	1.153	1.284
	(2.44)	(4.32)	(0.89)	(1.56)	(0.59)	(1.53)	(12.15)	(15.29)	(0.068)	(0.160)	(0.837)	(1.148)
Rice-Wheat-greengram	1.83	2.17	1.09	1.42	1.07	1.40	3.52	3.94	0.742	0.794	1.152	1.239
	(3.11)	(4.22)	(0.7)	(1.52)	(0.67)	(1.45)	(12.04)	(15.30)	(0.051)	(0.130)	(0.829)	(1.036)
Rice-potato-greengram	1.97	1.75	1.13	1.11	1.02	1.16	3.60	3.65	0.746	0.772	1.225	1.238
	(3.44)	(2.56)	(0.78)	(0.75)	(0.56)	(0.84)	(12.44)	(12.87)	(0.057)	(0.097)	(1.090)	(1.032)
Rice-wheat-cowpea (F)	1.76	2.09	1.11	1.21	0.91	1.32	3.50	3.76	0.738	0.783	1.164	1.253
	(2.78)	(3.89)	(0.73)	(0.96)	(0.33)	(1.24)	(11.84)	(13.7)	(0.046)	(0.113)	(0.858)	(1.074)
Rice-potato- cowpea (F)	1.72	1.84	1.02	1.20	1.08	1.18	3.55	3.64	0.726	0.773	1.169	1.244
	(2.67)	(2.88)	(0.56)	(0.94)	(0.67)	(0.90)	(12.28)	(12.83)	(0.027)	(0.098)	(0.867)	(1.049)
Rice-berseem-maize (F)	1.90	2.11	1.22	1.37	0.97	1.35	3.42	3.74	0.769	0.792	1.191	1.232
	(3.33)	(3.96)	(1.00)	(1.38)	(0.44)	(1.32)	(11.30)	(13.56)	(0.091)	(0.129)	(0.920)	(1.019)
Rice-berseem- cowpea (F)	1.76	1.82	1.02	1.18	1.01	1.17	3.45	3.62	0.740	0.774	1.166	1.219
	(2.67)	(2.83)	(0.56)	(0.901)	(0.53)	(0.88)	(11.42)	(12.6)	(0.048)	(0.099)	(0.861)	(0.988)
Rice-mustard-sudan grass (F)	1.76	2.15	1.07	1.39	1.07	1.38	3.46	3.91	0.739	0.791	1.126	1.234
	(2.78)	(4.14)	(0.67)	(1.44)	(0.67)	(1.42)	(11.59)	(14.78)	(0.046)	(0.127)	(0.678)	(1.023)
Rice-mustard-cowpea (F)	1.83	2.04	1.18	1.25	0.97	1.28	3.36	3.82	0.750	0.780	1.099	1.216
	(3.11)	(3.66)	(0.89)	(1.07)	(0.44)	(1.15)	(10.89)	(14.1)	(0.063)	(0.109)	(0.726)	(0.982)
Rice-cabbage-cowpea (F)	1.90	1.88	1.36	1.20	1.12	1.22	3.75	3.54	0.755	0.777	1.169	1.212
	(3.22)	(3.06)	(1.44)	(0.95)	(0.77)	(0.99)	(13.65)	(12.0)	(0.071)	(0.104)	(0.871)	(0.969)
LSD (p= 0.05)	NS	0.15	NS	0.09	NS	0.10	NS	NS	NS	0.017	NS	NS

Table 3. Effect of cropping sequences on weed density (no./m²) and weed dry wt. (g/m²) at 25 DAS in winter season

Treatment	Weed density (no./m²)								Weed dry wt. (g/m²)					
	Medicago denticulata		*Chenopodium album*		*Cynodon dactylon*		Total weeds		*Medicago denticulata*		*Cynodon dactylon*		Total weeds	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Rice-wheat	8.7	8.9	3.6	1.9	2.0	1.6	10.3	10	1.52	1.54	1.21	0.96	2.20	2.10
	(76.4)	(79.8)	(12.6)	(3.3)	(3.3)	(2.2)	(106)	(100)	(1.83)	(1.93)	(0.95)	(0.43)	(4.73)	(3.96)
Rice-Wheat-greengram	10.4	8.7	3.7	2.1	2.1	1.8	11.9	9.9	1.54	1.40	1.26	0.93	2.39	2.06
	(108)	(78.8)	(13.3)	(3.6)	(3.7)	(2.9)	(142)	(99)	(1.89)	(1.47)	(1.09)	(0.36)	(5.21)	(3.78)
Rice-potato-greengram	10.9	8.9	3.9	1.8	2.4	2.1	12.7	10	1.62	1.26	1.56	0.86	2.50	1.86
	(118)	(80)	(14.8)	(3.3)	(5.6)	(3.6)	(160)	(100)	(2.13)	(1.09)	(1.92)	(0.24)	(5.79)	(2.97)
Rice-wheat-cowpea (F)	10.2	9.2	3.6	2.1	2.4	1.8	11.7	10.3	1.53	1.47	1.43	0.96	2.46	2.09
	(103)	(84.6)	(12.6)	(3.6)	(5.3)	(2.8)	(136)	(106)	(1.85)	(1.66)	(1.55)	(0.43)	(5.55)	(3.88)
Rice-potato- cowpea (F)	10.8	9.1	4.0	2.2	2.5	1.7	12.2	10.5	1.59	1.44	1.54	0.90	2.40	1.80
	(117)	(81)	(15.5)	(4.1)	(5.7)	(2.4)	(144)	(110)	(2.04)	(1.59)	(1.88)	(0.31)	(5.25)	(2.76)
Rice-berseem-maize (F)	12.1	9.5	4.4	3.1	2.5	2.8	13.6	11.4	1.85	1.64	1.55	1.03	2.71	2.31
	(146)	(90)	(19)	(8.6)	(6.1)	(7.6)	(187)	(132)	(2.95)	(2.22)	(1.91)	(0.57)	(6.84)	(4.88)
Rice-berseem- cowpea (F)	11.8	9.8	4.3	2.9	2.5	2.8	13.4	11.6	1.83	1.70	1.39	1.05	2.50	2.35
	(139)	(96)	18.6)	(8)	(5.7)	(7.3)	(179)	(136)	(2.85)	(2.24)	(1.18)	(0.60)	(5.79)	(5.06)
Rice-mustard-sudan grass (F)	8.5	8.6	3.5	2.14	2.2	2.6	10.1	9.9	1.51	1.31	1.46	1.03	2.37	2.09
	(71.4)	(74.4)	(12)	(4.12)	(4.3)	(6.3)	(102)	(99)	(1.81)	(1.22)	(1.66)	(0.56)	(5.12)	(3.90)
Rice-mustard-cowpea (F)	8.3	8.5	3.4	1.8	2.2	2.6	9.8	9.8	1.48	1.21	1.29	1.02	2.34	2.13
	(68.5)	(73.4)	(11.7)	(2.8)	(4.4)	(6.6)	(96)	(95)	(1.70)	(0.97)	(1.15)	(0.55)	(4.99)	(3.88)
Rice-cabbage-cowpea (F)	12.4	10.2	5.2	3.7	3.1	2.9	13.9	12.4	3.13	3.21	1.64	1.19	2.93	3.65
	(153)	(104)	(26.3)	(13.6)	(8.7)	(8.3)	(207)	(153)	(4.81)	(5.29)	(1.28)	(0.91)	(8.13)	(8.39)
LSD (p= 0.05)	2.7	0.8	0.6	0.45	0.42	0.50	2.09	1.55	0.21	0.35	0.14	0.16	0.27	0.37

emergence. Berseem was sown in puddled condition, whereas cabbage was irrigated after planting which createed conducive environment for germination, emergence as well as growth of weeds.

Similar to weed density, the dry matter production (**Table 3**) of most of the weed species under mustard grown in rice grown in (rice-mustard-sudan grass fodder and rice-mustard-cowpea fodder), wheat grown in (rice-wheat, rice-wheat-greengram and rice-wheat-cowpea fodder) and potato grown in (rice-potato-greengram and rice-potato-cowpea fodder) sequences, remained statistically comparable among themselves and recorded lower dry matter production as compared to cabbage (rice-cabbage-cowpea fodder). Lower population of weeds as well as crop smothering effect due to closer spacing and broad leaf of mustard, in turn, might have reduced the growth of weeds, which resulted in reduced dry matter production of weeds under these sequences. However, highest dry weights of weeds were observed in cabbage (rice-cabbage-cowpea fodder). These findings might be due to its wide spacing accompanied with slow initial growth and establishment build favorable environment for vigorous growth of weeds. Similarly, dry weight of weeds was higher in berseem as compared to wheat, mustard and potato during both the years. These results could be attributed to higher density of weeds under berseem resulting in higher dry matter production.

Effect of cropping sequences on weed dynamics in summer season

The density and dry weight of different weed species during summer season varied under different cropping sequences during both the years (**Table 4**). Cowpea grown in rice-cabbage-cowpea fodder recorded significantly lower density as well as dry weight of *Cyperus rotundus* and *Cynodon dactylon* as well as total weeds, but it remained at par with rice-berseem-cowpea fodder and rice-berseem-maize fodder during both the years. The lower density and dry matter of these perennial weed under these sequence might be due to smothering effect of preceding crops and which reduced the population of weeds, which did not offer favorable environment for germination of weeds particularly *Cyperus rotundus* and *Cynodon dactylon.* However, the annual weeds did not differ significantly by different cropping sequences during both the years of study. These results were conformity with finding of Tripathi and Singh (2008) who reported that minimum dry weight was recorded under rice-vegetable pea-wheat-green gram, subsequently, rice-berseem-rice-wheat-rice-wheat cropping sequence. Singh (2008) working on different rice based cropping sequences recorded lower weed density in cowpea as compared to other crops during summer season and stated that cowpea with its good canopy coverage had better smothering effect on weeds resulting in lower density as well as dry matter production of all the three groups of weeds.

Grain yield of rice

Data on grain yield of rice under different cropping sequences are presented in **Table 5**. In general, as compared to rice-wheat sequence, the

Table 4. Effect of different cropping sequence on weed density (no./m^2) and weed dry wt. (g/m^2) at 25 DAS in summer crops

Treatment	Weed density (no./m^2)						Weed dry wt. (g/m^2)					
	Cyperus rotundus		*Cynodon dactylon*		Total weeds		*Cyperus rotundus*		*Cynodon dactylon*		Total weeds	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Rice-wheat	-	-	-	-	-	-	-	-	-	-	-	-
Rice-wheat-greengram	2.12	2.11	2.26	2.04	3.53	3.46	1.087	1.117	1.054	0.923	1.514	1.582
	(4.01)	(3.95)	(4.62)	(3.67)	(11.94)	(11.47)	(0.682)	(0.748)	(0.612)	(0.353)	(1.794)	(2.006)
Rice-potato-greengram	2.10	2.09	2.11	1.96	3.48	3.50	1.060	1.072	1.053	0.914	1.489	1.580
	(3.90)	(3.87)	(3.98)	(3.36)	(11.63)	(11.75)	(0.625)	(0.650)	(0.615)	(0.336)	(1.718)	(1.998)
Rice-wheat-cowpea (F)	2.15	2.15	2.13	2.03	3.49	3.54	1.165	1.150	1.059	0.946	1.554	1.636
	(4.12)	(4.15)	(4.12)	(3.65)	(11.72)	(12.06)	(0.860)	(0.823)	(0.621)	(0.395)	(1.918)	(2.145)
Rice-potato- cowpea (F)	2.11	2.09	2.14	1.93	3.49	3.36	1.051	1.054	1.064	0.983	1.477	1.506
	(3.90)	(3.89)	(4.10)	(3.24)	(11.57)	(12.81)	(0.606)	(0.611)	(0.639)	(0.468)	(1.681)	(1.773)
Rice-berseem-maize (F)	1.93	1.91	1.90	1.72	3.18	3.11	1.025	1.072	0.990	1.011	1.498	1.475
	(3.24)	(3.17)	(3.14)	(2.46)	(9.66)	(9.22)	(0.551)	(0.650)	(0.489)	(0.523)	(1.491)	(1.678)
Rice-berseem- cowpea (F)	1.94	1.90	1.98	1.68	3.22	3.34	1.027	0.985	1.077	1.009	1.462	1.501
	(3.27)	(3.12)	(3.45)	(2.34)	(9.89)	(10.69)	(0.555)	(0.471)	(0.661)	(0.518)	(1.528)	(1.758)
Rice-mustard-sudan grass (F)	2.25	2.18	2.47	2.19	3.71	3.62	1.204	1.155	1.190	1.046	1.663	1.629
	(4.57)	(4.24)	(5.61)	(4.29)	(13.33)	(12.62)	(0.950)	(0.835)	(0.919)	(0.595)	(2.274)	(1.156)
Rice-mustard-cowpea (F)	2.18	2.13	2.11	2.16	3.41	3.60	1.092	0.975	1.073	1.055	1.598	1.523
	(4.24)	(4.05)	(3.97)	(4.15)	(11.19)	(12.51)	(0.694)	(0.451)	(0.953)	(0.614)	(1.747)	(1.821)
Rice-cabbage-cowpea (F)	1.90	1.84	1.85	1.65	3.07	3.19	1.015	0.908	0.972	0.906	1.333	1.437
	(3.12)	(2.87)	(2.94)	(2.24)	(8.91)	(9.68)	(0.530)	(0.437)	(0.445)	(0.322)	(1.279)	(1.566)
LSD (p= 0.05)	0.17	0.20	0.23	0.24	0.27	0.24	0.070	0.056	0.085	0.055	0.091	0.117

S- Sequence, the figure in the parentheses were original grain yield of rice was enhanced in sequences having legume crops during winter and summer season. However, the yield differences were significant only during the second year of experimentation. Rice-berseem-cowpea fodder cropping sequences being at par with rice-potato-green gram, rice-wheat-greengram and rice-potato-cowpea fodder produced significantly higher grain yield of rice than rest of the sequences and the lowest was recorded in rice-wheat cropping sequence. The grain yield of rice was improved in sequences having legume crops during winter and summer season, which might have positive effect of preceding legume (green gram, berseem and cowpea fodder) on growth characters and yield attributes. The results are in conformity with Prasad *et al.* (2013), who reported that rice-potato-greengram sequence produced higher grain and straw yield of rice. They attributed this to residual effect of nutrients by growing potato during winter and the beneficial effect of legumes grown in summer season.

Economic yield of winter crops

Growth and yield of the component crops was found to differ under variation cropping sequences. It is clear from the data (**Table 5**) that, in general, slightly higher yield of winter season crops were recorded in 2017-18 as compared to 2016-17 in most of the sequences. Though, wheat and mustard yield were declined during second year as compared to first year of experiment in rice-wheat and rice-mustard-sudan grass fodder sequences, respectively. The better performance during second year might be due to better soil fertility condition in sequences having legume component might be due to legume effect of previous year.

Among the all cropping sequences berseem grown in rice-berseem-maize fodder and rice-berseem-cowpea fodder as winter crop out yielded rest of the other crops during both the years of experimentation. It was followed by cabbage in rice-cabbage-cowpea fodder sequence followed by potato in rice-potato-greengram and rice-potato-cowpea fodder. Among grain/seed crops, wheat yield was considerably higher than mustard grown in sequences rice-sudan grass fodder and rice-mustard-cowpea fodder this may be attributed to their high yield potential and harvesting of economic produce fresh at high moisture contents. These results are in conformity with the findings of Bohra *et al.* (2007) who reported that potato out yielded other crops followed by maize + vegetable pea intercropping. Further examination of the data indicated that among three sequences involving wheat as winter crop, wheat grown in rice-wheat-cowpea fodder produced 4.8 per cent higher grain yield than rice-wheat sequence during second year of study. Similarly, wheat in rice-wheat-greengram sequence registered 3.14 per cent higher yield over rice-wheat sequence during second year of experimentation. This could be because of beneficial effect of the inclusion of cowpea and greengram in the cropping sequences which added a significant amount of biomass and nitrogen in the soil. Ali *et al.* (2012) found a significant higher yield of wheat under rice-wheat-cowpea and rice-wheat-greengram than rice-wheat sequence.

Grain/fodder yield of summer crops

Grain yield of greengram was higher in rice-potato-greengram sequence than rice as compared to rice-wheat-greengram (**Table 5**). Greengram performed better when taken after potato (rice-potato-green gram) as compared to after wheat (rice-wheat-green gram). This was mainly due to timely sowing of greengram after potato that provided

Table 5. Economic yield (t/ ha) of rainy, winter and summer crops in different cropping sequences

Treatment	Rainy		Winter		Summer	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Rice-wheat	3.84	3.73	4.29	4.25	-	-
Rice-Wheat-greengram	3.87	4.06	4.36	4.39	0.63	0.67
Rice-potato-greengram	3.97	4.21	23.51	23.84	1.26	1.29
Rice-wheat-cowpea (F)	3.67	3.95	4.40	4.46	36.46	36.92
Rice-potato- cowpea (F)	3.87	4.02	23.34	23.54	40.74	41.04
Rice-berseem-maize (F)	3.92	3.91	41.31	41.36	59.26	59.79
Rice-berseem- cowpea (F)	3.79	4.25	41.48	41.75	41.14	41.59
Rice-mustard-sudan grass (F)	3.94	3.82	2.06	2.03	63.54	64.05
Rice-mustard-cowpea (F)	3.90	3.93	2.01	2.07	36.57	37.16
Rice-cabbage-cowpea (F)	3.78	3.95	32.22	32.49	34.72	35.14
LSD (p= 0.05)	NS	0.29	NA	NA	NA	NA

S- Sequence, NA- Not analyzed

favorable weather conditions for initial growth and development as well as sufficient period for two pickings before the onset of monsoon. Whereas, in rice-wheat-greengram sequence only one picking were possible in greengram due to delayed sowing of greengram.

Among the different summer crops, sudan grass grown in sequence rice-mustard-sudan grass fodder produced highest economic yield as compared to other crops. However, lowest yield were noted in greengram grown after wheat in rice-wheat-greengram sequence during both the years of experiment. As regards the cowpea grown in different cropping sequences, cowpea in rice-berseem-cowpea fodder sequence produced highest yield followed by cowpea in rice-potato-cowpea, rice-mustard-cowpea and rice-wheat-cowpea. However, the lowest yield was recorded in rice-cabbage-cowpea fodder sequence during both the years of study. The higher yield of cowpea in rice-berseem-cowpea fodder might be due to legume effect of preceding berseem. Similar, result were obtained by Yadav *et al.* (2013). The variation in the yield of crop might be attributed to the biological and environmental complexity and interaction in the cropping system (Francis 1989).

Therefore, the results of the experiment clearly indicated that diversification of rice-wheat system through substitution of wheat by other winter crops and inclusion of summer grain/fodder legumes might be one of the possible ways to reduce weed infestation and enhanced crop productivity in irrigated condition of eastern U.P.

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Bio-efficacy of readi-mix herbicides on weeds and productivity in late-sown wheat

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ABSTRACT

A field experiment was conducted during 2015-16 and 2016-17 at Rajasthan College of Agriculture, Udaipur, India to evaluate the bio-efficacy of readi-mix herbicides in late sown wheat. The experiment consisting of fifteen treatments was laid out in randomized block design with four replications. The results revealed that Readi-mix application of sulfosulfuron + metsulfuron (32 g/ha)) and mesosulfuron + iodosulfuron (14.4 g/ha) gave higher weed control index (95.36, 94.72%), lower weed index (2.00, 2.75%) and weed persistence index (0.349, 0.351) whereas, higher index value of crop resistance index (CRI), weed management index (WMI) and herbicide efficiency index (HEI) (28.61, 0.38 and 5.50). Both of these treatments recorded 34.3 and 33.3 per cent grain yield enhancement along with 49.0% and 47.7% higher net returns over the unweeded control with the highest benefit-cost ratio (2.34 and 2.32). Results from contract analysis indicated significant ($p < 0.0001$) interaction of year x treatments and response of Readi-mix v/s single/sequential herbicide application on grain yield, weed density and dry matter. The joint effect of parameters on grain yield was significant with high magnitude ($R_{\text{GY.Weed density total, Weed dry weight total, Total N, P and K uptake}} = 0.98$; $p < 0.0001$). Additionally, the regression model for grain yield on total weed density ($R^2 = 0.84$), weed dry weight (R^2=0.79), total N uptake (R^2=0.98), P uptake (R^2=0.93) and K uptake ($R^2 = 0.97$) demonstrated significant dependence. Moreover, no symptoms of phytotoxicity were seen in any of the treatment in the crop at 21 days after herbicide application.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one the most important food crop of world playing crucial role in global food security by providing food to billions of people and half of the dietary protein and more than half of the calories (Meena *et al.* 2017a and 2017b). Late sowing of wheat is a common practice in rice-wheat, cotton-wheat (Khan *et al.* 2010) sugarcane-wheat, potato-wheat, vegetable pea-wheat cropping systems in Asia. The reasons for late sowing of wheat are late transplanting of rice, late harvest of the preceding crops, use of long-duration rice varieties and heavy rains during later phase of rice. Sowing dates has the greatest effect on weed growth from the stage of initial development to shooting. In the early sowing, the weeds were able to emerge and become established before the onset of winter. But the level of weed infestation is more with the largest number of weeds in the late-sown wheat, where the crop did not form a closed canopy. In a study, Fodor and Palmai (2008) found that wheat produced less biomass after late sowing, while that of weeds was greater due to predominance and more infestation from complex weed flora. In cases where higher nitrogen applied, results showed fewer weeds in early and optimum sowing dates, while it increased weed infestation after late sowing. Late sowing of wheat significantly increased weed population and dry weight and hence reduced the crop growth and yield of wheat by enhancing the weed interference.

The reduction of grain yield in late sown wheat was reported up to 34.3% due to mixed weed flora (Meena *et al.* 2017a). Under these conditions, herbicides are one of the major groups of pesticides which contribute to the increased and economical production of crops. But the repeated applications of herbicides with similar modes of action exert a strong selection pressure on target weed populations that may consequence into herbicide resistance and weed shift.

Keeping all the above facts in view, an attempt was made to find out the efficacy and selectivity of different herbicides as tank-mix or pre-mix against complex weed flora to improve the productivity of wheat.

MATERIALS AND METHODS

This study was conducted for two consecutive years *i.e*. 2015-16 and 2016-17 in *Rabi* (winter) season at the Instructional Farm, Rajasthan College of Agriculture, Udaipur which is situated at 24°5' N latitude and 74°42' E longitude with an altitude of 582.17 m above mean sea level. The region falls under NARP Agro climatic zone IVa (sub-humid Southern plains and Arawali Hills) of Rajasthan (India). There was no rainfall during the crop growing period during both the years. The soil of the experimental site was clay loam in texture, non-saline and slightly alkaline in reaction. The soil was low in available nitrogen, medium in organic carbon and phosphorus and high in available potassium. The experiment consisted fifteen treatments. All the treatments were replicated four times indiscriminately in randomized block design on the same unit of cultivation. Before growing of wheat, the soybean crop was taken at the same experimental site during *Kharif* (rainy) season. Wheat variety '*Raj- 3765*' was used as a test crop. The crop was sown on 10th December, 2015 during first year and 12th December, 2016 during the second year at a row spacing of 22.5 cm with a recommended seed rate of 125 kg/ha. The crop was supplied with 90 kg N and 35 kg P_2O_5/ha through urea and DAP. Half dose of nitrogen and full dose of phosphorus were applied as basal at the time of sowing while remaining half dose of nitrogen was top dressed in two equal splits at the time of first and second irrigation. After sowing, a light irrigation was given to the crop for uniform germination and next day the pre-emergence herbicides were applied.

All the herbicides were sprayed with battery operated knap-sack sprayer fitted with flat-fan nozzle using spray volume of 500 l/ha. Data on density and dry matter of weeds were recorded at 60 DAS with the help of 0.25 m^2 quadrate selected randomly in each plot. After identifying, the weed species were grouped into monocotyledons and dicotyledons separately. Weed density was calculated on the basis of the total number of an individual weed species/m^2. On the basis of weed data, different weed indices were computed using the standard procedure as following details:

Weed control efficiency (WCE)

Weed control efficiency was computed by adopting the following formula given by Mani *et al.* 1973) as follows:

$$\text{WCE (\%)} = \frac{\text{WPc} - \text{WPt}}{\text{WPc}} \text{X } 100$$

Where, WP_C is the weed population in unweeded control (no. of plants per quadrate) and WPt is the weed population in treated plot (no. of plants per quadrate).

Weed control index (WCI)

Weed control index was calculated to compare the different treatments of weed control on the basis of dry weight. It indicates the per cent reduction in the dry weight in treated plots compared to weedy plots. The formula is as follows (Mani *et al.* 1973, Das 2008):

$$WCI \text{ (\%)} = \frac{\text{WDc} - \text{WDt}}{\text{WDc}} \text{X } 100$$

Where, WD_C is the weed dry matter in unweeded control (g/m^{-2}) and WDt is the weed dry matter in treated plot (g m^{-2}).

Weed index (WI)

Weed index is the per cent reduction in crop yield under a particular treatment due to the presence of weeds in comparison to weed free plot as suggested by Gill and Kumar (1969). This is used to assess the efficacy of a herbicide. Lesser the weed index, better is the efficiency of a herbicide. It is expressed in percentage and was determined with the help of following formula:

$$\text{WI (\%)} = \frac{\text{X} - \text{Y}}{\text{X}} \text{X } 100$$

Where, WI = Weed index; X = Crop yield from weed free plot (hand weeding) and Y = Crop yield from the treated plot for which weed index is to be worked out.

Weed persistence index (WPI)

This index indicates the resistance in weeds against the tested treatments and confirms the effectiveness of the selected herbicides, and the same was computed using the given formula as suggested by Mishra and Mishra (1997):

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

Crop resistance index (CRI)

The relationship between the crop biomass and weed biomass can be correlated with the help of crop resistance index and its shows indirect proportionate relationship to each other. The index can be calculated with the help of below mentioned formula given by Mishra and Mishra (1997) as follows:

$$\text{CRI} = \frac{\text{Crop dry weight in treated plot}}{\text{Crop dry weight in controlplot}} \text{ X } \frac{\text{Weed dry weight in control plot}}{\text{Weed dry weight in treated plot}}$$

Weed management index (WMI)

This index indicates the yield increase with respect to control because of weed management options taken and percent control of weeds by the respective treatment.

$$\text{WMI} = \frac{\text{Per cent crop yield increase over control}}{\text{Percent control of weeds}}$$

Herbicide efficiency index (HEI)

This index represents the potential of a particular herbicide for controlling the weeds along with their phyto-toxicity effect on the crop (Krishnamurthy *et al.* 1975).

$$\text{HEI (\%)} = \frac{\frac{\text{Yt} - \text{Yc}}{\text{Yt}} \text{ X } 100}{\left(\frac{\text{WDMt}}{\text{WDMc}}\right) \text{ X } 100}$$

Where, Yt- crop yield from treated plot, Yc- crop yield from weedy check plot, WDMt-weed dry matter in treated plot and WDMc-weed dry matter in weedy check plot.

Phyto-toxicity in terms of chlorosis, stunting, leaf burning, scorching, hyponasty and epinasty was visually observed at 7, 14 and 21 days after herbicide application (DAA) using rating scale of 0-10 scale, where 0 = indicate no effect on plant and 10 = shows complete death of plant (Rao 2000). Protein content in grain was worked out by multiplying nitrogen content in grain (%) with factor 6.25 (AOAC 1975) and expressed as per cent protein content. The economics of different treatments were worked out to evaluate the benefit accrued from the treatments applied in terms of net return (kg/ha) and benefit-cost ratio as follows:

$$\text{Benefit: Cost} = \frac{\text{Gross returns (`/ha)}}{\text{Total cost [cost of cultivation + treatment (`/ha)]}}$$

Data generated from the field experiments were subjected to the statistical analysis by using SAS 9.3. Analysis of variance was performed using PROC GLM after square root transformation ($\sqrt{x+0.5}$) of the original data as appropriate for weed density and dry weight to hold the normality assumption. The post hoc test for treatments mean comparisons under each parameter was done on the basis of Duncan's Multiple Range Test (DMRT) at p=0.05. Relationship of wheat grain yield on total weed density, total weed dry weight, total N uptake, total P uptake and total K uptake were studied by the linear bivariate regression analysis and to study the joint/combined effect of parameters on grain yield, multiple correlation study has been accomplished. Cluster analysis was performed using PROC CLUSTER to understand the different herbicides functional groups hierarchically based on dissimilarity/distance and presented by dendogram.

RESULTS AND DISCUSSION

Weed flora

The experimental field was utterly invaded with mixed flora of weeds consisting of both dicots and monocots. Among the total weeds, dicots weeds (91%) were more prominent than monocots (9%). The weed flora under dicots includes many species like *Melilotus indica* (45%), *Fumaria parviflora* (15%), *Chenopodium album* (9%), *Chenopodium murale* (6%), *Convolvulus arvensis* (5%) and others dicots (11%) (*Anagallis arvensis, Spergulla arvensis* and *Coronopus didymus*) whereas *Phalaris minor* (9%) was only grassy weed under monocot.

Effect on density and dry weight of weeds

Pooled analysis of data revealed significant reduction in all the weed control treatments with respect to weed density and dry matter over the unweeded control (**Table 1**). The highest reduction in density and dry matter of weeds were recorded under two hand weeding (18.93 no./m^2 and 6.44 g/m^2) due to complete removal of the weeds whereas sulfosulfuron + metsulfuron found more superior among the herbicides treatments in curtailing the weed population (23.18 no./m^2 and 8.13 g/m^2) followed by mesosulfuron + iodosulfuron (26.07 no./m^2 and 9.24 g/m^2) as compared to unweeded control. Sole application of a single herbicide was less effective in controlling weeds as compared to their readi-mix application but metsulfuron had significant effects on population of broad-leaf weeds (50.26 no./m^2 and 24.86 g/m^2) as compared to other single herbicide. The tank mixtures of broad-leaf and grassy weed killing herbicides provided higher order of performance in terms of weed density and intensity of total weeds (Meena *et al.* 2017a). Tank mix or readi-mix application of sulfosulfuron + metsulfuron provided excellent control of both dicot and monocot weeds. This combination exhibit properties of both foliar and soil activity that inhibits cell division in shoots and roots and growth by inhibiting plant enzyme acetolactase synthase, thereby, blocking branches chain of amino acid biosynthesis and hence the plant suffers. Due to this, phloem transport of the plant is hampered. A secondary effect is stunted growth on account of cessation of cell division and slow plant death. Contrary to the alone application of either of the herbicide was not found effective to control all sort of the weeds in the entire crop season (Lekh Chand and Puniya 2017, Chaudhari *et al.* 2017). The superiority of tank mix application of broad-leaf weed and grass suppressing herbicides over their individual applications in reducing total weed density and dry matter given better results (Chaudhari *et al.* 2017, Singh *et al.* 2017, Barla *et al.* 2017). Application of mesosulfuron + iodosulfuron inhibits the acetohydroxy acid synthesis enzyme in the plants, which is responsible for the synthesis of the branched chain amino acids valine, leucine, and isoleucine and cell division in the growing tips of roots and shoots. Further, its secondary effect on photosynthesis, respiration and ethylene production produce the symptoms of yellowing and reddening of monocot and leaf dropping in dicot weeds.

Effect on weed indices

The highest value of weed control indices (WCI) was obtained from hand weeding (96.32%) with respect to unweeded control (**Table 2**). Amongst herbicides, the maximum value of WCI was achieved by sulfosulfuron + metsulfuron (95.36%) closely followed by mesosulfuron + iodosulfuron (94.72%). Both these treatments are comparable to two hand weeding. The sole application of single herbicide registered less WCI. Similarly, the least value of WI and WPI was recorded under sulfosulfuron + metsulfuron (2.00 and 0.349) and mesosulfuron + iodosulfuron (2.75 and 0.351) followed by clodinafop + metsulfuron (3.98 and 0.350) and pinoxaden + metsulfuron (5.02 and 0.347) among the herbicidal treatments indicating broad spectrum effect in controlling the weeds. Whereas, pendimethalin (0.659) and pendimethalin + metribuzin (0.614) have recorded higher persistence of escaped weeds indicating resistance of escaped weeds to control measures. The rest of herbicidal treatments were not so much effective. These results indicate that tank mix application of different herbicides gave better results in comparison to their solitary application. Whereas, the least value of WI and WPI (0.00 and 0.338) was observed under two hand weeding. Furthermore, higher index values of CRI, WMI and HEI (28.61, 0.38 and 5.50) under combined application of sulfosulfuron + metsulfuron indicate potential of herbicides for significant control of weed

Table 1. Effect of weed control treatments on density and dry matter accumulation of weeds (pooled data of two year)

Treatment	Weed density (no./m^2)			Weed dry matter accumulation (g/m^2)		
	Monocot	Dicot	Total	Monocot	Dicot	Total
Pendimethalin (750 g/ha) PE	5.96(35.1)^b	9.83(96.2)^b	11.48(131.4)^b	5.18(26.3)^b	7.95(62.8)^b	9.47(89.1)^b
Sulfosulfuron (25 g/ha) PoE at 5 WAS	4.37(18.7)^c	6.91(47.3)^d	8.14(65.9)^d	3.14(9.4)^d	4.48(19.6)^d	5.43(29.0)^d
Metribuzin (210 g/ha) PoE at 5 WAS	4.09(16.3)^d	6.58(42.9)^e	7.72(59.2)^e	3.01(8.6)^{de}	4.25(17.5)^e	5.16(26.1)^e
Clodinafop (60 g/ha) PoE at 5 WAS	4.15(16.8)^d	6.46(41.3)^e	7.65(58.1)^e	3.02(8.6)^{de}	4.15(16.8)^e	5.09(25.4)^e
Metsulfuron (4 g/ha) PoE at 5 WAS	3.81(14.1)^e	6.05(36.2)^f	7.11(50.3)^f	2.95(8.2)^e	4.14(16.7)^e	5.04(24.9)^e
Pendimethalin + metribuzin (750 + 175 g/ha) PE	3.71(13.2)^e	8.68(75.0)^c	9.42(88.3)^c	4.09(16.2)^c	6.61(43.2)^c	7.74(59.5)^c
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE at 5 WAS	3.44(11.4)^f	5.63(31.3)^g	6.56(42.7)^g	2.08(3.8)^f	3.80(14.0)^f	4.28(17.8)^f
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE at 5 WAS	3.13(9.4)^g	5.22(26.9)^h	6.05(36.3)^h	2.00(3.5)^f	3.64(12.8)^{fg}	4.10(16.3)^{fg}
Pendimethalin *fb* metsulfosulfuron (750 + 4 g/ha) PE *fb* PoE at 5 WAS	3.09(9.1)^g	4.95(24.1)^i	5.80(33.2)^i	1.98(3.5)^{fg}	3.48(11.6)^g	3.95(15.1)^g
Sulfosulfuron + metsulfuron (30 +2 g/ha) PoE at 5 WAS	2.59(6.3)^i	4.15(16.8)^l	4.85(23.2)^l	1.64(2.2)^i	2.52(5.9)^i	2.94(8.1)^i
Pinoxaden + metsulfuron (60 =4 g/ha) PoE at 5 WAS	3.03(8.8)^g	4.61(20.8)^j	5.47(29.6)^j	1.85(3.0)^{hg}	2.78(7.2)^h	3.27(10.2)^h
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE at 5 WAS	2.81(7.5)^h	4.35(18.5)^k	5.14(26.1)^k	1.79(2.8)^h	2.64(6.5)^{hi}	3.12(9.2)^{hi}
Clodinafop + metsulfuron (60 +4 g/ha) PoE at 5 WAS	2.87(7.8)^h	4.50(19.9)^{jk}	5.30(27.7)^{jk}	1.82(2.8)^h	2.73(6.9)^h	3.20(9.8)^h
Two hand weeding at 30 and 45 DAS	2.36(5.2)^j	3.76(13.7)^m	4.38(18.9)^m	1.58(2.1)^i	2.21(4.4)^j	2.63(6.4)^j
Unweeded control	6.56(42.6)^a	13.35(177.8)^a	14.86(220.4)^a	5.40(28.7)^a	12.12(146.4)^a	13.25(175.1)^a

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

**Means with the same letter are not significantly different based on DMRT (p=0.05), PE - Pre-emergence; POE - Post-emergence; WAS - Weeks after sowing; *fb* - Followed by population to increase the per cent yield over the control treatment. The results with respect to CRI, WMI and HEI obtained from joint application of mesosulfuron + iodosulfuron (24.88, 0.37 and 4.73) were comparable with sulfosulfuron + metsulfuron. Sulfosulfuron and metsulfuron when applied alone failed to control the *Rumex dentatus* and other grassy weeds but their combined application as Readi-mix results in broad spectrum weed kill due to increased efficacy (Chhokar *et al.* 2011). Effective control of weeds under combined application of sulfosulfuron + metsulfuron and mesosulfuron + iodosulfuron could be assigned to the reason for superior weed indices. But identically reverse was true in case of rest of the herbicidal treatments (Mishra *et al.* 2016).

Effect on yield, net returns, BC ratio and harvest index

Pooled analysis exhibited that the treatment effect on yield (grain, biological and straw) was highly significant ($p<0.0001$) as well for both the years under all the weed control treatments. Two hand weeding recorded highest grain, straw and biological yield as compared to unweeded control which accounted for least of these values followed by pendimethalin alone (**Table 3**). Further data explicated that collective application of herbicides either as premix, tank mix or sequentially, gave significantly higher grain, straw and biological yield of wheat over singly applied herbicides. Among herbicides, the higher value of yield and nutrient uptake were

Table 2. Effect of weed control treatments on various weed indices in wheat

Treatment	Weed indices						
	WCE	WCI	WI	WPI	CRI	WMI	HEI
Pendimethalin (750 g/ha) PE	42.56	49.40	18.75	0.659	2.22	0.27	0.20
Sulfosulfuron (25 g/ha) PoE at 5 WAS	71.74	83.44	14.53	0.438	7.09	0.24	0.88
Metribuzin (210 g/ha) PoE at 5 WAS	74.43	85.08	14.90	0.436	7.83	0.22	0.96
Clodinafop (60 g/ha) PoE at 5 WAS	74.91	85.50	14.22	0.432	8.13	0.23	1.03
Metsulfuron (4 g/ha) PoE at 5 WAS	78.40	85.80	13.33	0.492	8.36	0.24	1.11
Pendimethalin + metribuzin (750 + 175 g/ha) PE	58.61	66.04	15.26	0.614	3.38	0.28	0.41
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE at 5 WAS	81.65	89.83	10.17	0.414	12.33	0.28	1.85
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE at 5 WAS	84.46	90.69	11.68	0.448	13.53	0.25	1.87
Pendimethalin *fb* metsulfosulfuron (750 + 4 g/ha) PE *fb* PoE at 5 WAS	85.84	91.38	10.62	0.455	14.81	0.26	2.13
Sulfosulfuron + metsulfuron (30 +2 g/ha) PoE at 5 WAS	90.05	95.36	2.00	0.349	28.61	0.38	5.50
Pinoxaden + metsulfuron (60 =4 g/ha) PoE at 5 WAS	87.44	94.17	5.02	0.347	22.34	0.35	3.98
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE at 5 WAS	88.76	94.72	2.75	0.351	24.88	0.37	4.73
Clodinafop + metsulfuron (60 +4 g/ha) PoE at 5 WAS	88.08	94.43	3.98	0.350	23.46	0.36	4.31
Two hand Weeding at 30 and 45 DAS	91.87	96.32	0.00	0.338	37.35	0.40	-
Unweeded control	0.00	0.00	27.03	-	1.00	-	-

Table 3. Effect of weed control treatments on yield (grain, straw and biological) and harvest index of wheat

Treatment	Yield (t/ha)						Net returns (x10^3 `/ha)			BC ratio			HI (%)		
	Grain			Straw											
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Pendimethalin (750 g/ha) PE	3.52^{n}	3.80^{n}	3.66^{m}	5.21^{n}	5.35^{m}	5.28^{j}	46.61^{f}	51.74^{f}	49.17^{f}	1.74^{h}	1.94^{h}	1.84^{h}	40.33^{c}	41.54^{c}	40.94^{c}
Sulfosulfuron (25 g/ha) PoE at 5 WAS	3.71^{k}	3.99^{k}	3.85^{jk}	5.32^{m}	5.48^{l}	5.49^{i}	49.55^{e}	54.71^{e}	52.35^{e}	1.81^{g}	2.00^{g}	1.92^{g}	41.05^{a}	42.13^{a}	41.23^{a}
Metribuzin (210 g/ha) PoE at 5 WAS	3.69^{l}	3.97^{l}	3.83^{kl}	5.40^{l}	5.65^{k}	5.50^{h}	49.99^{de}	55.40^{de}	52.65^{de}	1.87^{f}	2.07^{f}	1.97^{f}	40.61^{c}	41.30^{c}	41.05^{c}
Clodinafop (60 g/ha) PoE at 5 WAS	3.72^{j}	4.00^{j}	3.86^{j}	5.42^{k}	5.72^{j}	5.57^{gh}	50.42^{cde}	55.95^{cde}	53.19^{cde}	1.87^{f}	2.08^{f}	1.97^{f}	40.70^{c}	41.17^{c}	40.94^{c}
Metsulfuron (4 g/ha) PoE at 5 WAS	3.76^{i}	4.04^{i}	3.90^{i}	5.46^{j}	5.77^{i}	5.62^{fgh}	51.41^{cde}	56.97^{cde}	54.19^{cde}	1.92^{e}	2.13^{e}	2.03^{e}	40.78^{bc}	41.20^{bc}	41.00^{bc}
Pendimethalin + metribuzin (750 + 175 g/ha) PE	3.68^{m}	3.96^{m}	3.82^{l}	5.51^{i}	5.80^{h}	5.65^{efg}	49.99^{de}	55.50^{de}	52.26^{de}	1.87^{f}	2.07^{f}	1.95^{f}	40.03^{d}	40.56^{d}	41.12^{d}
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE at 5 WAS	3.83^{h}	4.06^{h}	4.04^{h}	5.53^{h}	5.83^{g}	5.68^{def}	52.58^{cd}	57.15^{cd}	56.57^{cd}	1.95^{d}	2.12^{d}	2.10^{d}	40.91^{c}	41.01^{c}	41.57^{c}
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE at 5 WAS	3.84^{g}	4.11^{g}	3.98^{g}	5.58^{g}	5.88^{f}	5.73^{de}	52.81^{c}	58.09^{c}	55.46^{c}	1.95^{d}	2.15^{d}	2.05^{d}	40.80^{c}	41.15^{c}	40.98^{c}
Pendimethalin *fb* metsulfosulfuron (750 + 4 g/ha) PE *fb* PoE at 5 WAS	3.86^{f}	4.15^{f}	4.02^{f}	5.64^{f}	5.92^{e}	5.78^{d}	53.02^{c}	58.79^{c}	56.26^{c}	1.95^{d}	2.16^{d}	2.07^{d}	40.62^{c}	41.24^{c}	41.06^{c}
Sulfosulfuron + metsulfuron (30 +2 g/ha) PoE at 5 WAS	4.27^{b}	4.55^{b}	4.41^{b}	6.06^{b}	6.35^{b}	6.20^{b}	61.07^{a}	66.58^{a}	63.83^{a}	2.24^{a}	2.44^{a}	2.34^{a}	41.36^{a}	41.77^{a}	41.57^{a}
Pinoxaden + metsulfuron (60 =4 g/ha) PoE at 5 WAS	4.14^{e}	4.42^{e}	4.28^{e}	5.93^{e}	6.27^{d}	6.10^{c}	58.63^{ab}	64.28^{ab}	61.45^{ab}	2.16^{b}	2.37^{b}	2.27^{b}	41.08^{abc}	41.32^{abc}	41.21^{abc}
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE at 5 WAS	4.24^{c}	4.52^{c}	4.38^{c}	6.00^{c}	6.34^{b}	6.17^{bc}	60.40^{a}	66.05^{a}	63.22^{a}	2.22^{a}	2.42^{a}	2.32^{a}	41.38^{ab}	41.60^{ab}	41.49^{ab}
Clodinafop + metsulfuron (60 +4 g/ha) PoE at 5 WAS	4.18^{d}	4.46^{d}	4.32^{d}	5.94^{d}	6.28^{c}	6.11^{bc}	58.71^{ab}	64.35^{ab}	61.53^{ab}	2.11^{c}	2.31^{c}	2.21^{c}	41.31^{abc}	41.54^{abc}	41.43^{abc}
Two hand weeding at 30 and 45 DAS	4.36^{a}	4.64^{a}	4.50^{a}	6.18^{a}	6.46^{a}	6.31^{a}	56.88^{b}	62.37^{b}	59.58^{b}	1.71^{i}	1.87^{i}	1.79^{i}	41.36^{a}	41.80^{a}	41.65^{a}
Unweeded control	3.15^{o}	3.43^{o}	3.29^{n}	4.95^{o}	5.29^{n}	5.12^{k}	39.99^{g}	45.64^{g}	42.81^{g}	1.52^{j}	1.73^{j}	1.62^{j}	38.84^{e}	39.29^{e}	39.07^{e}

Means with the same letter are not significantly different based on DMRT ($p=0.05$);WAS - Weeks after sowing obtained with weed controlling through sulfosulfuron + metsulfuron (4.41 t/ha and 102.55, 24.92 and 105.51 kg NPK/ha) and mesosulfuron + iodosulfuron (4.38 t/ha and 99.95, 24.38 and 104.38 kg NPK/ha) due to better control of total weeds in wheat over rest of the treatments and being at par with two hand weeding. Pooled data showed that both these treatments recorded significant increase of 34.3% and 33.3% in grain yield over unweeded control. This might be due to inhibition of the enzyme acetolactate synthase (ALS) which acts as the catalyst in the first step of the biosynthesis of essential amino acids (valine, leucine and isoleucine). Better expression of yield attributes due to reduced weed infestation through these treatments might have helped the crop plants to accumulate more dry matter through greater nutrient uptake that might have provided more quantity of photosynthates to developing sink in crop plants produced more yield. The grain yield improvement and weed control has already been reported with different herbicide combinations (Walia *et al*. 2010, Singh *et al*. 2017, Chaudhari *et al*. 2017, Punia *et al*. 2017). The other treatments in order of merit were clodinafop + metsulfuron and pinoxaden + metsulfuron which brought about 31.6 and 30.2% increase in pooled grain yield. Application of pendimethalin *fb* metsulfuron, pendimethalin *fb* clodinafop and pendimethalin *fb* sulfosulfuron were another order of significance. The solitary application of single herbicide resulted in lesser grain yield. Similar trend of increments were also followed with respect to straw yield.

All the weed control treatments tended to significantly surpass unweeded control in terms of gross returns, net returns and B-C ratio. Although, hand weeding recorded maximum yield, but the net returns and B-C ratio (` 63827/ha and 2.34) was higher with application of sulfosulfuron + metsulfuron and mesosulfuron + iodosulfuron (` 63226/ha and 2.32), which was around 49.1 and 47.7 per cent (net returns) more over unweeded control. Thus, results clearly endorsed to better economic feasibility of treatment linked with higher production potential over unweeded control (Meena *et al*. 2017a, Punia *et al*. 2017, Chauhan *et al*. 2017). Higher dry matter production by the crop is attributed to more uptake of nutrients (Kaur *et al*. 2017), which is positively correlated with each other. More nutrient availability for the crop under weed free environment might have increased nutrient concentration in plants which ascribed to more translocation from source to sink due to reduced crop-weed competition, which ultimately resulted in more biomass production by wheat that in turn to greater uptake of nutrients (Kumar *et al*. 2017, Meena *et al*. 2017a, Chauhan *et al*. 2017). Similar results were also found with respect to harvest index among the treatments.

Contrast analysis for weed control treatments

Combined results indicated significant ($p < 0.0001$) interaction of year x weed control treatments on wheat grain yield as well as total weed density and total weed dry matter along with the effect of year and weed control treatments (**Table 4**). Further, contrast analysis of the pooled data against the year x weed control treatments interaction clearly reflected significant ($p < 0.0001$) response of readi-mix v/s single herbicide, single herbicide v/s sequential and redi-mix v/s sequential to grain yield as well as total weed density and total weed dry matter.

Correlation and regression studies

The correlation matrix (**Table 5**) illustrated the linear association among the parameters with emphasizing that individual parameter, *viz*. total weed density, total weed dry weight, total N uptake, total P uptake and total K uptake significantly ($p < 0.0001$) influenced wheat grain yield under different weed control treatments. The matrix clearly indicated that wheat grain yield had strong negative relation with total density (r = - 0.92) and dry weight (r = - 0.89) of weeds whereas; high positive correlation was exhibited with total N (r = 0.99), P (r = 0.97) and K (r = 0.98) uptake. On the other hand, total density and dry weight of weeds had negative strong significant association with total N (r = - 0.91 and – 0.88), P (r = - 0.88 and - 0.85) and K (r = - 0.87 and – 0.84) uptake. The joint effect of the above said parameters

Table 4. Probability level of significance for pooled and contrast analysis of wheat grain yield and weeds

Source	Wheat grain yield	Total weed density	Total weed dry matter
Year	<0.0001	<0.0001	<0.0001
Weed control treatment	<0.0001	<0.0001	<0.0001
Year x Weed control treatment	<0.0001	<0.0001	<0.0001
Redimix v/s Single herbicide	<0.0001	<0.0001	<0.0001
Single herbicide v/s Sequential	<0.0001	<0.0001	<0.0001
Redimix v/s Sequential	<0.0001	<0.0001	<0.0001

Probability values <0.05 and 0.01 signify that the sources of variation are significantly different at 5 and 1% level of significance, respectively also influenced the grain yield. The multiple correlation coefficient that combined the effects of the parameters on grain yield was statistically significant with high magnitude ($R_{GY.Weed\ density\ total,\ Weed\ dry\ weight\ total,\ Total\ N,\ P\ and\ K\ uptake}$ = 0.98; p < 0.0001). The regression analysis clearly indicated that wheat grain yield was inversely proportional to the total density and dry weight of the weeds (monocot and dicot). Whereas, the positive linear relationship of grain yield was revealed with crop total N, P and K uptake (**Table 6**). The degree of goodness of the fitted regression model for grain yield on total weed density (R^2 = 0.84; p < 0.0001), total weed dry weight (R^2 = 0.79; p < 0.0001), total N uptake (R^2 = 0.98; p < 0.0001), total P uptake (R^2 = 0.93; p < 0.0001) and total K uptake (R^2 = 0.97; p < 0.0001) demonstrated the strong dependence of grain yield on the said parameters under different weed control treatments in robust sense.

Cluster analysis for functional group of herbicides

The herbicides used for weed control in the experiment belongs to the six functional groups *viz.* dinitroaniline (DNT), triazinones (TZ), aryloxyphenoxy propionate pyridines (APP), sulfonyl urea (SU), phenylpyrazolin (PP) and imidazolinone (IZ). The result of cluster analysis was illustrated through the dendogram (**Figure 1**) exhibiting different functional group of herbicides in the form of cluster based on the dissimilarity/distance. The functional group APP and TZ were constituted a cluster A at the distance of 0.05. Similarly, cluster A joined with DNT and formed a cluster B at the distance of 0.12. Furthermore, the functional group IZ and PP were structured a cluster C at the distance of 0.24. The functional group SU behaved differently from the other groups up to the distance < 0.64 and combined with cluster C at the distance of 0.64 and formed a new cluster D. At most distance of 1.25, all the functional groups formed one cluster and at the minimum distance of 0.00, all the functional groups individually formed a cluster.

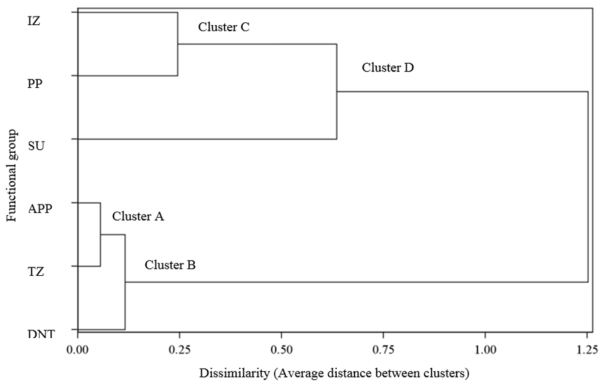

Figure 1. Dendogram from cluster analysis showing different herbicide functional groups hierarchically (DNT- Dinitroaniline; TZ-Triazinones; APP-Aryloxyphenoxy propionate pyridines; SU- Sulfonyl urea; PP-Phenylpyrazolin; IZ-Imidazolinone)

Table 5. Correlation coefficient (n = 60) with exact probability level of significance

Pearson correlation coefficients	GY	WDT	WDWT	TNU	TPU	TKU
Grain yield (GY)	1.00000	-0.91624 (<0.0001)	-0.89094 (<.0001)	0.99166 (<.0001)	0.96732 (<.0001)	0.98371 (<.0001)
Weed density total (WDT)		1.00000	0.99362 (<.0001)	-0.91011 (<.0001)	-0.88121 (<.0001)	-0.87431 (<.0001)
Weed dry weight total (WDWT)			1.00000	-0.87858 (<.0001)	-0.84713 (<.0001)	-0.83658 (<.0001)
Total N uptake (TNU)				1.00000	0.98488 (<.0001)	0.99226 (<.0001)
Total P uptake (TPU)					1.00000	0.98140 (<.0001)
Total K uptake (TKU)						1.00000

Table 6. Regression relationship of grain yield with independent variables

Independent variables	Estimated regression line	Adjusted R^2 value
Weed density total (TWD)	GY=4779.15** – 106.14** X TWD	0.84**
Weed dry weight total (TWDM)	GY=4526.72** – 100.41** X TWDM	0.79**
Total N uptake (TNU)	GY=1285.67** + 30.62** X TNU	0.98**
Total P uptake (TPU)	GY=1730.65** + 107.37** X TPU	0.93**
Total K uptake (TKU)	GY=648.85** + 34.49** X TKU	0.97**

**Parameters estimate are significant at p=0.01

Phytotoxicity

The herbicide toxicity on crop stand and growth was recorded at 7, 14 and 21 days after herbicide application (DAA) by rating it in the scale of 0 to 10, where zero rating represented no injury to crop plants and 10 represented complete destruction . Phytotoxicity scoring revealed that at 7 DAA metribuzin gave setback to wheat crop by causing moderate but persistent injury to wheat putting the plants under doubtful recovery zone. At 7 DAA sulfosulfuron, metsulfuron and pendimethalin + metribuzin caused slight injury or some stand loss and discolouration of wheat plants. With the progression of time, phytotoxicity cause by these herbicides was reversed. At 14 DAA, manifested some stunting of wheat plants under the effect of metribuzin, which showed slight injury only or discolouration. At 21 DAA, the crop plants under all these treatments had recovered and no symptoms of phytotoxicity were seen at this stage and onwards. However, in contradiction, mesosulfuron + iodosulfuron showed phytotoxic effect on the plant for a limited period (Chaudhari *et al*. 2017). Herbicide carryover effect was not observed in any of the treatment. No phyto-toxicity was seen in the crop plant at 21 days after herbicide application (Chhokar *et al*. 2011).

It was concluded that in late sown wheat, weeds should be controlled by the post-emergence application of either sulfosulfuron + metsulfuron (30 + 2 g/ha) RM or mesosulfuron + iodosulfuron (12 + 2.4 g/ha) RM at five weeks after sowing for getting higher yield and monetary benefits. Use of RM herbicides may help in effective and eco-friendly weed management in wheat and also to minimize the risk of weed resistance evolution in wheat field.

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Effect of sub-lethal doses of 2,4-D sodium salt on physiology and seed production potential of wheat and associated dicotyledonous weeds

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ABSTRACT

A field experiment was conducted in *Rabi* 2016-17 and 2017-18 to assess the effect of 2,4-D sodium salt at 5, 10, 20, 40 and 50 g/ha along with the recommended dose of 500 g/ha on wheat and associated dicotyledonous weeds (*Medicago denticulata* and *Rumex dentatus*). Foliar applied 2,4-D in the range of 5-20 g/ha increased the chlorophyll content index (CCI) and chlorophyll fluorescence (Fv/Fm) values in wheat as compared to control, demonstrating biphasic dose response (hormetic effect) of this auxinic herbicide. But the stimulatory effect of 2,4-D at low doses was observed only upto flag leaf stage of crop. Grain and straw yield of wheat was not boosted significantly by the low doses of 2,4-D, indicating that growth stimulation by sub-toxic doses of 2,4-D was not sustained over time. The foliar application of 2,4-D at ultra-low doses of 5-50 g/ha did not exert hormetic effect in *R. dentatus* and *M. denticulata* as application of different doses of 2,4-D led to a reduction in seed production potential of these weeds.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most widely cultivated winter cereal crop of North-Western Plain Zone and Central Zone of India, occupying an area of about 3.50 million hectares with total production of 17.64 million tonnes and average productivity of 5.05 t/ha in 2016-17 (Anon. 2018). In wheat, weed infestation is the major but less recognized constraint, causing 37-50% yield reduction. Burclover (*Medicago denticulata* Willd.) and toothed dock (*Rumex dentatus* L.) are two major dicotyledonous weeds infesting irrigated wheat under the rice-wheat cropping system in the country. Generally, herbicides are used as the cost-effective tool of weed management for reducing early crop-weed competition and achieving higher yields in wheat (Balyan and Malik 2000).

Many chemicals including herbicides are reported to exhibit stimulatory or beneficial effect at ultra-low doses, but they are toxic at higher doses. Ultra-low or sub-toxic doses of many herbicides stimulate the growth and yield of many crop species under field as well as controlled conditions. Such growth stimulating potential (herbicide hormesis) may change the use of herbicides from crop protection to crop enhancement (Cedergreen *et al.* 2007, Velini *et al.* 2008). Due to herbicide drift, some patches of crop and weeds growing at field edges may receive low doses of herbicides (1-10% of recommended field rate). This low or sub-lethal dose of herbicides equalizes to stimulatory dose, resulting in hormesis in crop plants with respect to different physiological and biochemical parameters such as gene expression, enzyme activity, growth, biomass, protein and chlorophyll content (Nadeem *et al.* 2016). Herbicides are also applied at sub-lethal rates due to lateral and vertical movements of nozzle boom and coverage by taller crop plants and/or mulches which cut down the number of spray drops that can reach weeds (Souza *et al.* 2007). Hormetic effect of herbicides depends mainly on the type of herbicide, its dose and time of application, type of crop or weed species, plant development stage and environmental parameters (light, nutrients, temperature, carbon dioxide) and many other management practices. Low doses of herbicides are reported to cause growth stimulation to the extent of 10-15 and 20-30% under field and controlled conditions, respectively (Cedergreen *et al.* 2007, 2009). Use of herbicides to stimulate crop growth may also promote weed growth and may alter intra-weed and crop-weed competition. If crop plants are affected by hormetic effects, the phenomenon of hormesis sometimes becomes beneficial. However, it may interfere in the management of weeds if hormetic effects are produced in weeds. Therefore, growth stimulation due to herbicides under uncontrolled condition often becomes unpredictable (Belz and Leberle 2012).

Hormetic responses have been demonstrated with respect of certain herbicides like glyphosate in maize, soybean, eucalyptus, coffee, chickpea and faba bean (Velini *et al*. 2008, Abbas *et al*. 2015, El-Shahawy and Sharara 2011); fenoxaprop-P-ethyl in littleseed canarygrass (*Phalaris minor*) and wild oats (*Avena fatua*) (Abbas *et al*. 2016). 2,4-D and metribuzin when used at low dose are effective hormetization herbicides for enhancing growth of cotton and corn plants (Allender *et al*. 1997).

Limited research studies are available regarding the effect of herbicide hormesis on crop and weed growth, crop yield and seed production potential of weeds. Most of the studies documented so far are related to the hormetic responses of herbicides on crop growth (Cedergreen *et al*. 2007). It is equally important to examine the effect of ultra-low doses of herbicides on the growth of weeds so far as practical application of hormesis to stimulate crop growth and yield is concerned. 2,4-Dichlorophenoxyacetic acid (2,4-D) is the first commercial herbicide used to control dicotyledonous weeds, and it is also a synthetic auxin and effective plant growth regulator. Studies on the hormetic effect of 2,4-D in wheat and associated weed flora are meager. Hence, the present study was taken up.

MATERIALS AND METHODS

Field experiments were conducted during *Rabi* season of 2016-17 and 2017-18 at the Research Farm, Punjab Agricultural University (PAU), Ludhiana, Punjab. The seedbed was prepared by ploughing the field with a disc harrow, followed by two passes with a field cultivator and two plankings. The seeds of *R. dentatus* and *M. denticulata* were broadcasted uniformly in the field prior to wheat sowing. The wheat variety "*PBW 677*" was sown by hand on 8 November, 2016 and 13 November, 2017 using a seed rate of 100 kg/ha, in 22.5 cm spaced rows. Uniform density of *M. denticulata* and *R. dentatus* was maintained by keeping fifteen plants of each weed species in individual experimental plot of 4.0 x 2.5 m. Other weeds emerging in the field were regularly uprooted from the field. Six treatments including different doses of 2,4-D sodium salt 80% WP (5, 10, 20, 40, 50 and 500 g/ha) were assigned in a randomized complete block design with three replicates. Irrespective of herbicide dosage, it was sprayed as post-emergence at 35 days after sowing of wheat using knapsack sprayer fitted with a flat fan nozzle. Simple water spray as the control treatment was included for comparison.

Visual observations on crop and weed injuries were recorded at 1, 3, 7, 15, 21 and 30 days after treatment (DAT) by comparing with water sprayed control plots. Toxicity was rated on visual scale of 0-10 (0 = no phytotoxicity and 10 = complete mortality). For recording weed biomass, five plants of *M. denticulata* and *R. dentatus* from each plot were uprooted, dried in sunlight and then placed in paper bags for oven-drying at 60°C for 48 hours. Dry weight was taken till constant weight was achieved. Weed control efficiency (WCE) was calculated by using the following formula suggested by Das (2008) and expressed in percentage:

$$\mathrm{WCE} = \frac{\mathrm{DMC} - \mathrm{DMT}}{\mathrm{DMC}} \times 100$$

Where, DMC is the dry matter of weeds in control (unweeded) plot and DMT is the dry matter of weeds in treated plot.

Chlorophyll fluorescence and chlorophyll content index (CCI) were recorded at 1, 3, 7, 15 and 30 DAT, and also at flag leaf stage of wheat from fully expanded apical leaves, using a portable Chlorophyll Fluorometer (Model-OS-30p, Opti-Sciences, Inc.) and portable Chlorophyll Content Meter (Model-CCM-200, Opti-Sciences, Inc.), respectively. The data on chlorophyll fluorescence and CCI were recorded from ten tagged plants of *R. dentatus* and *M. denticulata* at 7, 15, 21 and 30 DAT. For recording the observations on chlorophyll fluorescence, the middle portion of the leaf from which data was recorded was dark-adapted with plastic clips before exposing to the light emitted by the fluorometer. The readings were expressed as Fv/Fm (variable fluorescence/maximum fluorescence).

Spike length, number of grains/spike, grain weight/spike and 1000-grain weight were recorded from ten randomly selected spikes from each plot at three days before crop harvest. Data on grain and straw yield of wheat were also determined at harvest. Five plants of *R. dentatus* and *M. denticulata* were uprooted from each plot at maturity, and the number of fruits and seeds/plant were counted, averaged and expressed as fruit and seed number/plant. Seeds collected from each plot were bulked, cleaned, properly dried and stored at room temperature. A sample of 1,000 seeds of each treatment were counted and weighed.

The results of both the years were pooled before subjecting to ANOVA in randomized block design using statistical analysis software version 9.2 (SAS

2009). Means were separated at α ≤ 0.05 using Fisher's Protected Least Significant Difference (LSD) test (Cochran and Cox 1957).

RESULTS AND DISCUSSION

Effect on phytotoxicity and weed control efficiency

Post-emergence application of 2,4-D sodium salt at different concentrations (5-500 g/ha) did not show any phytotoxic effect on wheat at any stage, indicating that this herbicide formulation is safe to wheat. Application of 2,4-D sodium salt at sub-lethal doses (5-50 g/ha) did not show any phytotoxicity symptoms on *R. dentatus* and *M. denticulata*, whereas its highest dose (500 g/ha) adversely affected growth of both the weed species at 21 DAT, but failed to cause their complete mortality. 2,4-D sodium salt at 500 g/ha provided weed control efficiency (WCE) of about 60 and >75% against *R. dentatus* and *M. denticulata*, respectively, indicating poor herbicidal efficacy against these dicotyledonous weeds (**Figure 1**). The results of 2,4-D sodium salt on crop phytotoxicity were in consonance with the findings of Biswas *et al.* (2016), who reported non-phytotoxic effect due to application of 2,4-D ethyl ester at different doses (225, 450, 675 and 900 g/ha) in wheat. There was a good control of *R. dentatus* with the use of 2,4-D at 500 g/ha (Chhokar *et al.* 2007) and poor control with 2,4-D amine salt at 750 g/ha (Chhokar *et al.* 2015). Likewise, application of 2,4-D ethyl ester at 600 g/ha provided only 60% control of *R. spinosus* in wheat (Singh *et al.* 2011).

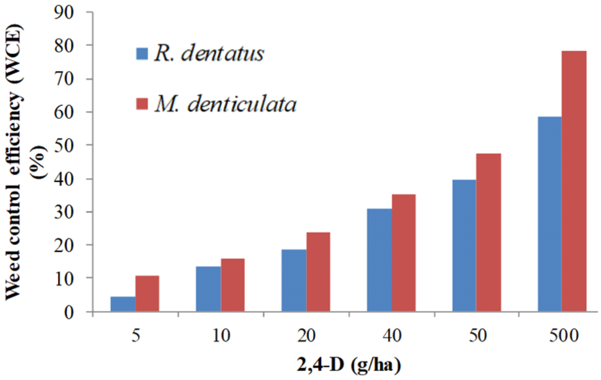

Figure 1. Effect of different doses of 2,4-D sodium salt on weed control efficiency against toothed dock and burclover weeds at 20 days after spray (pooled data of 2016-17 and 2017-18).

According to Grossmann (2010), stimulation of ethylene production due to 2,4-D application played an important role in eliciting herbicidal symptoms in the sensitive plants.

Effect on chlorophyll content index and chlorophyll fluorescence

Low doses of 2,4-D sodium salt (5-20 g/ha) increased the values of chlorophyll content index (CCI) and chlorophyll fluorescence (Fv/Fm) in comparison to control, exhibiting the highest values at the dose of 20 g/ha and hormetic effect of the herbicide at the sub-lethal doses till flag leaf stage (70 DAT) of wheat. 2,4-D sodium salt at 20 g/ha increased the CCI (**Table 1**) and Fv/Fm (**Table 2**) at 30 DAT by about 5.6 and 1.9% respectively as compared to control. There was a

Table 1. Effect of different doses of 2,4-D sodium salt on chlorophyll content index at different stages of wheat (pooled data of 2016-17 and 2017-18)

2,4-D (g/ha)	Chlorophyll content index					
	1 DAT	3 DAT	7 DAT	15 DAT	30 DAT	70 DAT (flag leaf stage)
5	17.3	24.6	26.9	31.3	47.9	49.9
10	19.2	25.2	28.5	33.0	48.3	50.8
20	24.2	28.2	29.8	33.7	49.9	53.6
40	15.5	22.6	24.8	28.9	45.8	47.8
50	14.4	21.7	23.7	28.0	45.0	47.8
500	13.7	13.1	12.6	26.8	43.9	45.5
Control (water spray)	15.9	24.3	26.6	29.8	47.1	49.1
LSD (p=0.05)	2.14	2.46	3.90	1.82	1.72	2.11

Table 2. Effect of different doses of 2,4-D sodium salt on chlorophyll fluorescence (Fv/Fm) at different stages of wheat crop (pooled data of 2016-17 and 2017-18)

2,4-D (g/ha)	Chlorophyll fluorescence					
	1 DAT	3 DAT	7 DAT	15 DAT	30 DAT	70 DAT (flag leaf stage)
5	0.583	0.590	0.661	0.706	0.764	0.685
10	0.588	0.597	0.671	0.709	0.767	0.688
20	0.590	0.605	0.681	0.715	0.771	0.700
40	0.569	0.580	0.642	0.687	0.736	0.673
50	0.562	0.572	0.606	0.663	0.725	0.661
500	0.554	0.532	0.520	0.648	0.720	0.655
Control (water spray)	0.574	0.584	0.632	0.695	0.756	0.683
LSD (p=0.05)	0.012	0.011	0.042	0.029	0.021	0.015

DAT- Days after treatment

constant increase in CCI from 1 to 70 DAT in the unsprayed control as well as with 2,4-D application at the doses of 5-50 g/ha. The lowest value of Fv/Fm and CCI was recorded under the highest dose of herbicide (500 g/ha) at all the dates of observation.

Application of different doses of 2,4-D sodium salt caused a decrease in CCI and Fv/Fm of *R. dentatus* (**Table 3**) and *M. denticulata* (**Table 4**) relative to the water sprayed check. The CCI and Fv/Fm values were decreased up to 15 DAT with the herbicide doses of 5-50 g /ha. Such decline was followed by a constant increase up to 30 DAT with the exception of dose level at 500 g /ha, which caused the CCI and Fv/Fm values to further decrease up to the final observation.

The CCI and Fv/Fm values decreased with the increase in herbicide dose, indicating the stress and lack of hormesis imposed by low doses of 2,4-D sodium salt in *M. denticulata* and *R. dentatus* plants. The decrease in chlorophyll content could be due to increased degradation of chlorophyll or by reduction of chlorophyll synthesis (Santos 2004). Herbicide stress might induce decline in chloroplast number (Cakmak *et al.* 2009). Arunrangsi *et al.* (2013) found that application of 2,4-D amine salt to detached basil leaves in the range of 2.16-10.80 g/L resulted in reduction of chlorophyll content, indicating the ability of this herbicide to degrade chlorophyll. In contrast to the results of present study, hormetic effect of metamitron and glyphosate was reported on growth and chlorophyll content of lamb's-quarters (*Chenopodium album*) at sub-lethal doses of these herbicides (Ketel 1996).

Effect on yield attributes and yield of wheat

Being the most important economic component, grain yield of a crop reflects the resultant impact of all

Table 3. Effect of different doses of 2,4-D sodium salt on chlorophyll content index (CCI) and chlorophyll fluorescence (Fv/Fm) at different stages of toothed dock weed (pooled data of 2016-17 and 2017-18)

2,4-D (g/ha)	Chlorophyll content index				Chlorophyll fluorescence			
	7 DAT	15 DAT	21 DAT	30 DAT	7 DAT	15 DAT	21 DAT	30 DAT
5	13.7	12.4	23.4	37.4	0.649	0.643	0.676	0.793
10	13.0	11.9	21.8	36.6	0.636	0.629	0.650	0.787
20	11.5	10.6	20.4	34.5	0.626	0.619	0.636	0.778
40	11.2	10.5	20.2	33.1	0.617	0.597	0.624	0.775
50	10.5	9.9	19.6	22.8	0.604	0.587	0.610	0.770
500	10.2	9.2	8.9	8.6	0.570	0.563	0.462	0.412
Control (water spray)	16.1	21.3	27.4	43.1	0.658	0.659	0.695	0.796
LSD (p=0.05)	1.46	1.72	4.61	5.00	0.027	0.041	0.028	0.039

DAT-Days after treatment

Table 4. Effect of different doses of 2,4-D sodium salt on chlorophyll content index (CCI) and chlorophyll fluorescence (Fv/Fm) at different stages of burclover weed (pooled data of 2016-17 and 2017-18)

2,4-D (g/ha)	Chlorophyll content index				Chlorophyll fluorescence			
	7 DAT	15 DAT	21 DAT	30 DAT	7 DAT	15 DAT	21 DAT	30 DAT
5	17.1	15.3	26.5	30.4	0.672	0.661	0.676	0.720
10	15.8	14.6	24.1	26.9	0.671	0.655	0.669	0.708
20	15.7	14.0	22.4	24.5	0.652	0.646	0.665	0.703
40	15.1	13.3	21.1	23.4	0.632	0.622	0.652	0.686
50	14.5	12.7	19.2	21.8	0.617	0.615	0.646	0.677
500	14.2	12.3	11.7	9.9	0.605	0.566	0.464	0.391
Control (water spray)	18.0	23.9	28.3	34.2	0.677	0.685	0.692	0.731
LSD (p=0.05)	NS	1.90	1.57	2.67	0.046	0.026	0.059	0.017

Table 5. Effect of different doses of 2,4-D sodium salt on yield attributes and yield of wheat at harvest (pooled data of 2016-17 and 2017-18)

2,4-D (g/ha)	Spike length (cm)	Grains/spike	Grain weight/spike (g)	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
5	10.75	52	2.40	45.84	4.26	8.43
10	10.63	53	2.45	45.14	4.19	8.35
20	10.82	53	2.53	48.82	4.23	8.29
40	11.02	58	2.60	46.87	4.32	8.49
50	11.13	55	2.50	46.74	4.34	8.59
500	11.37	58	2.63	50.17	4.52	8.63
Control (water spray)	10.60	51	2.32	44.73	4.41	8.37
LSD (p=0.05)	0.50	3.58	NS	NS	NS	NS

DAT-Days after treatment, NS- Non-significant crop growth parameters as well as yield attributes as influenced by various treatments. It was evident from the results that the treatments didn't show any significant difference in terms of influencing the grain yield of wheat (**Table 5**). 2,4-D sodium salt at 500 g/ha provided 2.4% higher grain yield as compared to control. Although no significant differences were noted, the crop plants in the plots treated with 2,4-D sodium salt at 500 g/ha produced longer spikes and bold grains having higher 1000-grain weight and number of grains/spike, while minimum spike length and 1000-grain weight was produced by the plants in water sprayed control.

The results of present study clearly indicated that 2,4-D sodium salt did not exhibit any hormetic effect in influencing grain or straw yield of wheat. Similar to the present findings, Cedergreen *et al*. (2009) observed that glyphosate application in the range of 4-63 g/ha did not affect grain production by influencing the grain number and grain weight in barley. Glyphosate and metsulfuron were reported to increase the biomass by about 25% when used at 5-10% of their recommended field rates, whereas the herbicides *viz*. acifluorfen-sodium, diquat, haloxyfop-P-methyl, MCPA, pendimethalin and terbuthylazine did not promote hormesis, thereby under-estimating the theory of hormesis as a general stress response (Calabrese and Baldwin 2001). Hormesis with glyphosate was not found in the growth of coffee plant at the doses of 57.6-460.8 g/ha. However, a significant decrease in plant height, leaf area, stem and leaf dry mass, and root density was observed as well as decline in the nutrient content of leaf were verified (Franca *et al*. 2010). In contrast to the results of present study, many studies showed that some herbicides at low doses promoted crop growth. Low doses of glyphosate application were reported to increase yield of many crops like faba bean, soybean and chickpea (Abbas *et al*. 2015, Silva *et al*. 2015, El-Shahawy and Sharara 2011). Although some studies revealed herbicide-induced hormetic effect in different crop species by improving their growth and yield (Cedergreen *et al*. 2009) but the unpredictability of hormetic response might be a question for its practical implementation in the field to increase growth and yield of different crop species.

Effect on seed production potential of weeds

The seeds of *R. dentatus* were enclosed in acutely trigonous brown nut (fruit) with one seed/fruit, and the seeds of *M. denticulata*, were enclosed in coiled pods called burs (fruit) with 3-5 seeds/pod. The results of fruit and seed production ability of *R. dentatus* and *M. denticulata* showed that the application of 2,4-D sodium salt at different doses led to a numerical reduction in fruits and seeds/plant relative to the unsprayed control (**Table 6**). The number of fruits/plant decreased with the increase in herbicide dose from 5 to 500 g /ha. Application of 2,4-D sodium salt at and above 10 and 20 g/ha caused a significant decrease in fruit number/ plant of *M. denticulata* and *R. dentatus*, respectively. In response to 2,4-D application at the highest dose of 500 g/ha, the plants of *R. dentatus* and *M. denticulata* produced 76.3 and 39.6% lesser number of seeds/plant as compared to their respective controls. Even though the treatments didn't show any significant difference from each other in terms of influencing the 1000-seed weight of *R. dentatus* and *M. denticulata*, the highest 1000-seed weight was observed for the seeds collected from water sprayed control plots while 2,4-D application at 500 g/ha recorded the lowest 1000-seed weight.

2,4-D sodium salt at ultra-low doses of 5-50 g/ha failed to exhibit any hormetic effect in *R. dentatus* and *M. denticulata*. The seed production potential of *R. dentatus* and *M. denticulata* decreased consistently with the increase in 2,4-D concentration from 0 to 500 g/ha. In contrast to the results of

Table 6. Effect of different doses of 2,4-D sodium salt on seed production potential and ancillary attribute of toothed dock and burclover weeds at harvest (pooled data of 2016-17 and 2017-18)

2,4-D (g/ha)	Weed species			1000-seed weight (g)	
	R. dentatus	*M. denticulata*		*R. dentatus*	*M. denticulata*
	Seeds/plant	Fruits/ plant	Seeds/plant		
5	2627	154	617	2.27	3.43
10	2548	139	557	2.15	3.30
20	2381	128	511	2.23	3.40
40	2422	130	521	2.22	3.37
50	1750	112	448	2.25	3.35
500	655	101	403	2.13	3.31
Control (water spray)	2766	167	667	2.35	3.50
LSD (p=0.05)	357	18	71	NS	NS

NS- Non-significant

present study, Nadeem *et al*. (2016) reported that foliar application of glyphosate at low doses in range of 4-32 g/ha resulted in stimulation of root and shoot growth, dry biomass and increase in seed number/ plant of different weed species (*Coronopus didymus*, *Chenopodium album*, *Rumex dentatus* and *Lathyrus aphaca*). On the other hand, glyphosate application at high dose of 64 g/ha significantly declined seed number/ plant in all the weed species. Abbas *et al*. (2016) reported that low dose of fenoxaprop-p-ethyl in the range of 1-6 g/ha produced hormetic effect in *Phalaris minor* and *Avena fatua*. They reported 28 and 17% increase in seed number/ plant in *P. minor* and *A. fatua*, respectively in response to fenoxaprop-P-ethyl application at ultra-low dose of 6 g/ha.

Low doses of 2,4-D sodium salt (5-20 g/ha) increased the CCI and Fv/Fm values in comparison to control, exhibiting the hormetic effect of this herbicide at sub-lethal doses upto flag leaf stage of wheat. But no significant difference was observed in grain and straw yield of control and treated plots at harvest, indicating that growth stimulation by sub-toxic doses of 2,4-D was not sustained over time. Foliar application of 2,4-D at low doses of 5-50 g/ha did not exert hormetic effect in *R. dentatus* and *M. denticulata* in terms of seed production potential of these weeds.

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Effect of herbicides and their combinations on weeds, productivity and profitability of maize in rainfed sub-tropics of Jammu

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ABSTRACT

A field experiment was conducted at Advanced centre for rainfed agriculture, Rakh Dhiansar of Sher-e- Kashmir University of Agricultural Sciences and Technology of Jammu during the crop growing seasons of 2016 and 2017 to identify the best herbicide option for weed management in maize (*Zea mayz* L.). Fifteen treatments were tested in randomised block design replicated thrice. The post-emergence treatment (PoE) of tembotrione 100 g/ha + atrazine tank mix formulation 750 g/ha at 15-20 days after sowing (DAS) has recorded highest weed control efficiency (93.22 and 93.71% during 2016 and 2017, respectively) followed by tembotrione 100 g/ha + atrazine 500 g/ha at 15-20 days after sowing (DAS) and sequential application of atrazine 1000 g/ha 0-3 DAS *fb* tembotrione 100 g/ha 15-20 DAS. Higher maize grain yield was recorded (3.64 t/ha and 3.74 t/ha during 2016 and 2017, respectively) with weed free which was statically at par with tembotrione 100 g/ha + atrazine 500 g/ha at 15-20 DAS, tembotrione 100 g/ha + atrazine 750 g/ha at 15-20 DAS, tembotrione 100 g/ha + halosulfuron 67.5 g/ha at 15-20 DAS, tembotrione 100 g/ha+ halosulfuron 52.5 g/ha at 15-20 DAS, atrazine 1000 g/ha 0-3 DAS *fb* metribuzin 250 g/ha 15-20 DAS, atrazine 1000 g/ha 0-3 DAS *fb* tembotrione 100 g/ha 15-20. B: C ratio (3.11 and 3.12 in 2016 and 2017 respectively) was high with PoE application of tembotrione 100 g/ha + atrazine 500 g/ha.

INTRODUCTION

Maize is one of the world's most important food crops and it is regarded as "Queen of cereals" because of its high production potential and wider adaptability. In the world, maize is grown over an area of about 168 million hectare with a production of about 945.8 million tonnes (Anonymous, 2016a) and provides food security to a large chunk of population. In India, maize occupies a proud place both as food and feed for animals and it is the third most important food crops after rice and wheat. It is cultivated over an area of 8.90 million hectares with a production of about 23.00 million tonnes and productivity of about 2584 kg/ha (Anonymous 2016b). If the present trend of population growth does not decline, India may need 301 million tonnes of food grains by 2050 AD (Shankaran *et al.* 2005). Maize contributes nearly 9 per cent to the national food basket and more than 100 billion to the agricultural GDP at current prices. In the state of Jammu and Kashmir, maize has special significance because it forms the staple diet of majority of the people living in the state. The total area under maize crop in the state is about 293.86 thousand hectares with the production and productivity of about 360,000 tonnes and 1.78 t/ha, respectively. The state of Jammu and Kashmir has the distinction of being 11th largest maize producing state in the country (Anonymous 2017a). Moreover, in Jammu region, the production and productivity of maize is about 392,900 tonnes and 1800 kg/ha, respectively (Anonymous 2017b), from an area of about 230.69 thousand hectares. Maize provides food to the human beings and feed to the cattle. During recent years, maize is being increasingly used as a feedstock and for the production of bio ethanol. Protecting maize from weeds, pests and diseases is very much essential to avoid heavy losses caused by them in maize yield and gain quality. Weed control is usually most important, as weed interference is a severe problem in maize, especially in the early part of the growing season due to its initial slow growth rate and wider row spacing. Yield losses due to weed infestation vary from 28-93% depending on the type of weed flora and their intensity, stage, nature and duration of crop weed competition (Sharma and

Thakur 1998, Pandey *et al.* 2001) The critical period of crop weed competition in corn range from 1 to 6 weeks after sowing (Dass *et al*. 2012). In order to realize the maximum yield potential of maize, weed management becomes indispensable during this period. Chemical weed management by using pre- or post-emergence herbicides can lead to the efficient and cost effective control of weeds during critical period of crop weed competition, which may not be possible in manual or mechanical weeding due to its high cost of cultivation (Triveni *et al*. 2017). Hence, there is an immense need to find out most suitable herbicidal options for effective weed management in maize. Therefore, this study was undertaken to identify the chemical weed management options in maize (*Zea mays* L.)

MATERIALS AND METHODS

A field experiment was conducted at Advanced Centre for Rainfed Agriculture, Rakh Dhiansar of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu during the *Kharif* seasons of 2016 and 2017. The soil of the experimental site was sandy loam in texture with neutral soil reaction (pH-6.9), electric conductivity-0.17 dS/m and low in organic carbon content (0.30%). Availability of nitrogen, phosphorus and potassium in the experimental site were low (166.5 kg/ha), medium (14.7 kg/ha) and medium (115.6 kg/ha), respectively. Total rainfall received during crop season was 636 mm and 576.50 mm in 2016 and 2017, respectively with mean maximum temperature varies from 31.6^{0}C to 35.2^{0}C in 2016 and 2017 and mean minimum temperatures varies from 11.5 ^{0}C to 27.8^{0}C, during 2016 and mean maximum temperature varies from 24.4 ^{0}C to 35.4 ^{0}C and mean minimum temperatures varies from 13.2 ^{0}C to 24.5^{0}C during 2017.

Experiment was conducted in a randomized block design with three replications. Treatments include tembotrione 100 g/ha 15-20 days after seeding (DAS), halosulfuron 67.5 g/ha 15-20 DAS, atrazine 1000 g/ha 0-3 g/ha, atrazine 750 g/ha 15-20 DAS, atrazine 500 g/ha 15-20 DAS, tembotrione + atrazine 100 + 500 g/ha 15-20 DAS, tembotrione + atrazine 100 + 750 g/ha 15-20 DAS, tembotrione + halosulfuron 100 + 67.5 g/ha 15-20, tembotrione + halosulfuron 100 + 52.5 g/ha 15-20 DAS, halosulfuron + atrazine 67.5 + 500 15-20 DAS, atrazine *fb* 2,4-D 1000 *fb* 500 0-3 DAS and 15-20 DAS, atrazine *fb* metribuzin 1000 *fb* 250 0-3 DAS and 15-20 DAS, atrazine *fb* tembotrione 1000 *fb* 100 0-3 DAS and 15-20 DAS, weed free and weedy check. Maize composite "*Mansar*" was sown on 30.06.2016 and 28.06.2017, during 2016 and 2017, respectively at 60 x 20 cm spacing. Before sowing, field was thoroughly ploughed and levelled. The crop was fertilized evenly irrespective of treatments with 60:40:20 kg NPK/ha with N in three equal split doses. Pre-emergence herbicides were applied within two days after sowing. Post-emergence herbicides were applied at 15-20 DAS. All the herbicides were used after making the spray volume of 500 L/ha. Weed density was recorded at 60 DAS by using a quadrat of 0.5 x 0.5 m size from the centre of the plot. The entire weeds inside the quadrat were uprooted and cut close to the transition of root and shoot in each plot and collected for dry matter accumulation (biomass). The samples were first dried in sun and then kept in oven at 70 ± 2°C. The dried samples were weighed and expressed as biomass (g/m^2). Cost of cultivation, gross returns, net returns and benefit cost ratio for each treatment were calculated by taking into consideration of total costs incurred and returns obtained. Square root transformation was done for weed density and weed biomass by using the formula ($\sqrt{x+1}$). Weed control efficiency (WCE), weed index (WI) were calculated using formulae as suggested by Mishra and Mishra (1997) and Raju (1998).

RESULTS AND DISCUSSION

Weed flora

In the experimental site, sedges weeds were dominant compared to the grasses and broad-leaved weeds *Echinochloa colona, Digitaria sanguinalis, Acrachne racemosa, Eragrostis tenella, Eleusine aegyptium* were the major grassy weeds and *Cyperus rotundus and Cyperus iria* were the dominant sedge weeds. *Amaranthus viridis* and *Solanum nigrum* were the major broad-leaved weed species during both the years of study.

Effect on weeds

At 60 DAS Weed free recorded significantly lesser total weed density and biomass (**Table 1**). Among herbicide treatments, total weed density and biomass was least with tembotrione 100 g/ha + atrazine 750 g/ha at 15-20 DAS, which was statistically at par with tembotrione 100 g/ha + atrazine 500 g/ha at 15-20 DAS, atrazine 1000 *fb* tembotrione 100 g/ha), tembotrione 100 g/ha + halosulfuron 67.5 g/ha at 15-20 DAS, tembotrione 100 g/ha + halosulfuron 52.5 g/ha at 15-20 DAS) and atrazine 1000 g/ha *fb* metribuzin 250 g/ha. The better performance of combination of herbicides was probably due to the synergestic effect of two herbicides with same or different modes or sites of action resulting in reduced density as well as biomass of differnt weed species (Singh *et al*. 2015). These results were in close conformity with those of Rao *et* *al.* (2009) and Yakadri *et al.* (2015). The higher WCE at 60 DAS was recorded with tembotrione100 g/ha + atrazine 750 g/ha at 15-20 DAS which was followed by tembotrione100 g/ha + atrazine 500 g/ha at 15-20 DAS and tembotrione100 g/ha + halosulfuron 67.5 g/ha at 15-20 DAS. The lowest weed index was observed with tembotrione100 g/ha + atrazine 750 g/ha at 15-20 DAS followed by tembotrione 100 g/ha + atrazine 500 g/ha at 15-20 DAS and atrazine 1000 *fb* tembotrione 100 g/ha) during both the years of experimentation during 2016 and 2017 (**Table 2**).

Effect on crop

Weed management treatments significantly affected the growth and yield attributing characters of maize. At 60 DAS, significantly higher plant height (176.48 cm) was recorded with weed free treatment, which was statistically at par with treatment atrazine 1000 g/ha *fb* metribuzin 250 g/ha, tembotrione100 g/ha + halosulfuron 52.5 g/ha at 15-20 DAS, atrazine 1000 g/ha 0-3 DAS *fb* 2,4-D 500 g/ha at 15-20 DAS, halosulfuron 67.5 g/ha + atrazine 500 g/ha at 15-20 DAS, atrazine 1000 g/ha at 0-3 DAS, tembotrione 100 g/ha at 15-20 DAS) and halosulfuron 67.5 g/ha at 15-20 DAS (**Table 3**). The numbers of grains/cobs and 1000 grain weight were higher in weed free which was stastically at par with tembotrione100 g/ha + atrazine 750 g/ha at 15-20 DAS, tembotrione 100 g/ha + halosulfuron 67.5 g/ha at 15-20 DAS, tembotrione100 g/ha + atrazine 500 g/ha at 15-20 DAS, atrazine 1000 *fb* tembotrione 100 g/ha (**Table**

Table 1. Effect of different weed management treatments on total weed density and biomass in maize

Treatment	Total weed density (no. /m^2) 60 DAS		Total weed biomass (g/m^2) 60 DAS	
	2016	2017	2016	2017
Tembotrione 100 g/ha at 15-20 DAS	7.21(51.0)	6.89(46.6)	7.09(49.3)	6.13(36.7)
Halosulfuron 67.5 g/ha at 15-20 DAS	9.11(82.0)	8.55(72.2)	9.06(81.0)	8.33(68.3)
Atrazine 1000 g/ha at 0-3 DAS	8.31(68.0)	7.87(61.0)	8.10(64.7)	7.36(53.3)
Atrazine 750 g/ha at 15-20 DAS	9.91(97.3)	9.41(87.8)	9.89(97.0)	9.32(86.0)
Atrazine 500 g/ha at 15-20 DAS	10.58(111.0)	10.10(101.0)	10.64(112.3)	10.16(102.3)
Tembotrione 100 g/ha + atrazine 500 g/ha at 15-20 DAS	4.20(16.7)	4.22(16.8)	4.16(16.3)	2.76(6.7)
Tembotrione 100 g/ha + atrazine 750 g/ha at 15-20 DAS	4.12(16.0)	3.83(13.7)	3.74(13.0)	2.28(4.3)
Tembotrione 100 g/ha + halosulfuron 67.5 g/ha at 15-20 DAS	5.66(31.0)	5.41(28.3)	5.60(30.3)	5.09(25.0)
Tembotrione 100 g/ha+ halosulfuron 52.5 g/ha at 15-20 DAS	6.00(35.0)	5.80(32.7)	6.08(36.0)	5.28(27.0)
Halosulfuron 67.5 g/ha + atrazine500 g/ha at 15-20 DAS	7.19(50.7)	6.97(47.5)	6.85(46.0)	6.58(42.3)
Atrazine1000 g/ha 0-3 DAS *fb*2,4-D 500 g/ha at 15-20 DAS	6.90(46.7)	6.77(44.8)	6.63(43.0)	5.97(34.7)
Atrazine 1000 g/ha 0-3 DAS *fb* metribuzin 250 g/ha at 15-20 DAS	5.10(25.0)	4.96(23.7)	4.79(22.0)	3.79(13.3)
Atrazine 1000 g/ha 0-3 DAS *fb* tembotrione 100 g/ha at 15-20 DAS	4.16(16.3)	4.26(17.2)	4.03(15.3)	2.63(6.0)
Weed free	1.00(0)	1.41(1.0)	1.00(0.)	1.00(0)
Weedy check	13.17(172.7)	12.38(152.4)	14.11(198.3)	13.36(177.7)
LSD (p=0.05)	0.34	0.48	0.48	0.49

The data were subjected to $(\sqrt{x+1})$ transformation; Figures in the parentheses are original values

Table 2 Effect of different weed management treatments on maize grain and stover yield, weed control efficiency and weed index

Treatment	Grain yield (t/ha)		Stover yield (t/ha)		WCE 60 DAS		WI	
	2016	2017	2016	2017	2016	2017	2016	2017
Tembotrione 100 g/ha at 15-20 DAS	2.93	3.03	6.16	6.22	66.5	66.1	19.6	19.0
Halosulfuron 67.5 g/ha at 15-20 DAS	2.74	2.84	5.00	5.06	56.3	55.8	24.8	24.1
Atrazine 1000 g/ha at 0-3 DAS	2.89	2.93	5.92	5.95	54.0	54.7	20.6	21.6
Atrazine 750 g/ha at 15-20 DAS	2.17	2.28	4.58	4.69	35.7	36.4	40.5	39.0
Atrazine 500 g/ha at 15-20 DAS	2.14	2.27	4.31	4.36	29.6	29.5	41.3	39.4
Tembotrione 100 g/ha + atrazine 500 g/ha at 15-20 DAS	3.52	3.62	7.34	7.39	92.5	93.3	3.3	3.2
Tembotrione 100 g/ha + atrazine 750 g/ha at 15-20 DAS	3.54	3.64	7.35	7.40	93.2	93.7	2.6	2.5
Tembotrione 100 g/ha + halosulfuron 67.5 g/ha at 15-20 DAS	3.48	3.52	7.19	7.26	86.7	86.9	4.5	6.0
Tembotrione 100 g/ha + halosulfuron 52.5 g/ha at 15-20 DAS	3.47	3.50	7.08	7.10	83.6	85.0	4.9	6.5
Halosulfuron 67.5 g/ha+ atrazine500 g/ha at 15-20 DAS	2.78	2.91	6.09	6.15	68.0	68.1	23.7	22.2
Atrazine1000 g/ha 0-3 DAS *fb*2,4-D 500 g/ha at 15-20 DAS	2.92	3.02	6.04	6.13	68.5	69.6	19.8	19.3
Atrazine 1000 g/ha 0-3 DAS *fb* metribuzin 250 g/ha at 15-20 DAS	3.37	3.50	6.86	6.92	78.7	80.6	7.5	6.5
Atrazine 1000 g/ha 0-3 DAS *fb* tembotrione 100 g/ha at 15-20 DAS	3.52	3.63	7.33	7.39	81.0	81.6	3.4	3.1
Weed free	3.64	3.74	7.82	7.90	100.0	100.0	-	-
Weedy check	1.96	2.06	3.61	3.68	-	-	46.3	44.9
LSD (p=0.05)	0.44	0.41	1.06	0.941				

Table 3. Effect of different weed management treatments on number of grains/cob, 1000- grain weight plant height, net return and B: C ratio in maize

Treatment	No. of grains/cob		1000- grain weight (g)		Plant height (cm) 60 DAS		Net returns (x10[3] `/ha)		B:C ratio	
	2016	2017	2016	2016	2016	2017	2016-17	2017-18	2016-17	2017-18
Tembotrione 100 g/ha at 15-20 DAS	383	385	164.3	164.3	164.3	166.0	33.12	34.31	2.62	2.65
Halosulfuron 67.5 g/ha at 15-20 DAS	346	349	159.9	159.9	159.9	160.2	25.52	26.65	2.10	2.13
Atrazine 1000 g/ha at 0-3 DAS	380	384	166.0	166.0	166.0	162.3	33.14	33.36	2.70	2.68
Atrazine 750 g/ha at 15-20 DAS	325	329	155.7	155.7	155.7	156.0	20.32	21.76	2.05	2.10
Atrazine 500 g/ha at 15-20 DAS	282	285	150.7	150.7	150.7	151.4	19.54	21.11	2.02	2.07
Tembotrione 100 g/ha + atrazine 500 g/ha at 15-20 DAS	543	547	174.0	174.0	174.0	178.2	43.62	44.73	3.11	3.12
Tembotrione 100 g/ha + atrazine 750 g/ha at 15-20 DAS	551	555	176.3	176.3	176.3	179.9	44.73	44.80	3.10	3.11
Tembotrione 100 g/ha + halosulfuron 67.5 g/ha at 15-20 DAS	544	547	174.4	174.4	174.4	175.0	38.75	38.99	2.57	2.56
Tembotrione 100 g/ha + halosulfuron 52.5 g/ha at 15-20 DAS	538	539	171.8	171.8	171.8	173.0	39.28	39.39	2.66	2.63
Halosulfuron 67.5 g/ha + atrazine500 g/ha at 15-20 DAS	391	363	166.7	166.7	166.7	167.9	27.83	29.42	2.19	2.23
Atrazine1000 g/ha 0-3 DAS *fb* 2,4-D 500 g/ha at 15-20 DAS	360	396	170.4	170.4	170.4	171.4	33.21	34.37	2.66	2.68
Atrazine 1000 g/ha 0-3 DAS *fb* metribuzin 250 g/ha at 15-20 DAS	403	405	171.8	171.8	171.8	172.9	40.86	42.40	3.01	3.04
Atrazine 1000 g/ha 0-3 DAS *fb* tembotrione 100 g/ha at 15-20 DAS	539	544	173.8	173.8	173.8	174.2	42.94	44.17	3.01	3.03
Weed free	553	557	176.5	176.5	176.5	180.3	19.48	20.63	1.41	1.43
Weedy check	268	270	144.5	144.5	144.5	144.9	16.22	17.49	1.87	1.92
LSD (p=0.05)	49	52	18.8	18.8	18.8	21.2				

3). Martin *et al.* (2011) observed that yield attributes of maize were higher when atrazine was applied along with tembotrione as PoE.

Economic

Preference of any herbicides by the farmers mainly depends on the weed control efficiency and economics. Currently, the cost of manual weeding is much higher than the chemical weed control, which encourages many farmers for switching over to herbicides from expensive and tiresome manual weeding. The net returns were found to be higher with tembotrione 100 g/ha + atrazine 750g/ha followed by tembotrione 100 g/ha + atrazine 750 g/ha and atrazine 1000 g/ha *fb* tembotrione 100g/ha during both years. Further, the benefit: cost ratio was higher for tembotrione 100 g/ha + atrazine 500 g/ha during both the years (3.11 and 3.12, respectively) tembotrione 100 g/ha + atrazine 750 kg/ha and atrazine 1000 g/ha *fb* tembotrione 100 g/ha during both years. (**Table 3**).

It may be concluded that post-emergence application of tembotrione 100 g/ha + atrazine 500 g/ha at 15-20 DAS was on effective method of managing weeds, improving maize grain yield and ensured better economic returns in maize crop grown in the rainfed area of Jammu.

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Phytotoxic effects of glufosinate ammonium on cotton and soil micro-flora

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ABSTRACT

A field experiment was conducted at Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India in *Kharif* season of 2016 and 2017 to evaluate the phytotoxicity of glufosinate ammonium 13.5% SL (15% w/v) on cotton and soil micro-flora and their consequent effects on crop growth, yield and economics. Findings depicted that there were no phytotoxic symptoms on cotton and there was better recovery of soil micro-flora population with the application of glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha, resulting in maximum growth, yield and economic profitability of cotton. However, prominent toxic effects of glufosinate ammonium 13.5% SL (15% w/v) on the crop and soil micro-flora were recorded at higher doses of 900 g/ha and 1800 g/ha, which significantly reduced cotton growth, yield and economic viability.

INTRODUCTION

Cotton (*Gossypium* sp.) is an important non-edible cash crop of India especially in north western, central and southern states. It plays a major role in Indian economy through amplifying textile industries. Globally, India is now at the first position in cotton cultivation with 12.24 mha area and 340.25 lakh bales of production (advance estimate for 2018-19 by Cotton Association of India 2019). This high value fibre crop due to its growing demand in textile sector, requires adequate attention for suitable cultivation practice in order to increase its productivity. It is disgrace to highlight that cotton growers in India are facing disparity between demand and supply of raw materials in textile sector due to lower productivity (506.07 kg/ha in 2017-18) as compared to global mean value (775 kg/ha) (Cotton Association of India 2019). Researchers are worried that India may lose its top position in cotton production to China in near future. While searching the reasons for such low yield of cotton, apart from climatic anomalies, infestations of pest and diseases have also received the spotlight. Recently, efforts are being made to improve productivity level through introduction of hybrid and Bt-cotton varieties by addressing the pest problems. However, weeds are still the major concern everywhere as they compete with crop for resources and make the crop vulnerable to insects and diseases by providing shelters for those harmful organisms and pathogens. If weeds are not checked on time, they may cause considerable or even full yield reduction of crop. Nandagavi and Halikatti (2016) highlighted that on an average, 40 to 85 % cotton yield can be reduced by weeds. Therefore, proper weed management practice is now the fundamental requisite for the cotton growers to address such drastic yield reduction. Quality is an important parameter for cotton which is also needed to be considered during advocating weed management practice.

Hand weeding/interculture by far is the best and common conventional practice to manage weeds and consequently to increase yield and quality of cotton crop. However, in the present scenario of labour shortage and frequent rise of wages coupled with its non-suitability for all agro-climatic conditions uniformly, this uneconomical weeding option is losing focus and alternative options are getting acceptance in its place. Chemical measures of weed control is now gaining popularity among farmers as it is quick, economical and effective way to destroy weeds and contribute higher crop yield (Prematilake *et al.* 2004, Mirghasemi *et al.* 2012). In cotton, among several herbicidal applications, a contact herbicide, glufosinate ammonium (synthetic version of phosphinothricin *i.e.* by-product of bialaphos from *Streptomyces viridochromogenes* and *S. hygroscopicus* as reported by Droge-Laser *et al.* in 1994) is now receiving high attention and getting widely used for successful management of wide range of weed flora

(Chompoo and Pornprom 2008) during critical crop-weed competition period. However, chemical formulations always leave footprint on crop and soil since they are toxic in nature. Residual toxicity depends on chemical structure, formulation, dose, time and way of application of herbicides. Phytotoxic effect of herbicide on crop *i.e.* visual symptoms of chlorosis, wilting, scorching, necrosis, epinasty, hyponasty, yellowing *etc*. and impairment of soil biological activity through toxic substances are the major obstacles in use of chemical measures of weed control as their consequent effect is associated with growth and yield of the crop. Considering the above facts, an experiment was executed to observe phytotoxic effects of glufosinate ammonium 13.5% SL (15% w/v) at different doses on cotton and soil micro-flora and their consequence on crop growth, yield and economics.

MATERIALS AND METHODS

The field experiment was conducted during 2016 and 2017 consecutively at Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India in randomised block design with 4 treatments (glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha, glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha, glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha, and Control (weedy check) keeping 5 replications. Sowing of *'KCH-14K59 BGII'* cotton variety was done on 18th and 21st June respectively during 2016 and 2017 at a spacing of 60 cm x 30 cm and harvested on 25th and 27th November in respective years. Individual plot size was 5 x 4 m. N:P_2O_5:K_2O 120: 60:60 kg/ha (50% of N through urea and 100% of P_2O_5 and K_2O through S.S.P. and M.O.P. respectively at basal and 50% N in 3 equal splits at 50, 80 and 110 days after sowing (DAS) were used in this study as crop nutrition. Herbicide glufosinate ammonium 13.5% SL (15% w/v) as treatment wise doses was subjected to early post-emergent spray at 2 days after emergence (DAE) through knapsack sprayer fitted with flat fan/flood jet nozzle with spray volume of 500 L/ha. Other agronomic and plant protection practices were followed as per the recommendations. Phytotoxic data such as yellowing of leaf tips and margins, chlorosis, wilting, hyponasty, epinasty and scorching were recorded at 1, 3, 5, 7 and 10 days after application (DAA) of herbicide through visual assessment of crop response, and levels of toxicity of herbicide at different doses were rated in the phytotoxicity rating scale (PRS) of 0-10. Ratings '0' and '10' indicate 'no visible injury' and 'complete destruction of the crop' respectively. Soil samples of 0-15 cm depth were also collected from experimental plots at different DAS and toxicity on soil rhizospheric micro-flora was analysed by counting aerobic non-symbiotic nitrogen fixing (25, 50, 75 DAS) and phosphate solubilizing (25, 50, 90 DAS) bacteria on agar plates as number of viable cells per gram of soil using Jensen's agar medium and Pikovskaia's agar medium respectively, through serial dilution technique, pour plate method (Pramer and Schmidt 1965) followed by incubation at 30°C. The counts were taken at 5th day of incubation. Observations on plant growth and yield such as plant height, no. of sympodial branches/plant, dry matter weight/plant, number of bolls/plant, boll weight and seed cotton yield were recorded at harvest and economics was calculated thereafter. For statistical analysis in standard statistical software, analysis of variance (ANOVA) method (Goulden 1952 and Cochran and Cox 1959) was used and comparison of treatment means was done for 5% level of significance using critical differences (CD) as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Phytotoxicity on cotton

Two years' experimental results delineated that there was no visible symptoms of yellowing, chlorosis, wilting, hyponasty/epinasty and scorching on cotton at 1, 3, 5, 7 and 10 DAA to exhibit phytotoxic effect of glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha. (**Tables 1 and 2**). However, phytotoxic effect of glufosinate ammonium 13.5% SL (15% w/v) on the crop became prominent at higher doses, *viz.* 900 g/ha and 1800 g/ha during both the years. As compared to glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha, visible symptoms of phytotoxicity during both 2016 and 2017 were more prominent when glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha was applied as weed control measure in cotton field. Specifically, based on the phytotoxicity rating scale (PRS), application of glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha imposed 0-20% phytotoxic visible symptoms of yellowing, chlorosis and wilting; 0-30% of scorching during both the years and 0-10% and 0-30% of hyponasty/epinasty in 2016 and 2017, respectively. While application of glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha induced 1-60% and 1-50% yellowing; 1-50% and 1-60% chlorosis; 1-40% and 1-50% wilting; 1-40% and 1-60% hyponasty/epinasty and 11-60% and 1-60% scorching respectively during 2016 and 2017. Prominent phytotoxic effects of glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha and 1800 g/ha on cotton were

Table 1. Phytotoxicity of glufosinate ammonium 13.5% SL (15% w/v) on cotton plants in 2016

Treatment	Yellowing DAA					Chlorosis DAA					Wilting DAA					Hyponasty/Epinasty DAA					Scorching DAA				
	1	3	5	7	10	1	3	5	7	10	1	3	5	7	10	1	3	5	7	10	1	3	5	7	10
Glufosinate ammonium 13.5% SL (15% w/v)450 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha	0	1	2	2	2	0	1	2	2	2	0	1	1	2	2	0	1	1	1	1	0	2	3	3	3
Glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha	1	3	5	5	6	1	2	5	5	5	1	2	4	4	4	1	2	4	4	4	2	5	6	6	6
Control (weedy check)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. Phytotoxicity of glufosinate ammonium 13.5% SL (15% w/v) on cotton plants in 2017

Treatment	Yellowing DAA					Chlorosis DAA					Wilting DAA					Hyponasty/Epinasty DAA					Scorching DAA				
	1	3	5	7	10	1	3	5	7	10	1	3	5	7	10	1	3	5	7	10	1	3	5	7	10
Glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha	0	2	2	2	2	0	1	1	2	2	0	1	1	2	2	0	1	1	2	3	0	2	2	3	3
Glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha	1	3	4	5	5	1	3	4	5	6	1	2	5	5	5	1	3	5	5	6	1	4	5	6	6
Control (weedy check)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3. Toxicity of glufosinate ammonium 13.5% SL (15% w/v) on soil micro-flora in 2016

Treatment	Non-symbiotic Nitrogen fixing bacteria (CFU x 10^4/g of soil)			Phosphate- solubilizing bacteria (CFU x 10^4/g of soil)		
	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	90 DAS
Glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha	25.16	66.73	86.64	9.67	31.48	49.82
Glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha	26.12	54.87	77.87	8.34	27.54	43.87
Glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha	21.44	46.76	61.78	6.89	20.61	35.16
Control (weedy check)	33.11	38.11	52.76	12.19	16.27	28.62

gradually noticed from 1 DAA to 3, 5, 7, 10 DAA and afterwards. Control (weedy check) plot did not show any visible crop injury as it was kept apart from herbicidal application.

Phytotoxicity of glufosinate ammonium 13.5% SL (15% w/v) at higher doses (900 g/ha and 1800 g/ha) on cotton through spray drift and root uptake from soil were prominent due to the non-selective, contact nature of the herbicide with some extent of systemic action. Glufosinate ammonium 13.5% SL (15% w/v) blocks glutamine synthetase, an enzyme that converts glutamate and ammonia into glutamine and plays important role in nitrogen metabolism in plant. Applications of glufosinate ammonium 13.5% SL (15% w/v) specially at higher doses thus increase NH_4^+ concentration in plant (Mersey *et al.* 1990) resulting in cell membrane leakage, wilting, scorching, chlorosis, hyponasty/epinasty, yellowing of leaves etc. Inhibition of glutamine synthetase also undergoes disturbance in electron transport system and production of free radicals resulting in lipid peroxidation and cell death (Hess 2000). Further, ammonium toxicity in plant cells functions as uncoupler of photophosphorylation which in turn inhibits CO_2 assimilation (Kocher 1983). You and Barker (2002) also observed phytotoxicity of glufosinate ammonium at higher doses in tomato plants.

Toxicity on soil micro-flora

Toxicities of glufosinate ammonium 13.5% SL (15% w/v) on soil rhizospheric micro-flora, *viz.* aerobic non-symbiotic nitrogen fixing and phosphate-solubilizing bacteria were observed during both the years at various doses of application (**Table 3 and 4**). Initially, as compared to control (weedy check) where no herbicide was applied (non-symbiotic nitrogen fixing bacteria at 25 DAS: 33.11 CFU x 10^4/g of soil in 2016 and 32.21 CFU x 10^4/g of soil in 2017; phosphate-solubilizing bacteria at 25 DAS: 12.19 CFU x 10^4/g of soil in 2016 and 10.97 CFU x 10^4/g of soil in 2017), there were noticeable reductions of soil micro-flora population with the application of the herbicide 450 g/ha (non-symbiotic nitrogen fixing bacteria at 25 DAS: 25.16 CFU x 10^4/g of soil in 2016 and 23.96 CFU x 10^4/g of soil in 2017; phosphate-solubilizing bacteria at 25 DAS: 9.67 CFU x 10^4/g of soil in 2016 and 8.45 CFU x 10^4/g of soil in 2017), 900 g/ha, (non-symbiotic nitrogen fixing bacteria at

25 DAS: 26.12 CFU x 10^4/g of soil in 2016 and 24.98 CFU x 10^4/g of soil in 2017; phosphate-solubilizing bacteria at 25 DAS: 8.34 CFU x 10^4/g of soil in 2016 and 7.11 CFU x 10^4/g of soil in 2017) and 1800 g/ha (non-symbiotic nitrogen fixing bacteria at 25 DAS: 21.44 CFU x 10^4/g of soil in 2016 and 20.32 CFU x 10^4/g of soil in 2017; phosphate-solubilizing bacteria at 25 DAS: 6.89 CFU x 10^4/g of soil in 2016 and 5.79 CFU x 10^4/g of soil in 2017). However, from 25 DAS onwards, toxic effects of glufosinate ammonium 13.5% SL (15% w/v) gradually faded away and recoveries of bacterial population were observed. It might be due to the fact that after initial catastrophe, soil microbes bounced back not only through degradation of herbicidal compound into its half-life (Bera and Ghosh 2013) but also obtaining carbon based substrates from the degraded herbicide for their developments, physiological processes and multiplications. As compared with other doses (*i.e.* 900 g/ha and 1800 g/ha) of glufosinate ammonium 13.5% SL (15% w/v), better and faster recoveries were noticed from the plot where it was applied 450 g/ha (non-symbiotic nitrogen fixing bacteria: 66.73 CFU x 10^4/g of soil in 2016 and 65.31 CFU x 10^4/g of soil in 2017 at 50 DAS and 86.64 CFU x 10^4/g of soil in 2016 and 85.24 CFU x 10^4/g of soil in 2017 at 75 DAS; phosphate-solubilizing bacteria: 31.48 CFU x 10^4/g of soil in 2016 and 30.28 CFU x 10^4/g of soil in 2017 at 50 DAS and 49.82 CFU x 10^4/g of soil in 2016 and 48.72 CFU x 10^4/g of soil in 2017 at 90 DAS). It indicated that toxicity of herbicide on soil did not last long at lower dose (*i.e.* 450 g/ha) and soil micro flora population again started to increase in short period of time. Persistence of herbicidal toxicity on soil and slow recoveries of bacterial population were however noted at higher doses of glufosinate ammonium 13.5% SL (15% w/v), specially with more pronounced effect at 1800 g/ha. High glufosinate ammonium 13.5% SL (15% w/v) toxicity immediately after application on soil and its residual toxicity persistence with the increment of dose were also reported by Ghosh *et al.* (2017) in tea.

Growth, yield attributes and yield of cotton

During both the years of experiment, phytotoxic effects of glufosinate ammonium 13.5% SL (15% w/v) at various doses on cotton and soil micro-flora in turn exhibited significant impacts on plant growth, yield attributes and yield (**Table 5**). Marked reductions of plant height, sympodial branches/plant, dry matter weight/plant, no. of bolls/plant, boll weight, and seed cotton yield were noticed with the increment of doses of glufosinate ammonium 13.5% SL (15% w/v) during 2016 and 2017 due to intensive build-up of phytotoxicity on crop and soil micro-flora.

Maximum growth in terms of plant height (84.7 cm in 2016 and 82.4 cm in 2017), sympodial branches/plant (16.3 in 2016 and 15.5 in 2017), dry matter weight/plant (146.5 g in 2016 and 141.3 g in 2017) was obtained with the application of glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha, followed by application of glufosinate

Table 4. Toxicity of glufosinate ammonium 13.5% SL (15% w/v) on soil micro-flora in 2017

Treatment	Non-symbiotic nitrogen fixing bacteria (CFU x 10^4/g of soil)			Phosphate- solubilizing bacteria (CFU x 10^4/g of soil)		
	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	90 DAS
Glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha	23.96	65.31	85.24	8.45	30.28	48.72
Glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha	24.98	53.67	76.57	7.11	26.24	42.75
Glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha	20.32	45.46	60.45	5.79	19.27	33.92
Control (weedy check)	32.21	36.91	51.56	10.97	15.07	27.38

Table 5. Growth, yield attributes and yield of cotton in 2016 and 2017

Treatment	Plant height (cm)		Sympodial branches/plant		Dry matter weight/plant (g)		No. of bolls/plant		Boll weight (g)		Seed cotton yield (t/ha)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha	84.7	82.4	16.3	15.5	146.5	141.3	28.02	25.70	4.14	3.25	1.97	1.89
Glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha	78.4	74.1	14.1	13.4	132.4	125.3	24.80	21.40	3.87	2.71	1.72	1.67
Glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha	71.8	68.3	12.3	11.8	121.7	115.9	19.60	16.30	3.43	2.34	1.51	1.43
Control (weedy check)	67.9	65.6	9.9	9.4	113.9	110.4	14.42	11.70	2.87	1.99	1.17	1.08
LSD (P=0.05)	3.15	2.92	0.78	0.50	4.55	4.23	1.62	1.06	0.16	0.11	0.13	0.13

ammonium 13.5% SL (15% w/v) 900 g/ha (plant height: 78.4 cm in 2016 and 74.1 cm in 2017; sympodial branches/plant: 14.1 in 2016 and 13.4 in 2017; dry matter weight/plant: 132.4 g in 2016 and 125.3 g in 2017) and lowest among herbicidal doses at 1800 g/ha (plant height: 71.8 cm in 2016 and 68.3 cm in 2017; sympodial branches/plant: 12.3 in 2016 and 11.8 in 2017; dry matter weight/plant: 121.7 g in 2016 and 115.9 g in 2017). Control (weedy check) resulted in lowest growth in all the mentioned attributes due to the rapid infestation of weeds competing with the crop for resources.

Yield attributes and yield of cotton also followed the identical trend of growth attributes under application of various doses of glufosinate ammonium 13.5% SL (15% w/v) during both the years of study. Highest no. of bolls/plant (28.02 in 2016 and 25.70 in 2017) and boll weight (4.14 g in 2016 and 3.25 g in 2017) were recorded where glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha was applied, followed by glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha (no. of bolls/plant: 24.80 in 2016 and 21.40 in 2017; boll weight: 3.87 g in 2016 and 2.71 g in 2017) and 1800 g/ha (no. of bolls/plant: 19.60 in 2016 and 16.30 in 2017; boll weight: 3.43 g in 2016 and 2.34 g in 2017). Consequently, seed cotton yield was also highest (1.97 t/ha in 2016 and 1.89 t/ha in 2017) with the application of glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha followed by glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha (1.72 t/ha in 2016 and 1.67 t/ha in 2017) and 1800 g/ha (1.51 t/ha in 2016 and 1.43 t/ha in 2017). Lowest no. of bolls/plant, boll weight and seed cotton yield were observed from control (weedy check). Lowest growth and yield of cotton due to weed infestation as in case of control (weedy check) was also reported by Anjum *et al.* (2007).

Increment of herbicidal dose imposed prominent phytotoxic effects on the crop and thus interfered with its internal metabolic processes and photosynthesis. Decrease of chlorophyll content through leaf yellowing, chlorosis, scorching etc. by non-selective herbicide spray drift and uptake from soil in turn decreased crop growth and thereby its yield through hampering photosynthetic process of dry matter production and partitioning. Interference of herbicidal phytotoxicity with chlorophyll content was also observed in different crops (Rao and Dubey 1983, Nandihalli and Bhowmik 1992, Singh *et al.* 1996, Kushwaha and Bhowmik 1999). De Snoo *et al.* (2001) also reported the phytotoxicity of glufosinate ammonium through spray drift and its consequent effects on growth and development of non-target vegetation. Further, impairment of plant nitrogen and phosphate nutrition through suppression of non-symbiotic nitrogen fixing and phosphate-solubilizing bacteria by toxic effects of glufosinate ammonium 13.5% SL (15% w/v) specially at higher doses (900 g/ha and 1800 g/ha) restricted cotton growth and yield as they play pivotal roles respectively, in nitrogen cycling (Zechmeister-Boltenstern 1996) and solubilisation and availability of inorganic phosphorus to the crop (Chen *et al.* 2006).

Economics

Production economics of cotton under different weed management options (**Table 6**) revealed that it was greatly influenced by phytotoxic effects of glufosinate ammonium 13.5% SL (15% w/v) at various doses on the crop and soil micro-flora. Maximum net returns (` 39,029/ha) and B:C (2.02) were obtained under application of glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha, which was followed by application of glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha (net returns: ` 28,429/ha and B:C of 1.72) and glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha (net returns: ` 17,029/ha and B:C of 1.41). Greater phytotoxicity of glufosinate ammonium 13.5% SL (15% w/v) at higher doses (*i.e.* 900 g/ha and 1800 g/ha) on cotton and soil beneficial micro-flora reduced the crop yields on one hand and incurred high mean cost of cultivations (` 39,371/ha and ` 41,771/ha, respectively) on the other through the use of high quantity of costly herbicide. Compared to others, glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha application was most profitable as less quantity of herbicide was applied (*i.e.* less cost of cultivation: ` 38,171/ha) and higher seed cotton yield was obtained due to no or negligible phytotoxic effects of

Table 6. Economics of cotton under different weed management options (mean of two years)

Treatment	Cost of cultivation (x10^3 `/ha)	Gross returns (x10^3 `/ha)	Net returns* (x10^3 `/ha)	B:C
Glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha	38.17	77.20	39.03	2.02
Glufosinate ammonium 13.5% SL (15% w/v) 900 g/ha	39.37	67.80	28.43	1.72
Glufosinate ammonium 13.5% SL (15% w/v) 1800 g/ha	41.77	58.80	17.03	1.41
Control (weedy check)	35.86	45.00	9.14	1.25

*Price of seed cotton in 2016 and 2017: ` 40,000/t.

the herbicide on crop and soil micro-flora. Control (weedy check) was economically atrophied (mean net return: ` 9,139/ha and B:C of 1.25) as no measure was taken to manage resource grabbing weeds and consequently crop could not express its natural yield. Higher dose of glufosinate ammonium 13.5% SL (15% w/v) *i.e.* 1800 g/ha was comparatively superior over weedy check in terms of yield and net return because of its high efficiency of suppressing dominant weed flora in the cotton field. However, considering the facts of significant phytotoxicity build up on cotton and soil biological health as well as higher cost of cultivation due to use of costly herbicide, farmers are advised not to go for application of such a high dose of herbicide when the same herbicide at low dose *i.e.* 450 g/ha has succeed to provide farmers best yield and highest economic viability (B:C).

Glufosinate ammonium 13.5% SL (15% w/v) 450 g/ha had shown no phytotoxicity symptom on cotton and negligible toxicity on soil micro-flora and thus it can be recommended as relatively a safe chemical for weed management in cotton in new alluvial zone of West Bengal, India for realising better growth, yield and economic profitability. But glufosinate ammonium 13.5% SL (15% w/v) at higher doses had toxic effects on cotton and soil micro-flora which consequently had affected crop growth, yield and economics.

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Integrated weed management in fennel production system and its residual effect on succeeding summer greengram

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ABSTRACT

A field trial was conducted during two consecutive *Rabi* season of 2016-17 and 2017-18 on loamy sand soil at AICRP-Weed Management, B.A. College of Agriculture, Anand Agricultural University, Anand (Gujarat) to study the effect of integrated weed management in fennel production system and its residual effect on succeeding summer greengram. Significantly, lowest and highest weeds density at harvest was recorded with farm yard manure (FYM) 20 t/ha and vermicompost 8.0 t/ha, respectively. However, highest fennel seed yield (2.09 t/ha) was recorded with vermicompost 8.0 t/ha application. Significantly higher plant height, number of umbels/plant and seed yield was recorded with paddy straw mulch 10 t/ha *fb* hand weeding *(*HW) at 30 and 60 days after transplanting (DATP) and it was at par with paddy straw mulch 5 t/ha *fb* HW at 30 and 60 DATP and twice inter cultivation (IC) + HW at 30 and 60 DATP *fb* earthing-up at 75 DATP. Higher fennel equivalent yield (2.43 t/ha) and gross return (₹ 243000/ha) was recorded with application of vermicompost 8.0 t/ha, while highest net return (₹ 138220/ha) and benefit cost ratio (2.56) was recorded with application of FYM. Paddy straw mulch 10 t/ha *fb* HW at 30 and 60 DATP recorded higher fennel equivalent yield (3.24 t/ha), gross returns (₹ 219816/ha), net returns (₹ 241976/ha) and benefit cost ratio (3.11). Application of FYM and vermicompost was found equally effective while mulching treatments recorded higher seed yield of succeeding greengram.

INTRODUCTION

Fennel (*Foeniculum vulgare* Mill.) belongs to the family Apiaceae (Umbelliferae) is one of popular seed spice in India. Fennel is traditionally used for medicinal and culinary purposes. Fennel is grown throughout India. However, major production states of fennel seed are Rajasthan, Andhra Pradesh, Telangana, Punjab, Madhya Pradesh, Uttar Pradesh, Gujarat, Karnataka, and Haryana (Meena and Mehta 2009). Vermicompost and FYM play an important role in the supply of macro and micronutrients. Mulches are commonly used in cultivation of vegetables and other spices (Massucati and Kopke 2014) and medicinal crops and are acceptable in organic farming as well as in any other crop production that requires reduced use of pesticides. Applying mulches after planting the main crop or before the weeds start to germinate, certainly bring about many benefits to cultivated crops.

Fennel generally takes much time for germination and also has slow initial growth which often leads to heavy crop weed competition (Gohil *et al*. 2015). If weeds are not controlled in weedy check, reduced the seed yield to the tune of 50 per cent (Gohil *et al.* 2015).

Further, application of herbicides in fennel effectively controls the weeds and reduced the loss of seed yield (Chaudhary, 2000). To keep the fennel field weed free, about 3–4 hand weeding are required (Parthasarathy *et al.* 2008). However, hand weeding is highly labor intensive, time-consuming and expensive. Therefore, the present study was conducted to evaluate the combined effect of organic manures and integration of herbicides with mulch on weeds and yield of fennel.

MATERIALS AND METHODS

The present field experiment was conducted at AICRP-Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat) during two consecutive *Rabi* season of the year 2016-17 and 2017-18 on loamy sand soil. The soil of the experimental field was low in available nitrogen and medium in available phosphorus and high in potassium with pH 8.0. The experiment was laid out in a split plot design and replicated thrice. Ten treatments were there. They are: two organic manures, farm yard manure (FYM) 20 t/ha and vermicompost 8.0 t/ha, were allotted to main plot while five weed management practices, paddy straw mulch 5 t/ha *fb* HW at 30 and 60 DATP, paddy straw mulch 10 t/ha *fb* HW at 30 and 60 DATP, IC+HW at 30 and 60 DATP *fb* earthing-up at 75 DATP, pendimethalin 0.75 kg/ha pre-transplant *fb* IC+HW at 40 DATP and weedy check, were assigned to sub-plots. The fennel cv. '*GF 12*' was transplanted in the experimental field on 15 and 16 September 2017 and 2018, respectively keeping the distance of 90 x 60 cm. All recommended packages of practices were followed throughout the growing season to raise the crop during both the years of experimentation. FYM and vermicompost were applied as per treatment directly in the furrow before transplanting of fennel for proper decomposition while as well as pendimethalin was also applied pre-transplanting with the help of a knap-sack sprayer fitted with flat-fan nozzle with a spray volume of 600 l/ha. Later paddy straw mulch was spread after transplanting as per the treatment. Interculturing (IC) and hand weeding (HW) were carried out as per the treatments. The observations on weed density and biomass were taken at 30 and 60 days after transplanting (DATP) from four randomly selected spots by using 0.25 m^2 iron quadrat from net plot area. Weed control efficiency (WCE) was calculated using standard formula suggested by Maity and Mukherjee (2011). The seed and stalk yield were recorded from the net plot area and converted in to hectare. Data on various observations during the experiment period was statistically analyzed as per the standard procedure developed by Cochran and Cox (1957).

RESULTS AND DISCUSSION

Weed flora

In general, dominance of dicot weed (62.6 %) was observed during the experimental period. Major weeds observed in the experimental field were, *Eleusine indica* (20.6 %), *Dactyloctenium aegyptium* (23.3 %), *Commelina benghalensis* (4.87 %), *Eragrostic major* (5.09 %) among monocot weeds, *Oldenlandia umbellate* (13.9 %), *Phyllanthus niruri* (14.2 %), *Boerhavia diffusa* (4.65 %) and *Digera arvensis* (2.21 %) in dicot weeds.

Effect on weeds

The weed density recorded in two organic manure treatments was non-significant at 30 and 60 DATP while it was significant at harvest. Weed management practices have showed significant effect on weed density at 30 and 60 DATP (**Table 1**). Among weed management practices, application of pendimethalin 0.75 kg/ha pre-transplant *fb* IC + HW at 40 DATP recorded significantly lower weed density and it was at par with paddy straw mulch either 5 or 10 t/ha *fb* HW at 30 and 60 DATP. The highest weed density was in weedy check at 30 DATP. Application of pendimethalin 0.75 kg/ha pre-transplant *fb* IC + HW at 40 DATP provide 100 per cent control of weeds at 60 DATP with no weed biomass at 60 DATP. The paddy straw mulch, either 5 or 10 t/ha, *fb* HW at 30 and 60 DATP as well as application of pendimethalin 0.75 kg/ha pre-transplant *fb* IC + HW at 40 DATP have recorded significantly lower weed biomass. Lower weed density and biomass in fennel with pendimethalin *fb* HW at 45 DAS was also observed by Gohil *et al.* (2014) and Kumar *et al.* (2015). The highest weed control efficiency of 69.1 and 100 per cent at 30 and 60 DATP, respectively was

Table 1. Effect of organic manures and weed management treatments on weed density, biomass and WCE in fennel

Treatment	Weed density (no./m^2)			Weed biomass (g/m^2)			Weed control efficiency (%)		
	30 DATP	60 DATP	At harvest	30 DATP	60 DATP	At harvest	30 DATP	60 DATP	At harvest
Organic manures									
Farm yard manure 20 t/ha	12.9(195)	11.4(183)	6.81(62.5)	9.44(104)	8.74(121)	13.2(251)	-	-	-
Vermicompost 8.0 t/ha	12.7(190)	11.2(196)	7.32(72.4)	10.1(115)	8.71(119)	13.6(313)	-	-	-
LSD (p=0.05)	NS	NS	0.495	0.397	NS	NS	-	-	-
Weed management									
Paddy straw mulch 5 t/ha *fb* HW at 30, 60 DATP	11.6(137)	10.8(127)	4.65(34.4)	9.20(91.0)	7.67(58.9)	7.22(90.5)	54.7	86.3	89.0
Paddy straw mulch 10 t/ha *fb* HW at 30, 60 DATP	9.01(81.3)	7.44(59.5)	4.02(24.7)	8.02(67.1)	6.14(37.2)	6.68(76.5)	66.6	91.4	90.7
IC + HW at 30 and 60 DATP *fb* earthing-up at 75 DATP	15.6(245)	16.5(317)	5.49(49.6)	10.5(125)	8.13(69.5)	7.68(104)	37.8	83.9	87.3
Pendimethalin 0.75 kg/ha pre- transplant *fb* IC + HW at 40 DATP	6.65(47.4)	1.00(0.00)	9.63(95.9)	7.83(62.1)	1.00(0.00)	17.6(319)	69.1	100	61.2
Weedy check	21.0(452)	20.8(443)	11.5(133)	13.2(201)	20.7(431)	27.8(822)	-	-	-
LSD (p=0.05)	7.45	12.7	NS	NS	5.07	NS	-	-	-
Interaction M x W	NS	NS	NS	Sig.	NS	NS	-	-	-

Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values.

recorded with pendimethalin 0.75 kg/ha pre-transplant *fb* IC + HW at 40 DATP, while at harvest it was the highest under paddy straw mulch 10 t/ha *fb* HW at 30 and 60 DATP. Similar results were reported by Meena and Mehta (2009).

Effect on crop

Plant stand (no./net plot), plant height at 120 DATP, No. of umbels/plant and stalk yield (t/ha) did not differ significantly amongst two organic manure treatments while significant differences occurred due to weed management practices except plant stand which was non-significant (**Table 2**). Significantly highest plant height of 34.2 cm at 45 DATP was recorded under application of farm yard manure 20 t/ha. The seed yield of fennel was highest (2.09 t/ha) with vermicompost 8.0 t/ha indicating that vermicompost is ideal organic manure for better growth and yield of many crops as it contain higher nutritional value than FYM. Patel *et al*. (2003) also recorded higher yield attributes when recommended dose of nitrogen (RDN) was applied through inorganic fertilizers in fennel.

Among weed management practices, significantly higher plant height at 45 and 120 DATP, number of umbels/plant and seed yield was recorded under paddy straw mulch 10 t/ha *fb* HW at 30 and 60 DATP and it was at par with paddy straw mulch 5 t/ha *fb* HW at 30 and 60 DATP and twice IC + HW at 30 and 60 DATP *fb* earthing-up at 75 DATP. Ko^{3}ota and Katarzyna (2013) reported that mulches reduce the rate of weed seed germination, as the mulches do not provide necessary conditions for weed seed germination.

Fennel equivalent yield and economics

The fennel equivalent yield (2.43 t/ha) and gross return (₹ 243000/ha) was higher under application of vermicompost 8.0 t/ha, while net

Table 2. Effect of organic manures and weed management treatments on growth of fennel

Treatment	Plant stand at harvest (no./net plot)	Plant height (cm) At 45 DATP	Plant height (cm) At 120 DATP	No. of umbels/ plant	Seed yield (t/ha)	Stalk yield (t/ha)
Organic manures						
Farm yard manure 20 t/ha	21.3	34.2	149	30.6	1.94	4.78
Vermicompost 8.0 t/ha	21.3	31.1	152	30.4	2.09	4.81
LSD (p=0.05)	NS	2.18	NS	NS	0.139	NS
Weed management						
Paddy straw mulch 5 t/ha *fb* HW at 30, 60 DATP	22.6	34.4	162	34.8	2.30	6.63
Paddy straw mulch 10 t/ha *fb* HW at 30, 60 DATP	23.0	36.8	166	40.6	2.88	6.67
IC + HW at 30 and 60 DATP *fb* earthing-up at 75 DATP	23.1	31.3	155	37.9	2.49	5.34
Pendimethalin 0.75 kg/ha pre- transplant *fb* IC + HW at 40 DATP	22.3	32.0	155	30.2	1.90	4.29
Weedy check	15.6	28.8	115	9.01	0.490	1.04
LSD (P=0.05)	NS	3.02	30.0	6.24	0.697	0.543
Interaction M x W	NS	NS	NS	NS	NS	NS

Table 3. Economics of organic manures and weed management treatments in fennel-greengram organic cropping system

Treatment	Fennel seed yield (t/ha)	Green-gram seed yield (kg/ha)	Green-gram haulm yield (kg/ha)	Fennel Equivalent yield (t/ha)	Gross returns (x10$_{3}$ `/ha)	Additional cost of treatment (x10$_{3}$ `/ha)	System Cost of cultivation (x10$_{3}$ `/ha)	Net returns (x10$_{3}$ `/ha)	B:C ratio
Organic manures									
Farm yard manure 20 t/ha	1.94	568	768	2.27	227.00	31.27	88.78	138.22	2.56
Vermicompost 8.0 t/ha	2.09	577	794	2.43	243.00	50.38	107.89	135.11	2.25
Weed management									
Paddy straw mulch 5 t/ha *fb* HW at 30, 60 DATP	2.30	617	831	2.66	266.00	40.78	167.71	189.87	2.71
Paddy straw mulch 10 t/ha *fb* HW at 30, 60 DATP	2.88	613	839	3.24	324.00	46.67	219.82	241.98	3.11
IC + HW at 30 and 60 DATP *fb* earthing-up at 75 DATP	2.49	575	765	2.83	283.00	45.03	180.46	202.62	2.76
Pendimethalin 0.75 kg/ha pre-transplant *fb* IC + HW at 40 DATP	1.90	560	775	2.23	223.00	40.30	125.19	147.35	2.28
Weedy check	0.490	498	696	0.78	78.00	31.33	-10.84	11.32	0.88

Price of produce:	Fennel seed = `100/kg	M_1 = ` 20000 + 1750 = ` 21780, M_2 = ` 40000 + 890 = ` 40890
	Green gram: seed at ` 55.75, Haulm at ` 2/kg	W_1 = ` 5000 + 890 + 3560 = ` 21780,
Cost of inputs:	Paddy straw mulch ` 1.0/kg	W_2 = `10000 + 1780 + 3560 = ` 15340
	FYM = ` 1/kg, Vermicompost = ` 5/kg	W_3 = ` 3200 + 8900 + 1600 = ` 13700
	Pendimethalin (Stomp 30 EC) = ` 490/lit	W_4 = ` 1225 + 800 +1600 + 5340 = ` 8965
	Herbicide application cost = ` 800/ha/application	BC ratio = Gross return Cost of cultivation

Table 4. Residual effect of organic manures and weed management treatments adopted in fennel on growth characteristics of greengram

Treatment	Plant stand at harvest (no./net plot)	Plant height (cm)		Plant biomass at 40 DATP (g/plant)	Seed yield (kg/ha)	Haulm yield (kg/ha)
		At 30 DAS	At 60 DAS			
Organic manures						
Farm yard manure 20 t/ha	10.8	18.8	44.3	10.6	568	768
Vermicompost 8.0 t/ha	11.2	21.9	47.5	10.7	577	794
LSD (p=0.05)	NS	1.33	2.60	NS	NS	NS
Weed management						
Paddy straw mulch 5 t/ha *fb* HW at 30, 60 DATP	11.2	21.7	47.8	10.8	617	831
Paddy straw mulch 10 t/ha *fb* HW at 30, 60 DATP	11.0	20.6	46.4	10.9	613	839
IC + HW at 30 and 60 DATP *fb* earthing-up at 75 DATP	10.9	21.5	46.7	10.8	575	765
Pendimethalin 0.75 kg/ha pre-transplant *fb* IC + HW at 40 DATP	11.3	19.4	44.6	11.2	560	775
Weedy check	10.4	18.7	44.0	9.49	498	696
LSD (p=0.05)	NS	NS	NS	1.01	54	77
Interaction M x W	NS	NS	NS	NS	NS	NS

returns (₹ 138220/ha) and benefit cost ratio (2.56) were higher under application of farm yard manure (**Table 4**). The higher net returns and benefit cost ratio under application of FYM might be due to high cost of vermicompost. Among weed management practices, paddy straw mulch 10 t/ha *fb* HW at 30 and 60 DATP recorded higher fennel equivalent yield (3.24 t/ha), gross returns (₹ 219816/ha), net returns (₹ 241976/ha) and benefit cost ratio (3.11) as compared to rest of the treatment.

Effect on succeeding crop

The organic manures did not differ in their effect on plant stand at harvest, plant biomass at 40 DAS, seed yield and haulm yield. However, plant height measured at 30 and 60 DAS showed significant differences due to organic manure with significantly higher plant height at 30 and 60 DAS under application of farm yard manure 20 t/ha and vermicompost 8.0 t/ha, respectively.

The plant stand at harvest and plant height at both dates did not differ significantly with weed management practices. Significantly higher plant biomass at 40 DAS was recorded with pendimethalin 0.75 kg/ha pre-transplant *fb* IC + HW at 40 DAS as compared to weedy check. Further, paddy straw mulch 5 t/ha *fb* HW at 30, 60 DAS recorded significantly higher seed yield than in pendimethalin 0.75 kg/ha pre-transplant *fb* IC + HW at 40 DAS and weedy check. However, all the weed management treatments were at par with each other and were superior over weedy check with respect to haulm yield. Among all the weed management practices, weedy check recorded significantly the lowest seed and haulm yield of greengram.

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Effects of environmental factors and ageing on germination of golden crownbeard (*Verbesina encelioides*) - A wide spread weed of Northern India

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ABSTRACT

Golden crownbeard (*Verbesina encelioides*), which is abundant along roadsides in Northern India, has started to invade field borders in the South West of Punjab. This study was conducted to find the effect of environmental factors and accelerated ageing on germination of this weed. It germinated over a wide range of temperatures (15/5-35/25°C) with optimum germination at 25/15°C. Light was not a pre-requisite for germination. Germination was completely inhibited at -0.6 MPa. The seeds germinated at 160 mM sodium chloride (13.3%), but no germination was observed at 180 mM NaCl. Germination of seeds was very low at pH less than 5 or more than 8. Germination was 95% when seeds were placed on the soil surface. No emergence was observed when seeds were buried to 6 cm or greater depth. Accelerated ageing of seeds for 20 or more days completely inhibited germination. Results indicate that this weed can emerge in multiple germination flushes. It also has the ability to invade drought affected areas, and can grow in soils that are moderately saline, slightly acidic, or alkaline. However, this weed is not expected to buildup persistent soil seed banks due to rapid loss of viability (time to 50% persistence = 4.11 days) under accelerated ageing.

INTRODUCTION

Verbesina encelioides (Cav.) Benth. and Hook. f. ex. Gray, commonly known as golden crownbeard, is a member of the Asteraceae family. It is native to tropical America, but has infested five continents, including America (Argentina, Arizona, Hawaii and Mexico), Africa (Algeria, Egypt and Morocco), Asia (India, Saudi Arabia and Yemen), Europe (Belgium, France and Spain) and Australia (CABI 2015). It was reported as a troublesome annual weed of many crops, *viz*., corn (*Zea mays* L.), rice (*Oryza sativa* L.), radish (*Raphanus sativus* L.), pearl millet (*Pennisetum glaucum* (L.) R.Br.), wheat (*Triticum aestivum* L.), chickpea (*Lens culinaris* M.), honeydew melon (*Cucumis melo* L.), rapeseed (*Brassica napus* L.) and peanuts (*Arachis hypogaea* L.) in Australia, Argentina and the United States (Kaul and Mangal 1987). In northern India, *V. encelioides* has not yet infested crops but it is a major roadside weed, especially in south west Punjab districts including Ferozepur, Fazilka, Bathinda, Barnala and Sangrur.

Golden crownbeard is an aggressive annual weed that grows very fast and produces large numbers of winged seeds, which disperse readily. The seed production potential of this weed is 300-350 seeds per capitulum and an average of 29-254 capitula per plant (Sayari *et al*. 2016). It is a poisonous plant, producing signs of galegine toxicity in livestock that were given water containing dried plant material (Lopez *et al*. 1996). The phytotoxic ability of floral and leaf extracts of *V. encelioides* is higher than root leachates and stem extracts (Goel 1987). It also possesses allelopathic properties as demonstrated by the presence of secondary metabolites, *viz*. flavonoids, terpenoids and sesquiterpenes, which have been reported to inhibit seed germination of plants like *Scaevola taccada* (Gaertn.) Roxb. and *Ipomoea pes-caprae* (L.) R. Br. The species is commonly found along roadsides and field boundaries and this weed serves as an alternate host of mealy bug which is a major insect pest of the cotton crop and a host for thrips which are responsible for spreading many viral diseases in cotton, chilli and onion *etc*.

Seed germination is the most critical event for the success of any weed as it is the first stage at which the weed can compete for an ecological niche where it encounters favourable environmental conditions such as temperature, light exposure, soil moisture, pH, soil salinity and burial depth (Chauhan and Johnson 2010). Light is an essential requirement for the germination of positively photoblastic seeds, promoting the germination of seeds located at or near the soil surface. Temperature is an important factor for seed germination, with some weeds germinating only within a narrow temperature range while others possess the ability to germinate at a wide temperature range. Salinity and moisture stress affects germination by decreasing the water uptake capacity of seeds. Sodium and chloride ions are mainly responsible for toxicity in plants (Yadhav *et al.* 2011). Sodium and chloride reduce germination rates as well as root growth of seedlings. Soil pH is also an important factor that affects seed germination and early seedling growth. Seed burial depth affects seedling emergence by influencing the availability of storage reserves, light, moisture and temperature (Shoab *et al.* 2012).

Studies of weed seed persistence under field conditions involve both biotic and abiotic environmental factors and are therefore useful but time-consuming, financially demanding and ineffective in large-scale studies (Ishikawa-Goto and Tsuyuzaki 2004). Artificial seed ageing under controlled conditions can be an important *ex-situ* tool for predicting the persistence of weed seeds in soil. Accelerated ageing helps to predict the long-term germination response of a particular weed species in a relatively short time span.

Information on different environmental factors affecting germination helps in understanding the invasion potential of weed species. Knowledge about weed seed persistence is key to understanding weed seed dynamics in the soil and can assist in improving weed management strategies. Limited information is available regarding the effect of environmental factors on germination of *V. encelioides*. The present study was conducted to study the effect of environmental factors *viz.*, light, temperature, moisture, salinity, pH and accelerated ageing on germination of a north Indian population of *V. encelioides*.

MATERIALS AND METHODS

Collection of seeds

Golden crownbeard plant bears fruits in the acropetal succession with younger fruits developing at the apex and older fruits on basal positions of the shoot. Mature seeds of golden crownbeard were collected from older fruits at basal positions of plants growing along roadsides from Ludhiana (30°19’N latitude and 75°29’E longitude), Faridkot (30°34’N latitude and 76°24’E longitude), Bathinda (30°46’N latitude and 75°08’E longitude) and Ferozepur (30°17’N latitude and 74°46’E longitude) districts of Punjab, India, in October 2015. Seeds were bulked, cleaned and stored at room temperature in airtight plastic containers until used in experiments. The harvested seeds were non-dormant and were capable of germination immediately after harvesting.

Experimental sites

Experiments were performed in the Weed Physiology Laboratory, Department of Agronomy, Punjab Agricultural University, Ludhiana, India from November 2015 to November 2016. The monthly data of maximum, minimum and mean temperatures at Ludhiana in 2016 was recorded by the School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana (**Table 1**). The burial depth experiment was done in pots placed under field conditions at the Punjab Agricultural University research farm (30°56' N latitude and 75°52' E longitude) in the months of December-January 2015-16, when environmental conditions are most favorable for the emergence of seedlings.

Germination protocol

Uniform sized seeds (visually selected) of golden crownbeard were surface sterilized with 0.1% mercuric chloride for two minutes to avoid any fungal infection, and then they were washed four times for two minutes each time with distilled water. Seed germination was tested by uniformly placing 30 seeds on Whatman No.1 filter paper in 9 cm

Table 1. Temperature at Ludhiana, Punjab, India during the year 2016

Month	Temperature		
	Maximum (°C)	Minimum (°C)	Mean (°C)
January	17.2	7.4	12.3
February	23.0	9.0	16.0
March	28.0	14.6	21.3
April	36.6	19.6	28.1
May	39.6	24.6	32.1
June	39.1	27.7	33.4
July	33.5	27.3	30.4
August	33.3	26.1	29.7
September	34.0	25.5	29.7
October	32.7	19.0	25.9
November	27.7	12.0	19.9
December	22.3	8.5	15.4

Petridishes. Either 5 ml of distilled water or a treatment solution was added to the Petridishes and they were incubated at 15 °C (optimum temperature for germination in both light and dark conditions) in an environmental chamber (Model MAC MSW-127, Delhi, India), unless otherwise specified.

Experimental treatments

Temperature

Seed germination was tested under both alternate day/night temperature regimes (12 h light/12 h dark), *viz*. 15/5, 20/10, 25/15, 30/20, 35/25 and 40/30°C; and constant temperatures (24 h light), *viz*. 10, 15, 20, 25, 30 and 35°C using distilled water.

Light

To study the effect of light on germination, seeds kept in Petridishes were incubated in three light regimes- 12 h light/12 h dark, 24 h light and 24 h dark at 15°C, which was found to be the optimum temperature for germination of this weed. To achieve complete darkness, Petridishes were wrapped with double layers of aluminum foil. Data on germination and seedling growth of dark-incubated dishes were recorded only on the 15th day after initiation of the experiment.

Salinity stress

The ability of seeds to germinate under different salt stress levels was examined by using sodium chloride (NaCl) solutions of 1, 10, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 320 and 400 mM concentrations.

Moisture stress

The ability of seeds to germinate under different levels of moisture stress was tested using solutions of polyethylene glycol (PEG) 8000 having water potentials of 0, -0.1, -0.2, -0.4, -0.6, -0.8 and -1.0 MPa (Michel and Kaufmann 1973).

pH

The effect of pH on germination of seeds was tested using buffered solutions with pH ranging from 3 to 10. Buffered solutions of pH 3 and 4 were prepared with 0.2 mM potassium hydrogen phthalate (Chachalis and Reddy 2000). A pH 5 and 6 buffer was prepared with 2 mM of 2-(N-morpholino) ethanesulfonic acid. A 2 mM solution of 4-(2-hydroxyethyl) piperazine-1-ethanesulfonic acid was used for preparation of buffered solutions of pH 7 and 8. To prepare buffered solutions of pH 9 and 10, 2 mM of tricine was used. Final adjustments of each buffer solution were made using 0.1 M HCl or 0.1 N NaOH.

Burial depth

The effect of seed burial depth on seedling emergence of golden crownbeard was studied using plastic pots of 25 cm diameter with holes at the bottom (for drainage and aeration). Pots were filled with soil from a field with no previous infestation of golden crownbeard. The soil filled in the pots was loamy sand having 0.61% organic matter, 7.3 pH and 0.17 dSm^{-1} electrical conductivity. Fifty seeds were placed on the soil surface or buried at 0.5, 1, 2, 4, 6, 8 and 10 cm deep. The pots were irrigated with sprinkler as needed.

Seed ageing

Five grams of freshly harvested seeds (one week after collection) were weighed and accelerated ageing was done by keeping them at 45°C under humid storage (Biabani *et al.* 2011) for 20 days. The seeds were contained in a mesh bag which was placed on a sieve suspended over water contained in a desiccator held at 45°C in an oven. Ageing was followed by air drying of seeds at room temperature for restoration of their original weight. The contents of various biochemical reserves were estimated from control and aged seeds. These aged seeds were also tested for germination at the optimum temperature in an environmental chamber.

Biochemical parameters

The contents of various biochemical reserves, *viz*., total soluble sugars (Dubois *et al.* 1956), total soluble proteins (Lowry *et al.* 1951), total free amino acids (Lee and Takahashi 1966) and starch content (Clegg 1956) were determined from the control and accelerated aged seeds for 1,4, 7 and 10 days.

Observations recorded

Germination counts were made at 24-h intervals for 15 days after the start of the experiments, with the criterion for germination being visible protrusion of the radicle. Germination (%) was calculated as: (no. of seeds germinated /total number of seeds sown) × 100.

The speed of germination (germination index, GI) was calculated as described by the Association of Official Seed Analysts (AOSA), 1983:

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

Mean germination time (MGT) was calculated as per the method given by Ellis and Roberts (1981):

MGT= ∑ (Dn) / ∑ n

Where n is the number of seeds germinated on day D and D is the number of days counted from the beginning of germination.

On the 15th day of each experiment, seedling length was measured with a centimeter scale. Seedling vigor index (SVI) was calculated as described by Abdul-Baki and Anderson (1973):

Seedling vigor index = seedling length (cm) x germination (%)

Statistical analyses

All experiments were conducted three times in a completely randomized design using three replications. There were no significant differences between the results of the repeated experiments, so data were pooled before being subjected to analysis of variance (ANOVA) using CPCS 1 software (the program that computes necessary statistics concerning design with equal or unequal numbers of replications), with means separated using least significant difference (LSD) at 0.05. Regression analysis was used for calculating 50% germination inhibition due to moisture stress, salinity, burial depth and ageing.

RESULTS AND DISCUSSION

Effect of temperature

The optimum day/night temperature regime for germination and seedling growth of golden crownbeard was 25/15°C (12 h light/12 h dark) (**Table 2**). The highest germination per cent and minimum germination time were observed at the 25/15°C day/night temperature regime. No seeds germinated at the alternate day/night temperature of 40/30°C. The maximum recorded seedling vigour index (SVI) occurred at the day/night temperature regime of 25/15°C, and it was decreased by about 86.5% at 35/25°C compared with 25/15°C. Germination of golden crownbeard was also tested at six constant temperatures under a 24 h dark period. The highest germination was observed at 15°C; however, the seeds were able to germinate over a wide temperature range from 15-30°C. The minimum germination time and mean germination time and the maximum speed of germination were recorded at 15°C. Temperatures above 15°C reduced the seedling growth of golden crownbeard (**Table 3**). As depicted in **Table 1**, temperatures at the experimental site in the months of October-March (except the month of January) were favorable for the emergence of golden

Table 2. Effect of day/night temperature regime on germination and seedling growth of golden crownbeard incubated with a 12 h/12 h photoperiod for 15 days

Temperature (°C) (12 h light/12 h dark)	Germination (%)	Time to start germination (days)	Mean germination time (days)	Germination speed	Seedling vigor index
15/5	80.0±2.52	2.0±0	5.50±0.02	4.88±0.04	230.9±25.5
20/10	76.7±1.20	2.0±0	5.53±0.15	4.63±0.03	198.7±25.5
25/15	94.4±2.94	2.0±0	4.63±0.09	7.87±0.18	400.9±16.8
30/20	61.1±2.94	2.0±0	5.69±0.09	4.20±0.17	101.0±5.18
35/25	45.6±2.94	3.0±0	6.81±0.07	2.82±0.04	31.1±3.79
40/30	0	0	0	0	0
LSD (α=0.05)	7.31	0.02	0.26	0.32	58.9

Data are mean ± standard error of three replicates

Table 3. Effect of constant temperature on germination and seedling growth of golden crownbeard incubated with a 24 h photoperiod for 15 days

Temperature (°C)	Germination (%)	Time to start germination (days)	Mean germination Time (days)	Germination Speed	Seedling vigor index
10	0	0	0	0	0
15	97.8±2.22	2.0±0	3.73±0.04	9.77±0.1	512.3±36.3
20	83.3±3.33	2.0±0	4.44±0.16	7.16±0.4	407.3±26.8
25	63.3±3.33	3.0±0	5.14±0.24	4.35±0.1	127.9±10.5
30	33.3±3.33	3.0±0	5.67±0.33	2.22±0.3	65.9±6.04
35	0	0	0	0	0
LSD (α=0.05)	7.78	0.59	0.55	0.66	58.8

Data are mean ± standard error of three replicates crownbeard, thus favoring multiple flushes of this weed throughout the year. Lu *et al*. (2006) studied the germination of *Eupatorium adenophorum* Spreng., a medicinal plant (Chakravarty *et al*. 2011) and a weed of the Asteraceae family and reported germination over a wide temperature range of 10–30°C, with optimum germination at 25°C.

Effect of light

Seed germination was similar statistically under the three light regimes, that is, 12h light/12h dark circardian rhythm, continuous darkness and continuous light conditions (**Table 4).** These findings indicate that germination of golden crownbeard was independent of light. However, seedlings grown in the dark were etiolated, having chlorotic and elongated shoots and resulted in maximum SVI. However, some members of the Asteraceae family have positively photoblastic seeds, like *Bidens tripartite* L. which can germinate only in the presence of light (Benvenuti and Macchia 1997).

Table 4. Effect of light on germination and seedling growth of golden crownbeard incubated at 15°C for variable photoperiods for 15 days

Photoperiod (hours)	Germination (%)	Seedling vigor index
24	83.3±3.33	303.5±14.7
0	86.7±3.33	673.3±28.5
12/12	90.0±0	470±49.3
LSD (α=0.05)	NS	117.5

Data are mean ± standard error of three replicates

Effect of moisture stress

The seeds of golden crownbeard could tolerate moisture stress upto -0.4 MPa, but no germination was recored at -0.6, -0.8 and -1.0 MPa. The osmotic potential required for 50% inhibition of the maximum germination was -0.3 MPa (**Figure 1**). Mean germination time was increased by two folds at -0.4 MPa relative to the control. Seedling growth was adversely affected by moisture stress, with 8.64, 68.6 and 93.8% reductions in seedling vigor index at -0.1, -0.2 and -0.4 MPa as compared with the control. This indicates that *V. encelioides* can tolerate moderate degree of moisture stress.

Effect of salinity

The seeds of golden crownbeard exhibited a significant reduction in germination under salinity stress. The concentration of NaCl required for 50% inhibition of maximum germination was 91.8 mM (**Figure 2**). Germination was completely inhibited at 180 mM NaCl (**Table 6**). It can germinate under a moderate level of salinity, which is an important

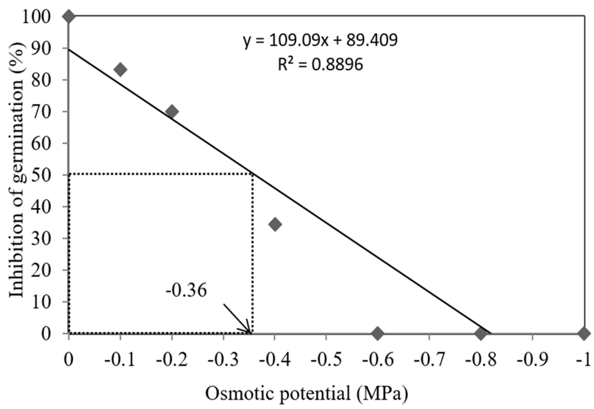

Figure 1. Effect of moisture stress on germination of golden crownbeard. Osmotic potential required for 50% inhibition of germination is shown by an arrow.

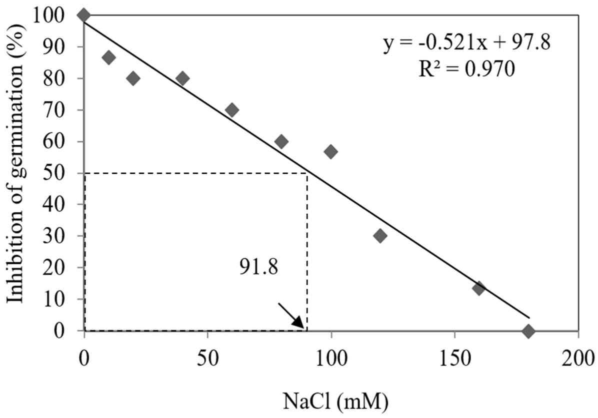

Figure 2. Effect of sodium chloride (NaCl) on germination of golden crownbeard incubated at 15°C with a 24-h photoperiod for 15 days. Sodium chloride concentration required for 50% inhibition of germination is shown by an arrow.

abiotic stress that limits the growth and development of plants. This species has already invaded field borders in some isolated patches in Bathinda district in Punjab (unpublished), where this weed may have a competitive advantage against crops in terms of emergence in salinity affected fields.

Effect of pH

Germination was very low when pH was ≤ 5 or > 8, but increasing pH from 5 to 7 enhanced the germination of *V. encelioides* (**Table 7**). The minimum germination was observed at pH 10, at which seeds also required the longest time to start of germination. Acidic pH condition also had detrimental effects on germination, with only 23-33% germination observed at pH 3-5. Maximum germination was recorded at pH 7, coupled with minimum mean germination time. The highest SVI

Table 5. Effect of moisture stress on germination and seedling growth of golden crownbeard incubated at 15°C with a 24-h photoperiod for 15 days

Osmotic potential (MPa)	Time to start germination (days)	Mean germination time (days)	Germination speed	Seedling vigor index
Control	2.33±0.33	4.03±0.13	8.83±0.61	578.7±49.0
-0.1	3.00±0	5.45±0.17	5.60±0.14	528.7±25.5
-0.2	3.00±0	6.42±0.21	4.09±0.46	181.8±10.1
-0.4	4.33±0	8.24±0.55	1.39±0.32	35.9±5.51
-0.6	0	0	0	0
-0.8	0	0	0	0
-1.0	0	0	0	0
LSD (α=0.05)	0.54	0.72	0.97	118.2

Data are mean ± standard error of three replicates

Table 6. Effect of sodium chloride (NaCl) on germination and seedling growth of golden crownbeard incubated at 15°C with a 24 h photoperiod for 15 days

NaCl (mM)	Time to start germination (days)	Mean germination time (days)	Germination speed	Seedling vigor index
Control	2.00±0	4.50±0.21	8.73±0.14	413.3±23.5
10	2.00±0	5.09±0.71	6.72±0.6	291.5±37.2
20	3.00±0	5.71±0.47	4.99±0.49	236.8±7.02
40	3.00±0	5.42±0.17	4.96±0.17	170.2±26.0
60	3.30±0.33	6.71±0.25	3.79±0.16	135.4±17.6
80	4.00±0	7.38±0.65	2.72±0.07	67.5±12.1
100	4.00±0	8.03±0.76	2.32±0.36	57.3±9.99
120	4.70±0.33	8.67±0.58	1.28±0.09	38.3±3.63
140	5.30±0.33	8.73±0.58	0.82±0.04	17.5±0.47
160	5.70±0.33	8.87±0.48	0.43±0	7.4±2.15
180	-	-	-	-
240	-	-	-	-
320	-	-	-	-
400	-	-	-	-
LSD (α=0.05)	0.52	1.17	0.70	65.4

Data are mean ± standard error of three replicates

Table 7. Effect of pH on germination and seedling growth of golden crownbeard incubated at 15°C with a 24-h photoperiod for 15 days

pH	Germination (%)	Time to start germination (days)	Mean germination Time (days)	Germination speed	Seedling vigor index
3	23.3±3.33	9.00±0	12.6±0.22	0.60±0.07	21.7±5.30
4	26.7±3.33	9.00±0	12.1±0.22	0.77±0.01	29.0±5.57
5	33.3±3.33	7.67±0.67	10.8±0.78	0.99±0.13	37.7±4.99
6	73.3±3.33	2.67±0.33	5.00±0.15	7.10±0.1	185.3±10.7
7	76.7±3.33	2.00±0	4.50±0.29	7.40±0.06	259.5±18.3
8	56.7±8.82	7.00±0	9.06±0.35	2.56±0.04	85.6±12.3
9	33.3±3.33	8.33±0.67	11.3±0.39	0.93±0.14	38.3±2.17
10	16.7±3.33	13.0±0	14.0±0	0.66±0	6.33±1.04
LSD (α=0.05)	12.3	0.99	1.06	0.39	38.5

Data are mean ± standard error of three replicates

was recorded at pH 7, followed by pH 6. Seed germination of golden crownbeard over a broad pH range (3-10) indicates that pH is not a limiting factor for germination of this weed. The pH of agricultural land in Punjab varies from 7 to 8. In this pH range, golden crownbeard exhibited 57 to 77% germination, indicating that pH is not likely to be a limiting factor for germination in most the Punjab soils. Unlike *V. encelioides*, *Bidens alba*, another wasteland weed found in northern India that belongs to the Asteraceae family, can only germinate over a narrow pH range of 5 to 7, indicating a lesser capacity of this weed to invade agricultural lands with slightly alkaline soils (Ramirez *et al*. 2012).

Table 8. Effect of accelerated ageing (at 45°C and 60% RH) on germination and seedling growth of golden crownbeard incubated at 15°C with a 24-h photoperiod for 15 days

Accelerated ageing (days)	Time to start germination (days)	Mean germination time (days)	Germination speed	Seedling vigor index
0	2.00±0	4.03±0.13	8.83±0.61	388.7±15.3
1	2.00±0	4.60±0.21	7.37±0.89	230.0±9.88
4	3.00±0	5.71±0.47	4.99±0.49	121.7±8.69
7	3.00±0	8.67±0.58	1.28±0.09	42.3±6.04
10	4.00±0	8.73±0.58	0.82±0.04	14.2±3.25
20	-	-	-	-
30	-	-	-	-
45	-	-	-	-
60	-	-	-	-
LSD (α=0.05)	0.13×10^{-5}	0.96	0.79	38.9

Data are mean ± standard error of three replicates

Effect of burial depth

Maximum germination (95%) of golden crownbeard seeds was recorded at the soil surface and emergence was reduced by 84% at 4 cm soil depth. The burial depth required for 50% inhibition of emergence of golden crownbeard was 2.1 cm (**Figure 3**). No seedling emergence was observed when seeds were buried in the soil profile deeper than 4 cm. Germination of golden crownbeard decreased with increased seed burial depth. Similar observation on decreased emergence of *S. oleraceus* with increased burial depth has also been reported (Chauhan *et al.* 2006). The highest emergence of *S. oleraceus* (77%) was recorded with seeds placed on the soil surface, whereas seedling emergence was reduced to 38, 22, 3 and 1% at burial depths of 1, 2, 3 and 4 cm, respectively. Seedling emergence was completely inhibited when seeds were buried at a depth of 5 cm. In contrast to *V. encelioides*, seeds of *Ambrosia artemisiifolia* L. and *Bidens alba* (weeds of the Asteraceae family) recorded 16.7 and 18% emergence when buried at the soil depth of 6 cm (Dinelli *et al.* 2013, Ramirez *et al.* 2012). However, the inability of golden crownbeard seeds to emerge from deep soil layers could be due to smaller seed size {1000 seed weight (without wings) = 1.38 g, 1000 seedweight (with wings) = 1.84 g}, and thus having limited food reserves. Therefore, farming practices such as no-till and minimum tillage may promote greater seedling emergence of *V. encelioides*.

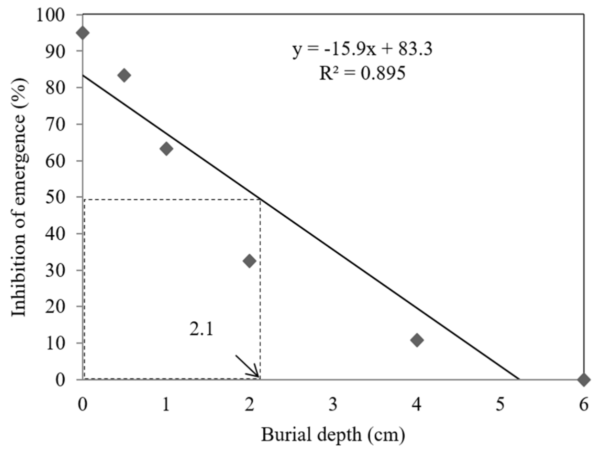

Figure 3. Effect of burial depth on seedling emergence of golden crownbeard. Burial depth required for 50% inhibition of emergence is shown by an arrow. Mean temperature during the months of December and January was 15.4 and 12.3°C, respectively.

Seed ageing

Accelerated ageing of the seeds caused considerable reduction in germination and seedling vigor of golden crownbeard. The P_{50} value for 50% inhibition of maximum germination due to accelerated ageing was 4.11 days. On the 10th day of ageing, germination of seeds was reduced to only 13% as compared to 86.7% germination of the control (**Figure 4**). The average germination time increased with a concomitant decrease in germination speed

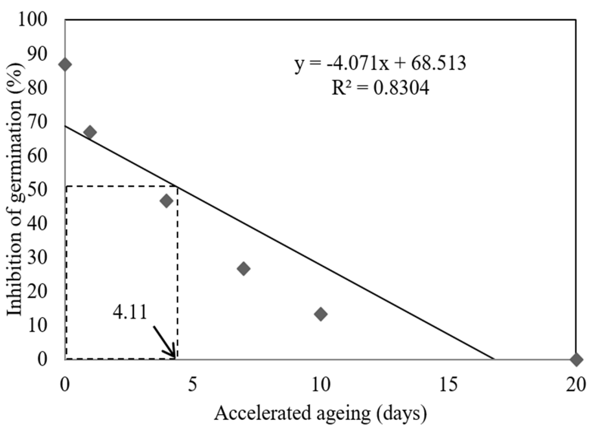

Figure 4. P_{50} value for 50% inhibition of maximum germination due to accelerated ageing of golden crownbeard is shown by an arrow.

due to accelerated ageing. Mean germination time increased almost two-fold on the 10th day of ageing, coupled with a 90.8% decrease in the speed of germination as compared with the control (**Table 8**). The process of seed ageing reduced golden crownbeard germination, which may be attributed to decreased starch and total soluble protein content of seeds, with a concomitant increase in the amount of total soluble sugars and total free amino acids (**Figure 5 and 6**).

Accelerated ageing is a process in which seeds are subjected to moist conditions and high temperatures under controlled conditions in the laboratory. No germination was observed when golden crownbeard seeds were aged for 20 days or more, indicating limited persistence of seeds. Based on the controlled ageing test (CAT), 13 species of emerging and common weeds of Queensland were assessed for their seed longevity. The seed longevity data of these species was linked with field seed-persistence, based on which Long *et al.* (2008) reported a positive correlation between controlled ageing conditions and field seed persistence. They categorized the weed species into three types for describing seed bank persistence: transient (<20 days to reach P_{50} with field persistence < 1 year), short lived (P_{50} value of 20-50 days with 1-3 years field persistence) and extended persistence (P_{50} value of > 50 days with > 3 years field persistence). Our results indicate that *V. encelioides* is not expected to buildup persistent seed banks like other weeds, *viz.* *Chenopodium album* L. and *Capsella bursa-pastoris* (L.) Medicus, which can persist for more than 20 years (Gulden and Shirtliff 2009). The process of ageing reduced content of starch and total soluble proteins, with a concomitant increase in the amount of total soluble sugars and total free amino acids in the seeds of golden crownbeard. Similar results were reported by Ravikumar *et al.* (2002) for the effect of accelerated ageing on sugar, starch, protein and amino acid content of *Dendrocalamus strictus* (Munro) Kurzseeds.

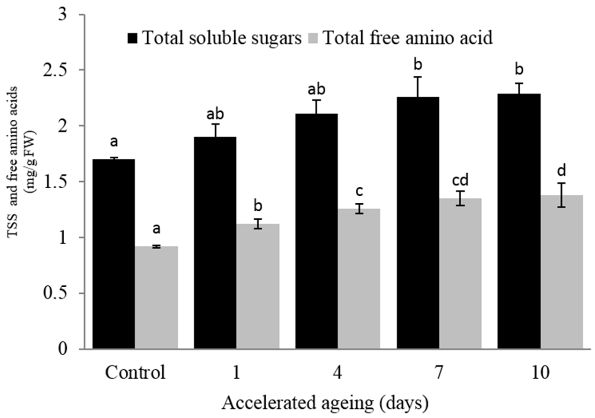

Figure 5. Effect of accelerated ageing on total soluble sugars and total free amino acids in golden crownbeard seeds. Vertical bars represent standard errors of the means. Means followed by common letters do not differ significantly at 5% level of significance

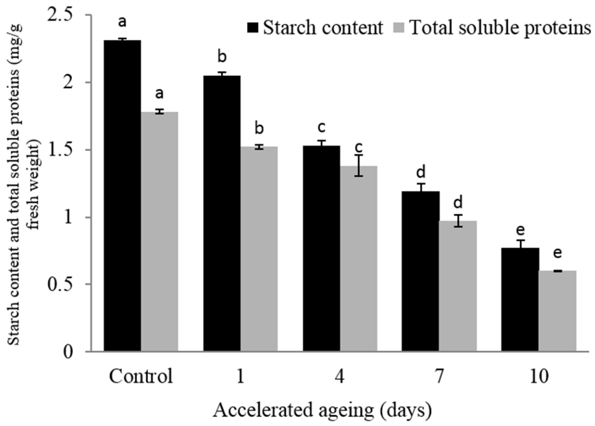

Figure 6. Effect of accelerated ageing on starch and total soluble protein content in golden crownbeard seeds. Vertical bars represent standard errors of the means. Means followed by common letters do not differ significantly at the 5% level of significance

The results of our studies showed the ability of this weed to germinate over a wide temperature range, favoring multiple flushes of this weed throughout the year. The study on accelerated ageing indicates that seeds of golden crownbeard may not have long-term persistence under field conditions. However, more studies under field conditions are needed to determine the fate and persistence of seeds of this weed.

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Phyto-sociological attributes of weed flora in brown mustard growing areas of temperate Kashmir valley

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ABSTRACT

A study on weed flora was conducted to evaluate the weed species distribution across different brown mustard (*Brassica rapa* var. brown *sarson*) growing areas of Kashmir valley during *Rabi* (2016-17 and 2017-18). The occurrence of weed species was assessed on the basis of different phyto-sociological attributes, *viz*. weed species density, relative density, relative frequency and importance value index. These were computed from the data collected during the month of March. In all twenty weed species were identified of which sixteen were broad-leaved. The crop was highly infested with the weed species of Poaceae family with the dominance of *Poa annua* (IVI of 84.9, 50.6 and 44.1 in Pulwama, Anantnag and Kulgam, respectively). Among the broad-leaved weeds, *Veronica persica* was the most dominant species found in Budgam with the abundance value of 17.25 and IVI of 34.5. Budgam had the highest weed species distribution with Simpson's diversity index (D) of 0.120123.

INTRODUCTION

Rapeseed-mustard occupies a pivotal position among oilseed crops in India. Belonging to the family brassicaceae, this group of oilseeds is an important source of edible oil, and ranks third after soybean and oil palm in terms of area and production in the world (Adnan *et al.* 2013). India has a growing demand for vegetable oil and fats to feed its ever increasing population with an estimated demand of 58 million tonnes (mt) by 2020 (Mittal 2008). In Jammu & Kashmir, rapeseed-mustard occupies an area of 0.05 million hectares with the production of 0.03 mt and productivity of 0.59 t/ha (Anonymous 2016). Brown mustard (*Brassica rapa* var. brown *sarson*) is an important and only winter *(Rabi)* season oilseed crop which fits well in rice-based cropping system of Kashmir. Since the crop is sown in the second week of October, the temperature after sowing dips low, enforcing the rosette formation in the crop, and subsequent crop growth gets slowed down, making a congenial environment for the weeds. Being a long duration crop (about 7-8 months), weeds severely compete with the crop for different resources, causing a significant decline in crop productivity to the extent of 10-70% depending upon type, intensity and duration of competition(Bijarnia *et al.* 2017). As the distribution and infestation of each weed is different, the extent of yield reduction will mainly depend on the type of the weed, its intensity and the stage of crop growth. In order to devise a cost-effective weed control strategy in brown mustard, it is worthy to know the floristic composition of weeds and their intensity and frequency. Thus, an attempt was made to investigate the weed flora and species diversity across different districts of Kashmir valley.

MATERIALS AND METHODS

The study was carried out in south (Anantnag, Kulgam and Pulwama) and central districts (Budgam) of Kashmir valley (**Figure 1**), located in the north of Himalaya at 73R˝ 45'- 75R˝ 35' E longitude, 32R˝ 25'- 34R˝ 55' N latitude and altitude of 1450-7,000 m above mean sea level. The sites had a varied topography with temperate climate, having moderate summer temperature of up to 37 R˝C and harsh winter with mercury dipping down to -10 R˝C. The surveys were conducted in brown *sarson* growing areas in the month of March during *Rabi* season of (2016-17 and 2017-18) under ICAR-AICRP-R&M, when the crop resumed growth after experiencing harsh winters with the temperatures dipping as low as -5.8 ^{fÀ}C (Singh *et al.* 2007). Weed survey was carried out using the quantitative survey method of Thomas (1985). The observations were recorded in the cropped field from each district at three locations. Quadrates of 50 × 50 cm were thrown randomly within each plot at three spots. The weeds within each quadrant were uprooted, sorted into species, identified, counted and recorded. Data were subjected to important quantitative analyses such as density, frequency, relative frequency, relative density, importance value index (IVI) and abundance using the following formulae given by Curtis and McIntosh (1950). IVI was used to determine the overall importance of each species in the community structure. Simpson's diversity index (D), Simpson's index of diversity (1-D), and Simpson's reciprocal index (1/D) were also computed.

$$\text{Density} = \frac{\text{Number of species}}{\text{Area of quadrant}}$$

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

$$\text{Relative density} = \frac{\text{Density of species}}{\text{Total density of all the species}} \times 100$$

$$\text{Importance value index (IVI)} = \text{Relative Frequency} + \text{Relative Density}$$

$$\text{Abundance} = \frac{\text{Relative Frequency} + \text{Relative Density}}{2}$$

$$Simpson\ diversity\ index\ (D) = \frac{\sum n\,(n-1)}{N(N-1)}$$

Where, n = the total number of weeds of particular species and N = the total number of weed of all species.

Where, D = Simson diversity index

$$\text{Simpson's reciprocal index} = \frac{1}{D}$$

$$\text{Simpson's index of diversity} = 1 - D$$

RESULTS AND DISCUSSION

Weed survey in brown mustard growing areas of different districts (**Figure 1**) revealed a total of 20 weed species belonging to fourteen families (**Table 1**). Poaceae represented maximum number of species (4) and proportional abundance of 0.2 and was followed by Asteraceae, Brassicaceae and Caryophyllaceae with two species each and proportional abundance of 0.01 (**Table 2**). The rest of the families contained single species, each representing proportional contribution of 0.05 of the total relative abundance. Further, it was observed that brown mustard fields were highly infested by the weeds of Poaceae family with proportionate share of 20%, followed by Caryophyllaceae and Brassicaceae (**Figure 2**). With regard to morphology, the weed infestation was dominated by sixteen broad-leaved weed (BLW) species (80.0%), three grass species (Poacae, 15.0%) and one sedge species (Cyperaceae, 5.0%). The dominance of BLW species could be attributed to higher colonizing power owing to their higher seed production potentials and efficient means of seed dispersal (Oluwatobi and Olorunmaiye 2014). *Arenaria serpyllifolia, Fumaria parviflora, Poa annua*, *Capsella bursa-pastoris* and *Stellaria media* were common in all the four districts, which could be attributed to their acclimatizing ability over a wide range of ecological conditions. Similar results were observed by Karaye *et al.* (2007) who reported that weed species had a wide range of adaptability in growth habitat. Greater diversity in weed species was recorded in Anantnag, Kulgam and Budgam as evidenced from more number of species (**Table 1**). Variability was observed in weed diversity across the locations studied. *Poa annua*, the most prolific weed in brown *sarson*, recorded the highest IVI value of 84.9, 50.6, 44.1 in Pulwama, Anantnag and Kulgam, respectively, whereas *Veronica persica* in Budgam preceded (34.5) by *Poa annua* (31.3). This was in conformity with the earlier report of Singh *et al.* (2007), who reported the highest IVI of 51.0 for *Poa*

Figure 1. Districts surveyed under the investigation

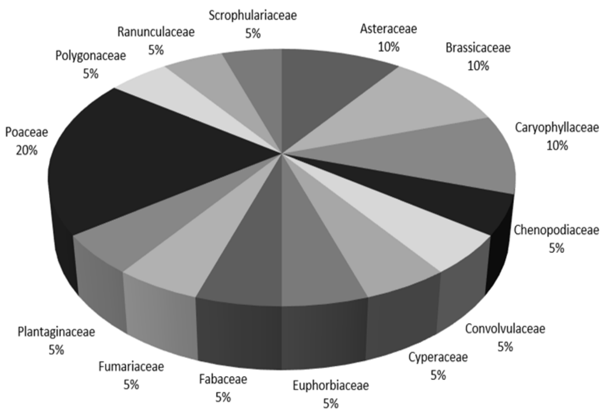

Figure 2. Proportion of weed infestation by different weed families

Table 1. Weed flora of brown *sarson* and its phyto-sociological attributes in south and central Kashmir (pooled data of 2 years)

Weed species	Anantnag				Kulgam				Budgam				Pulwama				Family	Group	Cotyledon
	Weed density/m2	Relative frequency(%)	Relative density(%)	IVI	Weed density/m2	Relative frequency(%)	Relative density(%)	IVI	Weed density/m2	Relative frequency(%)	Relative density(%)	IVI	Weed density/m2	Relative frequency(%)	Relative density(%)	IVI			
Arenaria serpyllifolia	14.3	8.5	9.9	18.4	12.3	9.0	10.9	19.9	12.0	3.0	13.3	16.3	60.0	24.4	21.9	46.4	Caryophyllaceae	BL	D
Capsella bursa-pastoris	1.7	7.6	1.1	8.7	2.3	8.0	2.0	10.0	3.0	6.0	3.3	9.4	64.0	5.8	23.3	29.2	Brassicaceae	BL	D
Chenopodium album	2.4	7.6	1.7	9.2	1.7	8.0	1.5	9.6	-	-	-	-	-	-	-	-	Chenopodiaceae	BL	D
Convolvulus arevensis	1.9	7.6	1.2	8.9	2.4	9.0	2.2	11.1	-	-	-	-	-	-	-	-	Convolvulaceae	BL	D
Conyza canadensis	-	-	-	-	-	-	-	-	3.33	9.1	3.7	12.8	-	-	-	-	Asteraceae	BL	D
Coronopus didymus	-	-	-	-	-	-	-	-	15.0	9.1	16.7	25.7	-	-	-	-	Brassicaceae	BL	D
Cynodon dactylon	3.9	8.5	2.7	11.2	2.8	9.0	2.2	11.5	3.0	6.0	3.3	9.4	-	-	-	-	Poaceae	G	M
Cyperus rotundus	-	-	-	-	-	-	-	-	16.0	3.0	17.8	20.8	-	-	-	-	Cyeprceae	S	M
Euphorbia hispida	2.5	7.6	1.8	9.4	3.1	8.1	2.7	10.9	-	-	-	-	-	-	-	-	Euphorbiaceae	BL	D
Fumaria parviflora	-	-	-	-	-	-	-	-	3.6	15.1	4.0	19.1	12.5	24.4	4.6	28.9	Fumariaceae	BL	D
Matricaria chamomilla	4.1	7.6	2.9	10.5	3.2	9.0	2.9	11.8	-	-	-	-	-	-	-	-	Asteraceae	BL	D
Plantago lanceolata	2.3	7.2	2.0	9.2	2.1	7.6	1.4	9.1	-	-	-	-	-	-	-	-	Plantaginaceae	BL	D
Phalaris minor	2.7	9.0	2.4	11.3	1.7	6.8	1.2	7.9	-	-	-	-	-	-	-	-	Poaeceae	G	M
Poa annua	46.8	9.0	41.7	50.6	51.7	8.4	35.6	44.1	12.0	18.1	13.3	31.3	132.6	36.6	48.4	84.9	Poaeceae	G	M
Polygonum hydropiper	12.2	9.0	10.9	19.9	14.8	8.4	10.2	18.6	-	-	-	-	-	-	-	-	Polygonaceae	BL	D
Ranunculus arvensis	22.6	8.4	20.1	28.4	30.8	7.9	21.3	29.1	-	-	-	-	-	-	-	-	Ranunculaceae	BL	D
Rumex acetosa	-	-	-	-	-	-	-	-	4.0	6.0	4.4	10.5	-	-	-	-	Poaeceae	BL	D
Stellaria media	15.5	8.4	13.8	22.1	14.2	7.9	9.8	17.7	3.5	6.0	3.9	9.9	2.0	5.8	0.7	6.6	Caryophyyllaceae	BL	D
Veronica persica	-	-	-	-	-	-	-	-	14.66	18.2	16.3	34.5	-	-	-	-	Scrophulariaceae	BL	D
Vicia sativa	-	-	-	-	-	-	-	-	-	-	-	-	3.0	24.4	1.1	25.5	Fabaceae	BL	D

*Broad-leaved = BL *Sedge= S *Grass =G

Table 2. Proportional contribution to relative abundance for fourteen taxonomic families (pooled data of 2 years)

Taxonomic family	No. of species	Proportion of abundance
Asteraceae	2	0.10
Brassicaceae	2	0.10
Caryophyllaceae	2	0.10
Chenopodiaceae	1	0.05
Convolvulaceae	1	0.05
Cyperaceae	1	0.05
Euphorbiaceae	1	0.05
Fabaceae	1	0.05
Fumariaceae	1	0.05
Plantaginaceae	1	0.05
Poaceae	4	0.20
Polygonaceae	1	0.05
Ranunculaceae	1	0.05
Scrophulariaceae	1	0.05
Total	20	0.99

annua in brown mustard grown across different altitudes in Kashmir. Similarly, *Poa annua* recorded the highest relative frequency and relative density at all the locations (**Table 1**).

Higher number of weed species were recorded in Anantnag and Kulgam followed by Budgam whilst it was the least in Pulwama. (**Table 1**). The possible reason might be the type of crop rotation prevalent in the study sites as in Pulwama the farmers were observed to follow the sequences of rice-brown *sarson* and rice-oats in comparison to the other districts having the only crop sequence of rice-brown mustard. Inclusion of oats in place of brown *sarson* in alternate years might have smothered the current weed species over the years and disturbed the weed seed bank, resulting in less number of weed species in brown mustard in comparison to other districts.

The study further revealed that the family Poaceae represented the highest number of species, with higher abundance of *Poa annua* in Anantnag and Kulgam followed by that of *Ranunculus arvensis*. However, it was followed by *Arenaria serpyllifolia* in Pulwama. At Budgam, *Veronica persica* represented higher dominance value, and was closely followed by *Poa annua* (**Figure 3**). This variation in the dominance of *Poa annua* and *Veronica persica* in south and central districts of Kasmir valley might be attributed to variation in soil fertility and soil texture as *Poa annua* was found to dominate in the areas of fertile soil with high organic matter and *Veronica persica* in heavy textured soils (Vahdati *et al.* 2017).

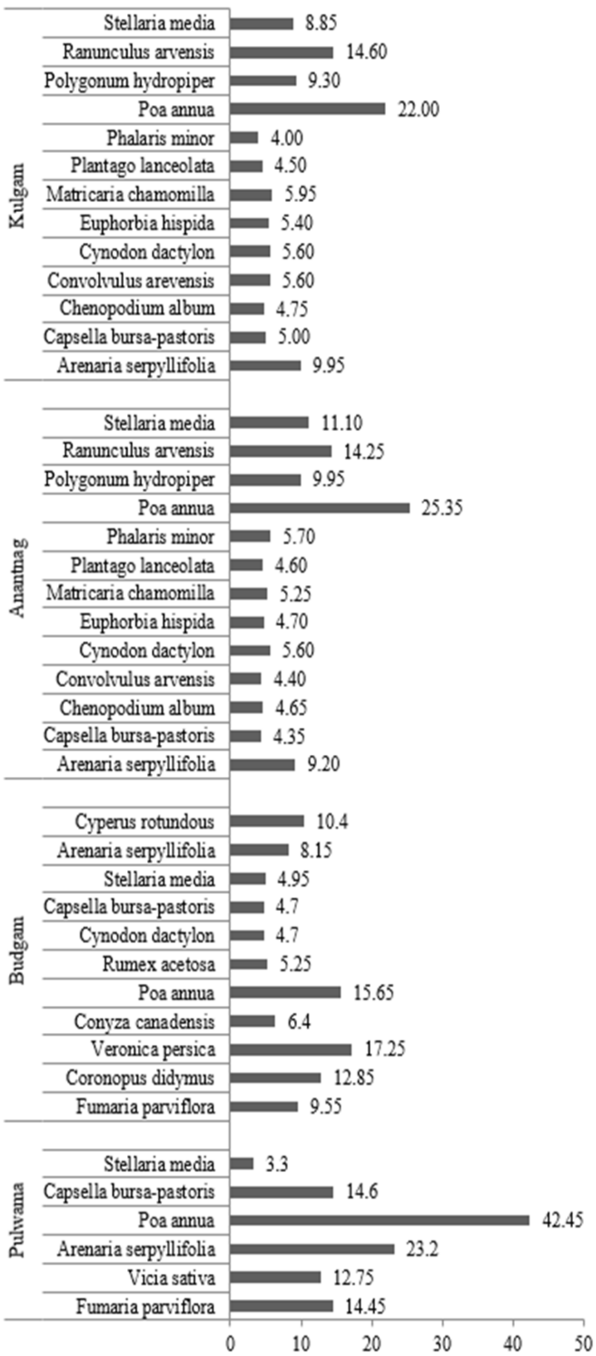

Figure 3. Abundance of weed species in brown mustard fields of south and central districts of Kashmir

The highest distribution of weed species was recorded from Budgam district as reflected by lower Simpson's diversity index (D = 0.120123), higher Simpson's index of diversity (0.879877) and Simpson's reciprocal index (8.324774). The lower the value of D or higher the values of (1-D) and (1/D), the greater is the diversity (**Table 3**). The decrease in weed diversity in brown mustard fields of Pulwama was due to less number of weed species observed (**Table 1**).

Table 3. Weed species diversity in different districts of Kashmir valley

Location	Simpson's diversity index	Simpson's index of diversity	Simpson's reciprocal index
Pulwama	0.336295	0.663705	2.973583
Budgam	0.120123	0.879877	8.324774
Anantnag	0.183963	0.816037	5.435861
Kulgam	0.201595	0.798405	4.960447

The study demonstrated that weed infestation in brown *sarson* fields of Kashmir valley was highly dominated by Poaceae family, with *Poa annua* as the most dominant weed.

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Effect of herbicides on weed control and potato tuber yield under different tuber eye orientations

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ABSTRACT

Weed management and planting methods in potato cultivation affect the tuber yield and quality significantly, and hence, requires proper management. Therefore, to explore the possibilities of developing a pre-emergence (PE) herbicide application system for potato planter specially for cut seed pieces (tubers) a study was conducted at ICAR-Directorate of Weed Research (DWR) during *Rabi* season of 2017-18 and 2018-19. The study includes different sprout-eye orientation of the potato tubers along with different weed management practices. The application of metribuzin at 0.75 kg/ha as PE effectively controlled the weeds and obtained a weed density of 2.43 and 2.04 weeds/m^2 and weed dry biomass of 1.35 and 1.64 g/m^2 respectively at 25 and 55 DAP. By application of the metribuzin as PE and paraquat as early-post emergence (PoE), the tuber yield was increased from 9-16.5%. The sprout-eye orientation has significant effect on tuber yield. The tuber yield was reduced by 28.3% and 16.7% respectively, in 270^0 sprout-eye orientation and random dropping over sprout-eye orientation of 90±30^0. The highest tuber yield of 28.4 t/ha was obtained in planting of whole tuber having the size of 40 to 50 g per tuber. The application of metribuzin as PE effectively controlled the weeds, thus a PE applicator system can be developed along with the potato planter.

INTRODUCTION

Potato (*Solanum tuberosum L.)* is a most important food crop in the world and India ranks second in production of 51.3 million tonnes (Anonymous 2018). Indo-Gangetic Plains comprising of Uttar Pradesh, West Bengal, Bihar, Punjab and Haryana produces 80% of the total potato (Anonymous 2006). The production process of the potatoes is mainly depends on cultivation and weed management practices. The wider row spacing, frequent irrigations, use of manures and fertilizers favour the environment to early appearances of the weeds before germination of the tubers, and causes the tuber yield loss by 40-65% or even more in some cases (Singh *et al.* 2002). Thus, an effective weed management is required to reduce the tuber yield loss. The traditional manual and mechanical weed management involves human drudgery and becomes costlier compared to chemical weed management (Chethan and Krishnan 2017, Chethan *et al.* 2018a, Kumar *et al.* 2019). Different weed management practices have followed in potato cultivation; however the chemical management of the weeds has become popular because of its ease, economic and effective control of the weeds (Tomar *et al.* 2008, Kaur *et al.* 2016, Chethan *et al.* 2018b&c).

At present application of herbicides and planting of potatoes are done separately as two different operations. The effective control of weeds in potato cultivation by pre-emergence (PE) herbicides gives a possibility to develop a PE applicator along with the planter. Thus, labor required to apply PE herbicides and cost of potato cultivation may be get reduced. Therefore, a study has been conducted at ICAR – Directorate of Weed Research (DWR), Jabalpur to explore the possibilities to develop PE herbicide application system for potato planter especially developed for potato cut seed pieces.

MATERIALS AND METHODS

The experiment was conducted during the *Rabi* season of 2017-18 and 2018-19 at the research farm of ICAR-DWR, Jabalpur (23°13'57.3"N 79°58'14.4"E). The study site comes under the subtropical region with average rainfall of 1386 mm and evaporation of 1502mm.Soil properties of the study site had low organic carbon with clay loam texture having pH of 7.6 and bulk density of ~1.3 g/cm^2. The experiment was conducted in split plot design and replicated thrice.

The potato (v. *Kurfi Jyoti*) crop was cultivated with the three different weed management practices along with five different tuber sprout eye orientation treatments. The treatment was conducted in a plot having the dimensions of 6 × 7 m^2 area and the total area of potato crop cultivation was obtained by multiplying the number of treatments with treatment plot area. The weed management practices involved the application of metribuzin at 0.75 kg/ha as PE (Channappagoudar *et al.* 2007), paraquat at 0.5 kg/ha as early post-emergence (PoE) and control. The metribuzin was applied immediately after the planting of the potato tubers. Later, 4 hours of application of the metribuzin, a light irrigation for about two hours was provided through the sprinkler system. This treatment was conducted to simulate the condition which will be obtained during planting of potatoes by potato planter followed by irrigation and application of PE herbicides. In this condition, assumptions were made that, the metribuzin was applied along with the planter through PE application system. The paraquat was applied after five per cent germination of the planted tubers. The tubers germination was measured by placing a quadrant of size 2×5 m^2 randomly within the plot and then counting the germinated tubers. Two earthing-up operations, one at 25 days after planting (DAP) and another at 55 DAP (Sharma *et al.* 2012) was followed at all the treatments to support the potato plants and to ensure a proper soil environment for tuber growth and development. The control treatment does not involve any weed control activities except the recommended two earthing-up operations. The weed flora obtained within the treatment plots was measured by placing a quadrant of size 0.5×0.5 m^2 randomly over a field and recorded the data. The weed dry bio mass was estimated as per the standard procedure. The weed data was recorded at different intervals, such as at 25 and 55 DAP before earthing-up operations.

The potato tuber placement treatment involves the five different sprout-eye orientation of the tuber such as, 90±30^0, 0 or 180^0, 270^0, random drop and whole tuber. The whole tuber was cut longitudinally into two equal halves (Kabir *et al.* 2004, Hossain *et al.* 2011) and the size of the cut tubers varied from 25 to 30 gram per cut piece, whereas, whole tuber size varies from 40 to 50 gram per tuber. The random drop and the whole tuber was selected on the assumption that, the existing potato planters are planting the both cut and whole tubers, just by randomly dropping into the furrow. During dropping of the tubers randomly, the sprout-eye orientation was not maintained upward direction, and it was reported that due to random dropping yield reduction was the major issue (Sharma and Singh 2005). The tubers were planted on the ridges 60×20 cm spacing during *Rabi* season of 2017-18 and 2018-19. The tuber yield data was recorded by placing a quadrant of size 2×5 m^2 randomly within the plot at 120 DAP. The number of tubers obtained per unit area under different tubers was also recorded. Based on the performance of the treatments at field condition a PE applicator for potato planter specially developed for potato cut tubers will be developed.

RESULTS AND DISCUSSION

Effect on weeds

The treatment plots were heavily infested with *Medicago denticculata* followed by *Avena fatua, Rumex dentatus, Sonchus* sp., *Chenopodium ficifolium, Chenopodium album, Phalaris minor* and others. All the herbicides treatments significantly reduced the weed density and weed dry bio mass compared to the control treatments, where control treatments only contained two earthing-ups (Kaur *et al.* 2016). The earthing-up operation was followed in both tuber placement and weed management treatments to support the potato plant for tuber growth and as well as to control the weeds. After the application of herbicides as explained in materials and methods portion, the weed data was recorded at 25 DAP and 55 DAP of potato tubers *i.e.* before first and second earthing-up operations. Toxicity effect on the germinated tubers at initial stages in paraquat applied treatments was observed. At 25 DAP, it was observed that the highest weed density of 6.00 and 6.49 weeds/m^2 was recorded in control plots followed by paraquat applied plots (4.25 and 4.34 weeds/m^2) and metribuzin applied plots during 2017-18 and 2018-19, respectively. Similarly the weed dry biomass was also the highest in the control plots (3.59 and 3.84 g/m^2) followed by paraquat and metribuzin applied plots during 2017-18 and 2018-19. The least weed density of 2.43 weeds/m^{2}and weed dry biomass of 1.35 g/m^2 (pooled values) were obtained in the plots where metribuzin was applied at 25 DAP. Thus, the application of metribuzin at 0.75 kg/ha was effectively controlled the weeds. As like in 25 DAP, the similar type of results were also recorded at 55 DAP of potato tubers. However, it has seen that the first earthing-up operation followed in the treatments have controlled the weeds to some extent (**Table 1** and **2**). The highest weed density of 2.59 and 2.72 was recorded in the control treatments followed by paraquat and metribuzin applied treatments. The weed density values observed in the paraquat applied treatments was at par with control treatments. These values were differed from the metribuzin treatment because of the effective control of the weeds at germination level. This effect combined with the first earthing-up operation further lead to the significant control of the weeds. The same may be seen when it compared with the values obtained at 25 DAP. However, the case was not same when it was compared to the weed dry biomass obtained at 55 DAP. A significant difference in controlling the weeds was seen as the weed dry biomass obtained varied among the weed controlling treatments. A highest weed dry biomass of 4.56 and 5.03 g/m^2 was obtained in control treatments followed by paraquat (3.19 and 2.63 g/m^2) and metribuzin (1.61 and 1.67 g/m^2) applied treatments during 2017-18 and 2018-19, respectively. The effect of different weed management on weed control at 25 DAP and 55 DAP given seen in **Table 1** and **2**. Similarly, the effect of tuber placement on weed control can be seen in the tables. The similar type of results were also recorded by Mishra *et al.* (2002), Kaur *et al.* (2016). The tuber placement treatments, did not have any significant effect on weed control, however values obtained among the different tuber placement treatments varied due to the appearance of weed flushes in that particular plot. The findings were conforms with the findings of Singh *et al.* 2002, Mishra *et al.* 2002 and Tomar *et al.* 2008.

Effect on tuber yield

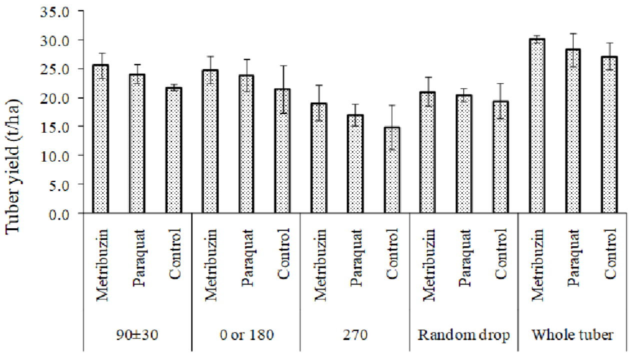
The tuber yield was significantly affected by both tuber placement (sprout-eye orientation) and weed management practices. Tuber yield was reduced significantly Practicing of recommended two earthing-up operations and obtained a very least tuber yield of 20.99 and 20.31 t/ha was recorded in control treatments during 2017-18 and 2018-19, respectively (**Table 3** and **Figure 1**). The pooled tuber yield for the treatments was 20.65 t/ha. But, by practicing the herbicide application, tuber yield was increased. It was seen that, 16.5 and 9% increase in tuber yield was obtained due to application of metribuzin and paraquat, respectively (**Figure 2**). Reduction in the tuber yield in paraquat treatments was due to its inefficacy to control the weeds effectively. The metribuzin was applied after planting of the tubers followed by sprinkler irrigation for two hours to create a situation as like in planting by the potato planter, controlled the weeds effectively. Thus, the application of metribuzin as PE was an effective weed control practice to increases the tuber yield. Therefore, an attachment for PE herbicide application in potato planter can be developed to reduce the weeding cost and time without compromising tuber yield.

The significant effect of sprout-eye orientation on potato tuber drastically reduces the tuber yield, which can be seen in **Table 3**, **Figure 1** and **3**. Downward placing of the tuber sprout-eye (270^0) recorded a very least tuber yield of 17.07 and 16.87 t/ha followed by the random dropping (20.35 and 19.08 t/ha), horizontal placing *i.e.* 0 or 180^0 (23.45 and 23.03 t/ha) and upward placing *i.e.* 90±30^0 (23.85 and 23.50t/ha) during 2017-18 and 2018-19, respectively. The lower yields in the downward placing of the tubers were may be due to the late

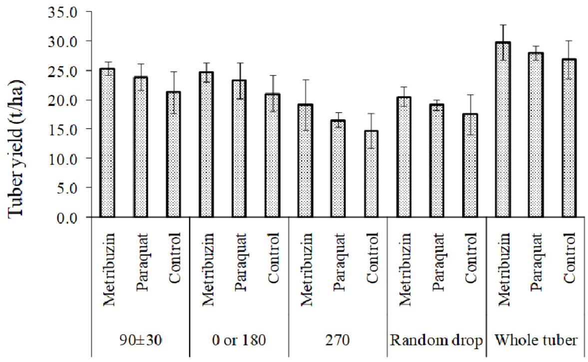
Table 1. Effect of treatments on weed density

Treatment	25 DAP			55 DAP		
	2017-18	2018-19	Pooled value	2017-18	2018-19	Pooled value
Sprout eye orientation						
90^0 ± 30^0	4.14 (20.1)	4.22 (20.6)	4.18 (20.3)	2.21 (4.7)	2.33 (5.3)	2.28 (5.0)
0^0 or 180^0	4.22 (22.0)	4.47 (23.8)	4.35 (22.9)	2.66 (7.1)	2.81 (7.6)	2.76 (7.3)
270^0	4.33 (21.2)	4.51 (22.4)	4.43 (21.8)	2.22 (4.7)	2.35 (5.3)	2.29 (5.0)
Random dropping	4.05 (21.2)	4.39 (22.9)	4.25 (22.1)	2.44 (5.7)	2.41 (5.6)	2.43 (5.6)
Whole tuber	4.22 (18.6)	4.65 (24.2)	4.48 (21.4)	2.43 (5.6)	2.21 (4.8)	2.36 (5.2)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Weed management						
Metribuzin 3 DAP (PE.) *fb* earthing-up	2.32 (5.4)	2.51 (5.9)	2.43 (5.7)	2.04 (4.1)	1.97 (3.6)	2.04 (3.9)
Paraquat (PoE) 5% of crop emergence *fb* earthing-up	4.25 (18.6)	4.34 (19.2)	4.31 (18.9)	2.53 (6.1)	2.58 (6.4)	2.56 (6.3)
Control	6.00 (37.9)	6.49 (43.2)	6.27 (40.5)	2.59 (6.3)	2.72 (7.1)	2.67 (6.7)
LSD (p=0.05)	0.88	0.70	0.73	0.42	0.37	0.29

Weed data subjected to square root transformation ($\sqrt{(x+0.5)}$; original values are in parentheses germination of tubers, poor growth, damage to sprout-eye and poor plant vigour. In random dropping of the tubers the probability of upward facing of the sprout-eye is very less and there will be maximum chances of getting the same results like in sprout-eye orientation at 270^0. There was 28.3% and 16.7% reduction in tuber yield for sprout-eye orientation at 270^0 and random dropping, respectively compared to the sprout-eye orientation at 90 ± 30^0. However, there was very little variation in tuber yield among the sprout-eye orientation at 90 ± 30^0 and 0 or 180^0 (**Figure 3**). It is might be because in both the treatments, sprout eye orientation was within the safer zone for healthier sprout development and plant vigour. The whole tuber treatment produced the highest tuber yield of 28.54 and 28.25 t/ha during 2017-18 and 2018-19, respectively even though it was dropped randomly from above the surface. It was mainly because that, the whole tuber contained the more number of sprout-eyes over it surface and



1.a Effect of treatments during 2017-18



1.b Effect of treatments during 2018-19

Figure 1. Effect of different treatment on potato tuber yield

Table 2. Effect of treatments on weed dry weight

Treatment	25 DAP			55 DAP		
	2017-18	2018-19	Pooled value	2017-18	2018-19	Pooled value
Sprout eye orientation						
90 ± 30^0	2.25(6.5)	2.39(7.5)	2.32(7.0)	2.25(5.3)	2.96(10.4)	2.66(7.8)
0 or 180^0	2.62(8.6)	2.78(9.8)	2.71(9.2)	3.12(13.0)	3.28(14.9)	3.20(14.0)
270^0	2.42(6.1)	2.58(7.0)	2.53(6.6)	2.78(9.6)	2.90(10.8)	2.85(10.2)
Random dropping	2.10(4.9)	2.23(5.6)	2.18(5.2)	3.01(9.4)	3.18(11.6)	3.14(10.5)
Whole tuber	2.37(5.6)	2.52(6.5)	2.48(6.1)	4.44(24.6)	3.24(13.4)	3.96(19.0)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Weed management						
Metribuzin 3 DAP (PE) *fb* earthing-up	1.29(1.4)	1.35(1.6)	1.35(1.5)	1.61(2.3)	1.67(2.6)	1.64(2.5)
Paraquat (PoE) 5% of crop emergence *fb* earthing-up	2.17(4.7)	2.31(5.3)	2.25(5.0)	3.19(11.2)	2.63(6.9)	2.99(9.0)
Control	3.59(13.0)	3.84(14.9)	3.73(14.0)	4.56(23.6)	5.03(27.2)	4.86(25.4)
LSD (p=0.05)	0.41	0.42	0.32	0.71	0.87	0.73

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

Table 3. Effect of different treatments on potato tuber yield

Treatment	Year wise tuber yield (t/ha)		Pooled yield (t/ha)
	2017-18	2018-19	
Sprout eye orientation			
90 ± 30^0	23.85	23.50	23.68
0 or 180^0	23.45	23.03	23.24
270^0	17.07	16.87	16.97
Random dropping	20.35	19.08	19.72
Whole tuber	28.54	28.25	28.40
LSD (p=0.05)	3.07	5.92	3.52
Weed management			
Metribuzin @ 3 DAP (PE) *fb* earthing-up	24.17	23.93	24.05
Paraquat(PoE) @ 5% of crop emergence *fb* earthing-up	22.80	22.20	22.50
Control	20.99	20.31	20.65
LSD (p=0.05)	1.83	2.47	1.63

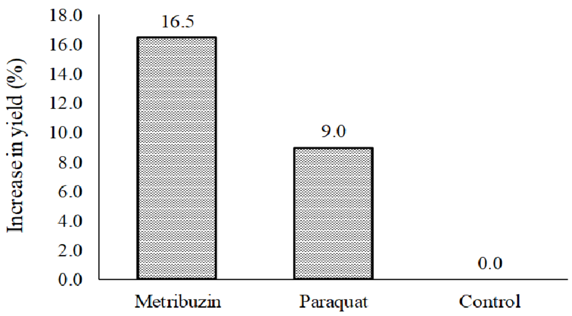


Figure 2. Percentage of increase in tuber yield due to weed management practices

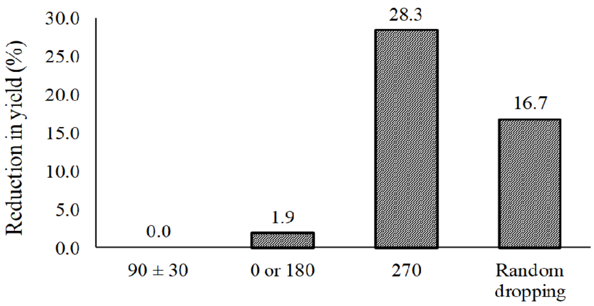


Figure 3. Percentage of reduction in tuber yield under different sprout-eye orientation

during dropping, one or the other sprout-eye might have orientated upward direction. More number of sprout-eyes helps more plant vigour and production of more number of tubers. The similar findings were also observed by Kabir *et al.* 2004 and Sharma and Singh 2005. The obtained results from the experiment showed that, application PE herbicide *i.e.* metribuzin effectively controls the weeds without compromising the tuber yield. Thus a PE applicator can be developed along with the planter for effective weed control.

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Allelopathic effect of sorghum and sunflower on *Phalaris minor* and wheat

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ABSTRACT

A field experiment was conducted in G.B Pant University of Agriculture and Technology, Pantnagar during *Rabi* season of 2018-19 to evaluate the bioefficacy of aqueous extracts of sorghum and sunflower on *Phalaris minor,* as well as their effects on yield and yield attributing characters of wheat. The experiment was carried out with eight treatments, each with three replications in randomized block design (RBD). Treatment with pre *fb* early post-emergence application of sunflower extract recorded highest weed control efficiency and yield among the treatments having aqueous extract application. Maximum WCE was recorded in pre *fb* early post-emergence application sunflower followed by pre *fb* early post-emergence application sorghum in every stages of observation. The grain yield of weedy, pre- *fb* early post-emergence application sorghum, pre- *fb* early post-emergence application sunflower, weed free plot was recorded as 2.33, 4.13, 4.38, 5.14t/ha, respectively.

Uncontrolled weeds caused 45.6% reduction in the grain yield of wheat as compared to weed free condition (Singh *et al.* 2001). Among all the weed species associated with wheat *Phalaris minor* is the most severe one and require a huge application of herbicides for its control (Om *et al.* 2002). *Phalaris minor* gradually developed resistance due to continuous application of herbicides to many of the conventional herbicides like isoproturon (Chhokar and Malik 2002).To tackle the emerging problem of herbicide resistance in *Phalaris minor* allelopathic approach can be a potential tool (Dimitrova 2008). In several experiments it is reported that both sorghum and sunflower have a very good allelopathic effect in controlling *Phalaris minor*, without hampering wheat crop (Cheema 1988, Naseem 1997).

An one year field experiment was conducted during *Rabi* season of 2018-19 at N.B Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand). The soil of the experimental site was clay loam in texture with 0.92% organic matter, and pH of 6.9. Available N, P and K content in the soil was 248.3, 27.7 and 182.4 kg/ha, respectively. Wheat variety '*DBW 17*' with seed rate of 100 kg/ha was sown manually in 20 cm row-row spacing. The seeds of *Phalaris minor* were broadcasted over the experimental area evenly and duly incorporated. Crop was fertilized with 120:60:40 kg N, P_2O_5 and K_2O/ha. P_2O_5 and K_2O were supplied asbasal and N was applied with three splits (50% basal, 25% at first irrigation, and 25% at second irrigation). The experiment was laid out in a randomized block design with three replications. The details of the treatments and their scheduling are given in **Table 1**. The aqueous extracts were applied at pre-emergence (1 DAS) and early post-emergence (10 DAS) using 400l/ha of water with knapsack sprayer fitted with a flat fan nozzle.

For preparing aqueous extract of sorghum and sunflower, the fresh biomass of these crops were dried under shade for one week and then dried at 65±5^{0}C in electric drier for 72 hours. After full drying, the biomass was ground finely in electric grinder. 10% (w/v) aqueous extract was prepared by dissolving 400 g of dried biomass powder in 4l of distilled water.

At the time of sampling (20, 40, 60 days after sowing and maturity; DAS), a quadrate of 50 × 50 cm^2 was placed at a fixed place in each plot to determine the dry weight of *Phalaris minor*. Dry weight was recorded after drying the samples at 65±5^{0}C for 72 h. Weed control efficiency was calculated based on the data recorded at 20, 40, 60 DAS and maturity in wheat as per standard formula. Number of spikes/m^2, spike length (cm), grains/

spike, 1000 grain weight (g), grains/panicle, grain and straw yield (kg/ha) was recorded just before harvesting. The grain and straw yield was recorded from net plot area of 1.2 m^2 area, and wheat grain yield was expressed at 12% moisture content.

Data were analyzed using statistical package STPR, developed by College of Basic Science and Humanities, GBPUA&T, Pantnagar. The data of *Phalaris minor* dry matter was square root transformed before analysis. The CD was provided at 5% level of significance.

Dry matter of *Phalaris minor*

Significant variation was observed with dry matter accumulation of *Phalaris minor* at 20 DAS. Significantly lowest dry matter accumulation was recorded in aqueous extract of sunflower 10% pre-*fb* early post-emergence application which was statistically at par with aqueous extract of sorghum 10% pre *fb* early post-emergence spray Control plot has significantly highest (1.69 g/m^2) dry matter accumulation of *Phalaris minor* than other treatments.At 40 and 60 DAS, lowest dry matter accumulation was under aqueous extract of sunflower 10% pre-emergence spray, followed by aqueous extract of sorghum 10% pre-emergence spray. The weed control efficiency was found maximum with application of aqueous extract of sunflower10% pre *fb* early post-emergence spray in every stage of the crop growth. This reveals that treatments with aqueous extracts of sunflower have better allelopathic effect on *Phalaris minor* in comparison to other treatments. The allelopathic effect of sunflower is due to allelochemicals like chlorogenic, caffeic, syringic, vanillic and ferulic acid (Ghafar*et al.* 2001). Dry matter accumulation had direct relation with number of shoots at every stage.

It can be observed that the WCE rapidly decreased after 60 DAS due to deterioration of the allelochemicals effect. Hence at maturity, two best performing treatments *i.e.* aqueous extract of sunflower10% pre *fb* early post-emergence spray and aqueous extract of sorghum 10% pre *fb* early post-emergence spray recorded lower weed control efficiency of 23.43 and 20.08% only respectively. These results were in agreement with the reports of Cheema *et al.* (1997), Cheema and Khaliq (2000) and Naseem (1997). Hence, an inference can be drawn that aqueous extracts of sunflower are more efficient in managing *Phalaris minor* population than that of sorghum for a longer period of time.

Wheat yield and yield attributing characters

Various aqueous extract of sorghum and sunflower treatments significantly affected the number of spikes per square meter. Weed free plot recorded significantly highest number of spikes per square meter and grain yield and was statistically at

Table 1. Effect of aqueous extracts of sorghum and sunflower (10%) on dry matter accumulation (g/m^2) of *P. minor*

Treatment	Dry matter accumulation (g/m^2) of *Phalaris minor*			
	20 DAS	40 DAS	60 DAS	At maturity
Control (no application)	1.69(1.92)	8.19(51.49)	12.25 (148.97)	20.90(436.51)
Sorghum (10%) PE	1.46(1.15)	6.19(37.63)	11.05(121.06)	18.98(359.56)
Sorghum (10%) EPoE	1.62(1.61)	7.08(48.12)	11.88(140.21)	20.35(413.09)
Sorghum (10%) PE *fb*EPoE	1.34(0.87)	5.33(29.47)	9.93(97.66)	18.70(348.84)
Sunflower (10%) PE	1.52(1.32)	6.37(40.70)	10.94(118.79)	19.21(368.37)
Sunflower (10%) EPoE	1.59(1.52)	6.76(44.97)	11.55(132.49)	20.22(408.16)
Sunflower (10%) PE *fb*EPoE	1.30(0.68)	4.03(22.23)	9.13(82.44)	18.30(334.29)
Weed free	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)
LSD (p=0.05)	0.20	0.18	0.24	0.92

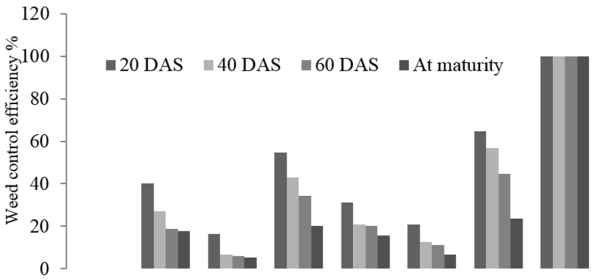
*Original values are given in parentheses; PE= pre-emergence; EPoE= early post-emergence

Table 2. Effect of aqueous extracts of sorghum and sunflower (10%) on yield attributes of wheat

Treatment	No of spikes /m^2	Spike length (cm)	No of grains/spike	Thousand grain weight (g)
Control (no. application)	322	9.98	18	41.16
Sorghum (10%) pre-emergence	436	10.34	27	41.39
Sorghum (10%) early post-emergence	411	10.15	25	41.54
Sorghum (10%) pre-emergence *fb* early post-emergence	452	10.10	29	42.68
Sunflower (10%) pre-emergence	449	10.31	29	41.37
Sunflower (10%) early post-emergence	422	10.28	27	42.56
Sunflower (10%) pre-emergence *fb* early post-emergence	476	10.21	31	42.31
Weed free	511	10.46	32	42.87
LSD(p=0.05)	100	NS	NS	NS

Table 3.Effect of aqueous extracts of sorghum and sunflower (10%) on yield of wheat

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Grain: straw ratio	Harvest index
Control (no. application)	2.33	3.37	5.68	0.70	0.41
Sorghum (10%) pre-emergence	3.88	4.78	8.66	0.83	0.45
Sorghum (10%) early post-emergence	2.92	3.58	6.50	0.87	0.46
Sorghum (10%) pre-emergence *fb* early post-emergence	4.13	5.30	9.43	0.80	0.44
Sunflower (10%) pre-emergence	3.57	4.73	8.30	0.76	0.43
Sunflower (10%) early post-emergence	3.32	3.61	6.93	0.92	0.48
Sunflower (10%) pre-emergence *fb* early post-emergence	4.38	5.56	9.73	0.82	0.45
Weed free	5.14	5.63	10.70	0.93	0.48
LSD(p=0.05)	0.77	1.54	1.98	NS	NS



T_1= Control (no. application); T_1= Sorghum (10%) pre-emergence; T_3= Sorghum (10%) early post-emergence; T_4= Sorghum (10%) pre-emergence *fb* early post-emergence; T_5= Sunflower (10%) pre-emergence; T_6= Sunflower (10%) early post-emergence; T_7= Sunflower (10%) pre-emergence *fb* early post-emergence; T_8= Weed free

Figure 2. Effect of aqueous extracts of sorghum and sunflower (10%) on weed control efficiency at various growth stages

par with aqueous extract of sunflower 10% pre-emergence *fb* early post-emergence spray.

The most probable reasons behind higher grain yield were higher dry matter production by wheat, higher weed control efficiency which ranged up to 23.04%, 12.08% and 17.63% under aqueous extractsunflower 10% pre-emergence *fb* early post-emergence spray, aqueous extract of sorghum 10% pre-emergence *fb* early post-emergence spray and aqueous extract of sorghum 10% pre-emergence spray and higher number of spikes per square meter.

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Effects of brown manure species, seed rate and time of application of 2,4-D on weed control efficiency, productivity and profitability in maize

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ABSTRACT

Weeds result in yield losses up to 40% in maize in India. Brown manuring can suppress weeds better and provide ecosystem services. It has been hardly studied in crops other than rice. It offers potential for adoption in maize, but needs to be optimized because maize differs from rice in growth habit and architecture and has no tillering capacity. Therefore, this study was undertaken to optimize brown manuring option(s) that involved two brown manure species, their mixture and seed rates, and the times of application of 2,4-D. Results revealed that all brown manuring treatments suppressed noxious weed *Cyperus rotundus* better than the recommended tank-mixture of atrazine + pendimethalin. Among them, a brown manuring option that involved 1:1 mixture of *Sesbania bispinosa* (12.5 kg seed/ha) + *Crotalaria juncea* (12.5 kg seed/ha) + 2,4-D 0.5 kg/ha applied at 35 DAS resulted in highest reduction in weed density (~91%). Another brown manuring option, *i.e.*, *Sesbania* + *Crotalaria* (12.5+12.5 kg/ha) mixture and 2,4-D 0.5 kg/ha applied at 25 DAS gave similar weed suppression, and was superior to it on maize grain yield (~13.4%), gross return (~15.7%) and gross benefit:cost (~15.6%). This brown manuring would be a profitable weed management practice in maize. It may lead to sequester C and N in soil and provide ecosystem services as well.

Maize (*Zea mays* L.), the 'Queen of Cereals' is an emerging cereal crop, ranking third after rice and wheat in India with an area of 9.5 million ha and annual production of 24.5 million tonnes (Das *et al.* 2018). It, due to wider adaptability to diverse environments and seasons, could be a potential driver for diversification of the most dominant rice-wheat system in the Indo-Gangetic Plains (IGP) of India (Hobbs and Gupta 2003, Humphreys *et al.* 2010). Maize productivity in India, however, is about half of the world average due to several biotic and abiotic stresses. Wider spacing, initial slower crop growth, and higher nutrients and water requirement of maize provide an ideal microclimate to weeds for stronger interference from the early stages (Susha *et al.* 2018). The sole use of herbicides may lead to shift and resistance of weeds. Besides, the lack of effective sedge killing herbicides, and usually less tolerance of maize plants to most post-emergence herbicides suggest that herbicides cannot be fool-proof strategy for weed management. Rather, efficient weed management strategy needs to be explored through integration of herbicides with other alternative options.

Brown manuring (BM) is a practice of growing *Sesbania*/*Crotalaria* as co-culture with a crop for a short period of 25-30 days after sowing (DAS), and then, killing by the application of post-emergence herbicides selective to the crop of prime interest (Tanwar *et al.* 2010, Maitra and Zaman 2017). It decreased weed density by 40-50% (Rehman *et al.* 2007), 37-42% (Singh *et al.* 2009) and 41-56% (Nawaz *et al.* 2017) in rice through concurrent/smothering and residual (allelopathic) effects and reduce herbicide usage (Gupta and Seth 2007, Ramachandran *et al.* 2012). Several workers (Singh *et al.* 2008, Kumar and Mukherjee 2008, Dubey 2014, Seema *et al.* 2015, Sen *et al.* 2018) have reported better weed suppression through BM in rice. Maize being a cereal crop is selective to 2,4-D, which offers opportunities for adoption of BM in maize. But, maize unlike rice is a non-tillering crop and might suffer from interference by the brown manure plants at the initial stage (0-30 DAS) that could affect the emergence, plant stand, crop growth and, ultimately yield of maize. Hence, BM in maize requires to be optimized in terms of seed rate of BM species individually or in mixtures, and time and dose of 2,4-D application for an optimum balance between maize and BM species apart from the weed control effects of BM.

This experiment was conducted at the ICAR-Indian Agricultural Research Institute, New Delhi, India during the rainy season of 2017 in maize under natural infestations of weeds to assess the impacts of brown manuring on weed control efficiency and maize crop productivity and profitability, The experiment had 12 treatments including eight BM treatments laid out in a randomized complete block design with three replications. The plot size was 5 m (along the rows) x 4.9 m (across the rows). The BM treatments included two brown manure species (*Sesbania bispinosa*; *Crotalaria juncea*) sown at two seed rates (15 and 25 kg/ha) as sole or mixture (1:1). The BM plants were knocked down at two stages (25 and 35 DAS) using 2,4-D at 0.5 kg/ha. Four controls, namely, unweeded control (UWC), weed-free control (WFC), pre-emergence tank mixture of pendimethalin 0.75 kg/ha + atrazine 0.75 kg/ha (*i.e*., recommended herbicides control), and atrazine 0.75 kg/ha + hand-weeding (HW) at 35 DAS (*i.e*., farmers practice control) were also adopted in this study. All BM treatments were applied with a common pre-emergence application of pendimethalin 1.0 kg/ha to control initial flushes of weeds. The maize variety '*PMH 1*' was sown at 70 cm (row to row) x 30 cm (plant to plant) spacing with a seed rate of 20 kg/ha on July 13, 2017. An area of 90 cm (along one row) x 70 cm (both sides of the row, *i.e*., one row-width) was randomly selected from the central rows in each plot at 60 DAS and weeds species were collected from that area. Individual weed species were counted and categorized into grassy, broad-leaved and perennial *Cyperus rotundus* L. (~nutsedge) weeds. Weed samples were sun-dried for 2 days and kept in an oven at 70 ± 5°C for 48 h for recording weed dry weight (Das 2001), which is considered a reliable estimate for evaluating weed control effects of the treatments. Having recorded the densities and dry weights of weeds collected/sampled from the above-mentioned areas, weed control efficiency (WCE) was determined (Das and Yaduraju 2012). Maize cobs were harvested manually from the net plot areas and grain yield was recorded at 15% moisture content (Oyeogbe *et al*. 2018). The minimum support price of maize grains was used for calculating economics. The gross returns (GR), and gross benefit:cost (GB:C) were worked out as per Das and Das (2018). Weed data on density and dry weight having greater coefficient of variation than 20%, were transformed through square-root $(x+0.5)^{1/2}$ method (Das 1999), and the transformed weed data were used for the ANOVA (Pal and Sarkar 2015).

Trianthema portulacastrum L. (Horse purslane) among broad-leaved weeds; *Acrachne racemosa* Heyne ex Roem Ohwi (Goose grass) among grassy weeds; and *Cyperus rotundus* L. (purple nutsedge) among sedges were dominant weed species in the experimental maize field. Besides, *Commelina benghalensis* L. (tropical spiderwort); *Digera arvensis* Forsk. (false amaranth); *Amaranthus viridis* L. (slender pigweed); *Setaria glauca* (L.) Beauv. (Yellow foxtail); and *Cynodon dactylon* (L.) Pers. (Bermuda grass) was present at lower frequencies. There was a significant reduction in density of broad-leaved weeds (~97%), grassy weeds (~94%) and total weeds (~92%) due to the atrazine + HW at 60 DAS (**Table 1**). The reduction was comparable with those observed in the BM treatments such as *Sesbania* + *Crotolaria* (1:1) mixture 12.5+12.5 kg/ha with 2,4-D applied at 35 DAS, *Sesbania* 25 kg/ha with 2,4-D applied at 25 DAS, and *Sesbania* + *Crotolaria* (1:1) mixture 12.5+12.5 kg/ha with 2,4-D at 25 DAS. In atrazine + HW treatment, the vigorously growing maize crop canopy suppressed grassy and broad-leaved weeds effectively and led to greater reduction in weed interference. Hand weeding, however, incurred more cost, and could not control the problematic perennial sedge *Cyperus rotundus* effectively. But, the *Sesbania* + *Crotolaria* (1:1) mixture 12.5+12.5 kg/ha with 2,4-D applied at 35 DAS (~2.7/m²) resulted in 90% reduction of this weed compared to the unweeded control. The other treatments, namely, the *Sesbania* 25 kg/ha with 2,4-D applied at 25 DAS, atrazine +HW, and *Sesbania* + *Crotolaria* (1:1) mixture 12.5+12.5 kg/ha with 2,4-D applied at 25 DAS were comparable with it. There was a poor control (~21%) of *Cyperus rotundus* due to the application of tank-mixture of atrazine + pendimethalin, which was as similar/inferior as the unweeded control. The physical interference of BM species capturing space early, and/or allelopathic effects might have played roles. Besides, some activities of 2,4-D against tender *C. rotundus* plants, although less known/ reported, cannot be ignored.

In this study, kinds of weeds, BM species, and the time of application of 2,4-D influenced the overall weed control efficacy of the treatments. Among the treatments of mixed stand of BM species, the treatment having 2,4-D application at 35 DAS was superior to that having at 25 DAS. The prolonged space capture by BM species in the former BM mixture, probably, led to slightly higher WCE than the latter (Behera and Das 2019). These BM mixtures were comparable with the atrazine + HW, which, among the weed control treatments, was most effective against weeds. The overall positive effect of BM might be due to early space capture, higher growth rate and biomass accumulation, and larger canopy cover of BM species, leading to better suppression of weeds, particularly late-emerging weeds through live and dead residues/mulches.

The weed-free control, atrazine + HW, *Sesbania* + *Crotalaria* (1:1) at 25 kg/ha with 2,4-D applied at 25 DAS; *Sesbania* 25 kg/ha with 2,4-D applied at 25 DAS and pendimethalin + atrazine treatments **(Table 1)** gave 69.4, 65.4, 63.2, 61.2 and 47.3% higher maize grain yield, respectively than the unweeded control (3.53 t/ha), and the grain yields were comparable. Higher grain yield in the atrazine + HW could be attributed to greater maize biomass (source), which was mobilized to the reproductive parts (sink). Lower crop-weed interference in this treatment (discussed above) shifted the balance in favour of maize. The 25 kg seed of BM species/ha (sole or mixture) as against 15 kg/ha; and prolonged space capture for 35 DAS as against 25 DAS under the BM mixture *Sesbania* + *Crotalaria* (1:1) at 25 kg/ha with 2,4-D applied at 35 DAS gave better weed suppression *vis-à-vis* offered greater interference with maize during the initial 35 DAS. Probably, this might be the reason why this BM mixture in spite of having better weed suppression, gave lower grain yield than the other BM mixture, which had slightly lower but comparable weed suppression. This suggested that the optimum BM combination in terms of seed rate of brown manure species mixture and time of 2,4-D application could be the 1:1 mixture of *Sesbania* (12.5 kg/ha) + *Crotalaria* (12.5 kg/ha) and 2,4-D 0.5 kg/ha applied at 25 DAS. This BM intervention likely offered greater interference against weeds but less-limiting interference on maize by the brown manure species during initial stages of growth, thus, providing competitive advantage to the maize crop against weeds. Sharma *et al.* (2008) reported that the yield of direct-seeded rice with *Sesbania* brown manuring (~3.65 t/ha) was comparable with conventional transplanting (~3.69 t/ha) and significantly higher than direct-seeding without brown manuring (3.24 t/ha).

The atrazine + HW fetched lower gross returns by 2,300 `/ha, but 13.7% higher gross benefit:cost than the WFC (**Table 1**). The weed-free control, atrazine + HW, *Sesbania* + *Crotalaria* (1:1) at 25 kg/ha with 2,4-D applied at 25 DAS, *Sesbania* 25 kg/ha with 2,4-D applied at 25 DAS and pendimethalin + atrazine tank-mixture were similar with each other on gross returns, and gross benefit: cost. This suggested that the *Sesbania* + *Crotalaria* (1:1) mixture with 12.5 + 12.5 kg seed per ha and 2,4-D applied at 25 DAS might be as profitable as the herbicide mixture, herbicide + HW, or complete weed-free control (WFC). Kumar and Mukherjee (2008) also reported similar results that the butachlor 1.5 kg/ha as pre-plant surface application + brown manuring with *Sesbania rostrata* + 2,4-D 0.50 kg/ha treatment resulted in highest net returns and benefit:cost in rice.

The combined analysis of variance (ANOVA) was done for weed density and dry weight, weed

Table 1. Effect of brown manuring/weed control treatments on category-wise and total weed density, and weed control efficiency (WCE) at 60 DAS, maize grain yield, gross return and gross benefit:cost

Treatment	Weed density (no./m^2)§			Total weed density (no./m^2)§	WCE (%)	Grain yield (t/ha)	Gross returns (x10^3 `/ha)	Gross benefit: cost
	Broad-leaved	Grassy	*Cyperus rotundus*					
Sesbania 15 kg/ha 2,4-D at 25 DAS*	4.8 (23.3)†	5.7 (32.0)†	5.5 (29.3)†	9.2 (84.6)†	71.9	4.84	80.9	2.51
Sesbania 25 kg/ha 2,4-D at 25 DAS*	2.7 (8.7)	3.9 (14.7)	3.4 (12.0)	5.9 (35.4)	87.9	5.69	92.9	2.85
Crotalaria 15 kg/ha 2,4-D at 25 DAS*	5.5 (30.7)	6.9 (48.7)	6.4 (40.7)	10.9(120.1)	63.8	4.55	76.9	2.38
Crotalaria 25 kg/ha 2,4-D at 25 DAS*	5.1 (26.0)	6.0 (36.0)	5.8 (34.0)	9.8 (96.0)	69.4	4.79	80.1	2.44
Crotalaria 15 kg/ha 2,4-D at 35 DAS*	5.3 (28.7)	6.5 (41.3)	6.0 (36.0)	10.3 (106.0)	67.0	4.73	79.5	2.46
Crotalaria 25 kg/ha 2,4-D at 35 DAS*	4.2 (18.0)	4.9 (23.3)	5.1 (25.3)	8.2 (66.6)	79.2	5.15	86.2	2.62
Sesbania + *Crotalaria* mixture (12.5+12.5 kg/ha) 2,4-D at 25 DAS*	3.3 (10.7)	4.1 (18.7)	4.0 (15.7)	6.7 (45.1)	86.2	5.76	94.4	2.89
Sesbania + *Crotalaria* mixture (12.5+12.5 kg/ha) 2,4-D at 35 DAS*	2.7 (7.3)	3.4 (11.3)	2.7 (7.3)	5.1 (25.9)	91.1	5.08	81.6	2.50
Atrazine + pendimethalin	4.1 (16.7)	3.5 (12.7)	7.4 (54.7)	9.2 (84.1)	73.9	5.20	87.2	2.85
Atrazine + HW	2.2 (4.7)	2.6 (6.7)	3.6 (12.7)	4.9 (24.1)	91.9	5.84	95.7	2.90
Unweeded control	12.0 (146.7)	10.5 (110.0)	8.3 (69.3)	18.0 (326.0)	0.0	3.53	63.3	2.26
Weed-free control	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	100.0	5.98	98.0	2.55
LSD (p=0.05)♣	1.8 (25.2)	1.5 (17.7)	1.3 (15.6)	2.0 (46.5)	8.9	0.77	11.6	0.36

*All brown manuring treatments were applied with a pre-emergence application of pendimethalin 1.0 kg/ha. §Data presented are $(x+0.5)^{1/2}$ transformed values; †Figures in parentheses are original values; ♣LSD, least significant difference at p=0.05

Table 2. Analysis of variance for various parameters of weeds and crop yield observed in this study

Source	DF	Weed density (no./m^2)	Weed dry weight (g/m^2)	Weed control efficiency (WCE) (%)	Grain yield (t/ha)
Replication(R)	2	-	-	-	-
Treatments (T)	11	37.26*	32.72*	71.84*	6.88*
Contrasts					
Sesbania BM *vs* pendimethalin + atrazine	1	NS	NS	NS	NS
Sesbania BM *vs* atrazine + HW	1	9.75*	8.20*	10.35*	NS
Sesbania BM *vs* unweeded control	1	150.65*	152.83*	460.79*	29.28*
Sesbania BM *vs* weed-free control	1	-	-	-	NS
Crotalaria BM *vs* pendimethalin + atrazine	1	NS	NS	NS	NS
Crotalaria BM *vs* atrazine + HW	1	39.59*	33.33*	42.25*	12.51*
Crotalaria BM *vs* unweeded control	1	111.80*	118.92*	421.86*	18.84*
Crotalaria BM *vs* weed-free control	1	-	-	-	16.12*
Mixture BM *vs* pendimethalin + atrazine	1	21.56*	10.16	15.61*	NS
Mixture BM *vs* atrazine + HW	1	NS	NS	NS	NS
Mixture BM *vs* unweeded control	1	292.01*	197.51	566.10*	34.75*
Mixture BM *vs* weed-free control	1	-	-	-	NS

DF = Degrees of freedom; *Sesbania* BM treatment = *Sesbania* 15 kg/ha 2,4-D at 25 DAS and *Sesbania* 25 kg/ha 2,4-D at 25 DAS; *Crotalaria* BM treatment = *Crotalaria* 15 kg/ha 2,4-D at 25 DAS, *Crotalaria* 25 kg/ha 2,4-D at 25 DAS, *Crotalaria* 15 kg/ha 2,4-D at 35 DAS and *Crotalaria* 25 kg/ha 2,4-D at 35 DAS; Mixture BM treatment = *Sesbania* + *Crotalaria* mixture (12.5+12.5 kg/ha) 2,4-D at 25 DAS and *Sesbania* + *Crotalaria* mixture (12.5+12.5 kg/ha) 2,4-D at 35 DAS; NS= non-significant; * = significant at p=0.05.

control efficiency (WCE), and maize grain yield (**Table 2**). The effects of treatments (8 BM + 4 controls) and three kinds of contrast [*Sesbania* BM vs controls; *Crotalaria* BM vs controls; and Mixture BM vs controls] were analyzed. It was observed that *Sesbania* and *Crotalaria* BMs individually was comparable with the pendimethalin + atrazine, but inferior to atrazine + HW treatments in terms of weeds suppression. However, the 1:1 mixture of *Sesbania* and *Crotalaria* (BM) was superior to pendimethalin + atrazine as well as was comparable with the atrazine +HW in this regard. This indicated that the mixture BM had lower weed density, dry weight, higher weed control efficiency and led to better weed suppression. This was reflected on the maize grain yield. The sole *Crotalaria* BM was inferior to the atrazine + HW and weed-free control, but was comparable with the pendimethalin + atrazine on maize grain yield. In this regard, the sole *Sesbania* BM and the 1:1 mixture of *Sesbania* and *Crotalaria* BM were comparable with the three controls (*i.e.*, weed-free control; atrazine + HW; pendimethalin + atrazine) adopted in this study. But, the contrast analysis revealed that the mixture BM was superior to the sole *Sesbania* and *Crotalaria* BMs with respect to weed suppression and maize yield enhancement and proved to be the best BM option.

This study shows that BM although poses slight interference to maize during first 25 DAS, can be an effective management practice for diverse weeds, including noxious *Cyperus rotundus* without significant penalty on maize yield. A combination of 1:1 mixture of *Sesbania bispinosa* and *Crotalaria juncea* (12.5 + 12.5 kg/ha) and 2,4-D 0.5 kg/ha applied at 25 DAS would be the best possible BM practice in maize for higher weed control efficiency, maize crop productivity and profitability. This may be adopted in maize under irrigated and rainfed conditions across the States of the North-western Indo-Gangetic Plains of India and in similar agro-ecologies of the tropics and sub-tropics.

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Seed germination response of an invasive weed *Alternanthera ficoidea* to temperature and salinity stress

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ABSTRACT

Alternanthera ficoidea (Sanguinarea) (Amaranthaceae) is an exotic weed that has widely spread in most of the terrestrial habitats including saline soils under different climatic conditions. Seed germination is an important stage in seedling establishment and maintaining health and vigour of every plant. Seed germination studies were carried out under temperature and salinity stress. Weed seeds showed adaptation to temperature as well as salinity stress in laboratory as well as field conditions. Such type of adaptation may be one of the reasons for rapid spread and establishment of this weed.

Worldwide biological invasion became a serious threat to native agriculture and natural ecosystems. Seed germination is an important development phase, playing a key role in seedling establishment and overall environmental adaptation in the life cycle of plant. High vigour seed is necessary to obtain fast and better establishment of seedling providing essential nutrients until it can photosynthesize independently. Frequency, amount of precipitation, seed germination and growth of seedlings during decrement of soil moisture and osmotic potentials, affects successful establishment of seedlings. Plants have a remarkable ability to cope up with extremely variable environmental stresses, including cold, drought, soils with changing salt and nutrient concentrations (Kreps *et al*. 2002). Drought and salinity are the two major environmental factors that reduce plant productivity. Temperature and salinity stress to invasive weeds were widely studied (Ebrahimi and Eslami 2011).

A. ficoidea, an exotic weed belongs to family Amaranthaceae, introduced from Tropical America is widely spread and established in most of terrestrial habitats all over India posing threat to biodiversity. Negative allelopathic effects on greengram and sorghum seed germination due to leaf leachets of *A ficoidea* were previously reported (Patil and Kore 2017). It produces numerous small seeds and propagates rapidly vegetatively as well as by seeds and becomes a successful invader. Seed germination is one of the most important life-stages contributing to the ability of a plant to became invasive. Acclimatisation to broad range of environmental conditions to germinate seeds rapidly is a crucial characteristic of invasive species. Investigation on effect of temperature and salinity stress on seed germination in *A. ficoidea* facilitates understanding invasive characteristics and adaptability of this weed to abiotic stress conditions studied.

Germination percentage alone does not reflect the speed or pattern of germination. Hence other germination indices, *viz*. rate, speed, percentage, vigour, establishment of the germinated seeds with addition to germination percentage made determination of germination potential of the seed. Lower the mean time for germination (MTG), faster the development of a population through seed germination. Coefficient of velocity (CVG), is an indication of rapidity of germination. Seedling length vigour index and seedling weight vigour index are the tests for vigour measurement.

In this study, eleven germination indices like germination percentage, radicle length, plumule length, seedling fresh weight, seedling dry weight, mean time for germination (MTG), mean daily germination (MDG), coefficient of velocity(CVG), seedling length vigour index(SLVI) seedling weight vigour index (SWVI) and daily germination speed (DGS) were studied. These parameters helped in comparison, interpretation and confirmation of results.

Experiments were carried out during 2015-2017 in triplicate. Thoroughly washed 10 seeds were kept in each sterilized Petriplate (9 cm diameter) lined with filter paper. For salinity stress, the filter papers in Petriplates were moistened with 10 ml solution of NaCl (10, 20, 30 and 40 m M concentrations). For temperature stress seeds were placed in air tight glass vials and were treated with high (60 ^{0}C) and low (4 ^{0}C) temperature, once for 24 h. before germination. These treated seeds then placed on germination paper moistened with D.W.

Untreated seeds were placed in Petriplates which lined with moistened filter papers by D.W. considered as control. Experiments were arranged in triplicates by using seed germination chamber at 26 °C with natural light and dark period. Finally, ten normal seedlings were selected randomly and average root and shoot length per seedling, and dry and fresh weight per 10 seedlings were recorded. In order to evaluate germination time and speed, Petri dishes were checked daily and number of germinated seeds were recorded. By daily counting of germinated seeds, seed germination and seedling vigour indices were calculated on 7th day as following:

Final germination percentage (FGP): (Scott *et al.* 1984)

FGP=Final number of seeds germinated in a seed lot × 100

Mean time to germination (MTG): Mean time to germination is an index of seed germination speed and velocity (Orchard 1977) and calculated by:MTG= $\sum(n\ d) / \sum_n$

n : number of germinated seeds during seven days,d :number of day(s),

$\sum_n$: total of germinated seeds

Mean daily germination (MDG): (Roberts 1981)

This is an index of daily germination speed and calculated by MDG = FGP/d

FGP: final germination percent,d: test period

Daily germination speed (DGS): This index is converse of mean daily germination and calculated by DGS=1/ MDG

Coefficient of velocity of germination (CVG): (Jones and Sanders 1987)

This is another index of seed germination speed and velocity and calculated by: CVG= $[(G_1+G_2+G_3+...+G_n)] / [(1\times G_1)+(2\times G_2)+(3\times G_3)+...+(n\times G_n)]$

G_1-G_n: number of germinated seeds from the first to the last day

Daily Germination Speed (DGS): Daily Germination speed calculated by this formula (ISTA 1999).DGS =(number of normal seedlings/ Days to days to first count) +...+ (number of normal seedlings/days to final count)

Seedling vigour index: After measuring shoot and root length, fresh and dry weight of seedlings, weight and length vigour indices, were determined by using following formulae:

Seedling length vigour index (SLVI)= (mean shoot length + mean root length) × FGP.

Seedling weight vigour index (SWVI)/10seedlings= mean seedling weight × FGP

Most invasive plants primarily relay on seed dispersal and seedling recruitment for population establishment and persistence. Rapid spread of many invasive plants frequently correlated with germination and dormancy pattern. In nature, all living organisms including weeds frequently exposed to unfavourable environmental conditions that have adverse effects on their survival. Natural stress limit proliferation of weeds up to a certain extent.

Successful establishment of a plant species is dependent on adaptive mechanisms of seed germination and seedling growth. Seedling establishment is a critical stage in crop production and considerably depends on biochemical and physiological structures of seed. Seeds have the highest resistance to adverse environmental conditions during life cycle of a plant. They may be more sensitive to stresses than mature plants because of exposure to the dynamic environment close to the soil surface.

Salinity, drought stress biology and plant or seed responses at different levels have been discussed over two decades (Chauhan and Johnson 2009). Effect of salinity stress on germination of seeds of *A. ficoidea* are represented in **Table 1** and temperature stress in **Table 2.** Different indices were studied for clear interpretation and comparison of results.

Salinity stress on seed germination

Reducing trend in germination per cent and seedling performance was observed. A considerable variation in all the germination attributes such as germination percentage and rate as well as seedling fresh and dry weights under salt stress was observed (**Table 1**).

CVG and MTG showed very minute effect. Seeds require higher amount of water uptake during the germination under salt stress and there is increase in osmotic pressure due to the accumulation of the soluble solutes around the seeds .This causes excessive uptake of ions which results in toxicity in plant (Jones 1986). Osmotic and toxic effects of the salts have been implicated in the inhibition of the germination (Machado Neto *et al.* 2004).

With increasing salinity level, germination per cent, seedling length and weight, MDG and SLVI were gradually decreased and are inversely proportional to salinity stress. This gradual declination was effect of reduction in ability to absorb water for germination, scarcity of nutrients for development of embryo as well as adverse effect of salinity on cell division and cell elongation.

The minimum SLVI and SWVI in all of the salinity levels were observed than that of control. Salt stress inhibited the seedling growth, but root length was more affected than shoot length. The reduction in growth observed in many plants subjected to salinity stress, is often correlated with salt-induced osmotic effect, nutrient deficiency or specific ion toxicity (Munns 2002). His work supports present results. Growth and survival of plants at elevated salinity levels depends on adaptation to stumpy water potentials and high sodium concentrations. DGS increased showed fluctuations as water imbibition and germination capacity of the seeds declined with increasing salt concentrations.

The maximum germination results are observed in control than stress conditions. The root and shoot lengths are the most important parameters for salt stress, as roots are in direct contact with soil and absorb water from soil and supply it to the rest of the plant. With increasing salinity level, the length of root and shoot of seedling was decreased. Interaction of salinity and root, shoot and seedling length was also showed a highly significant difference. Apparently ion active uptake by roots against concentration gradient needs energy, so it may be one of the reasons for decrease in root length under salinity treatments

Temperature stress to seed germination

Temperature is an important factor for growth. Even though plants grow within very wide range of temperature, there may be difference in requirement of optimum temperature. More or less temperature than optimum value adversely affects seed germination. Seeds of *A. ficoidea* treated with temperature stress depicts (**Table 2**) inhibition of germination per cent, seedling length and weight, MTG, MDG, SLVI and SWVI. Gradual decrease in the above germination indices is more in hot stress than cold stress, possibly due to destruction of embryo and denaturation of enzymes required for germination .While due to cold stress, the enzyme activity may be trigger to increase germination per cent. More seedling fresh weight in hot stress could be due to growth of seedling than cold stress .

Seedling length and fresh weight is affected more in cold stress whereas hot stress showed unnoticible effect, this might be due to some genetic factors as this weed acclimatizes to hot climatic conditions from its native region. Length of seedling was less at lower temperature as cell division and cell elongation process might have affected. Vigour index and speed of germination decreased as germination capacity affected. Seedling length and fresh weight affected more in cold stress whereas hot stress showed very minute effect might be due to some genetic reasons as this weed acclimatizes to hot climatic conditions from it's native region.

Table 1. Effect of salinity stress on seed germination

Parameter / Stress	FG %	Radicle length mm	Plumule length mm	Seedling f. w.mg/10 seedlings	Seedling d.w. mg /10 seedlings	MTG	CVG	MDG	DGS	SLVI	SWVI/10 seedlings
Control	98.2±0.8	25±3	32±3	104±4	9 ±2	1.15±0.05	0.2±0.01	14.1±0.6	0.065±0.01	560±27	10.21± 0.4
10 mM NaCl	84±2	20±2	25±3	62±6	6±3	0.9±0.04	0.2±0.01	12±0.7	0.08±0.01	227±11	5.2±0.3
20mM NaCl	73±3	20±1	22±2	53±7	5±2	1.02±0.04	0.19±0.1	10.4±0.5	0.095±0.01	175±10	3.9±0.2
30mM NaCl	71±3	15±3	18±2	52±5	4±2	0.6±0.05	0.22±0.1	10.1±0.5	0.098±0.01	138±12	3.7±0.2
40mM NaCl	65±2	15±2	17±2	51±2	2±2	0.68±0.03	0.24±0.1	9.28±0.4	0.107±0.01	120±13	3.3±0.2

Table 2. Effect of temperature stress on seed germination

Indices / Stress	FG %	Radicle length mm	Plumule length mm	Seedling f.w. mg/10 seedlings	Seedling d.w.mg/10 seedlings	MTG	CVG	MDG	DGS	SLVI	SWVI/10 seedlings
Control	98.2±0.8	25±3	32±3	104±4	9 ±2	1.15±0.05	0.2±0.1	14.1±0.6	0.065±0.01	560±27	10.21±0.4
Cold(4 ^{0}C)	98±0.2	23±2	28±1	95±5	6±3	0.87±0.02	0.21±0.1	14±0.2	0.071±0.01	500±22	9.31±0.5
Hot (60^{0}C)	79.5±0.5	24±2	30±1	79.5±0.5	5±3	0.76±0.01	0.21±0.1	13.7±0.1	0.067±0.01	528±25	9.97±0.45

Length of seedling was less at lower temperature as cell division and cell elongation process might have affected. Vigour index and speed of germination decreased as germination capacity affected. DGS and CVG were inversely proportional to the MTG so it minutely increased from control to cold stress.

Seed germination decreases with increase in temperature showed signs of stagnation or decrease in seedling growth in important crops like maize, rice and sorghum reported by Lloh *et al.* (2014). According to Neelambari *et al.* (2018), germination percentage, root shoot ratio, fresh weight ratio decreased in some wheat varieties due to salinity and temperature stress.

A. ficoidea seed germination showed very minute effect of temperature stress as interpreted in **Table 2**. Negligible adverse effect of temperature stress shown by all germination indices studied proves its adaptability to temperature stress and potential to use as subsidiary food during scarcity.

Species with great plasticity and environmental tolerance may easily find suitable habitats in the introduced localities. Establishment of a plant species in high and low temperature area than optimum is related to germination response of seeds to temperature and early establishment usually decides population's survival to maturity.

Greater tolerance and adaptability exhibited by seeds of *A. ficoidea* to temperature and salinity stress. This may be one of the reason for invasiveness and rapid spread of this exotic weed in terrestrial habitats including saline soil as well as drastic temperatures. Different germination indices studied helped in comparison and confirmation of the results. This invasive weed may be used as an alternative to regular food during adverse conditions for removing scarcity.

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Degradation of pyrazosulfuron-ethyl in the agricultural soil by *Alternaria alternata*

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ABSTRACT

Herbicides are now used throughout the globe and a majority of applied chemicals enter into the soil to form short or long-term residues, resulting in toxicity to sensitive crops and adverse effects on human and other life forms. Therefore, present work was undertaken to isolate and identify pyrazosulfuron-ethyl degrading fungi from soil of rice field. *Alternaria alternata* was isolated and identified from rhizosphere soil of rice field, as a potent pyrazosulfuron-ethyl degrading fungus and its degradation potential was evaluated under controlled conditions. In the soil pyrazosulfuron-ethyl was efficiently degraded by *A. alternata*. Degradation of pyrazosulfuron-ethyl by *A. alternata* was achieved by the cleavage of sulfonylurea bridge and hydrolysis. *A. alternata* used in the study can effectively be used for the enhanced degradation of pyrazosulfuron-ethyl in agricultural soil or mixed with other microbial consortia for rapid degradation with half life of 7.9 days.

According to FAO (2016) estimate, an amount of 3.3 x 10^6 tones of active ingredient of pesticides is being used annually throughout the globe for management of various pests in agricultural and crop production. Use of sulfonylurea group of herbicides has been tremendously increased on a wide range of crops due to their very high herbicidal activity on broadleaf weeds and sedges in rice. This class of herbicides has low mammalian toxicities and categorized to toxicity category V (Zhu *et al.* 2002, Sondhia *et al.* 2013). Pyrazosulfuron-ethyl is frequently used in rice as pre-emergence and early post-emergence. It hampers weed growth through inhabitation of acetolactate synthase (ALS), the first enzyme that catalyzes the biosynthesis of branched amino acids valine, leucine, and isoleucine in the weeds. However, in rice, crop selectivity derives from rapid metabolism through the demethylation of the methoxy group in green plants. Some crops such as legumes and pastures are found to be very sensitive towards trace-level residues of sulfonylurea herbicides in different soils (Zhu *et al.* 2002, Sondhia 2008, Wang *et al.* 2012).

Due to large-scale commercial use of herbicides, a majority of these chemicals entered into the soil to form short or long-term residues and resulted in phytotoxicity to sensitive crops. In some studies, adverse effect of sulfonylureas to soil microbial population has also been reported (Xu *et al.* 2009). Besides this, application of herbicides including sulfonylureas in the agricultural fields also resulted in residues in surface and groundwater through runoff and leaching (Sondhia 2008, Xu *et al.* 2009).Alike other class of herbicides, sulfonylurea also detoxified in the agricultural soils mainly through microbial degradation (Huang *et al.* 2007, Sondhia *et al.* 2013, 2016).

Even though pyrazosulfuron would appear to be degraded fast in the soil, its widespread and repeated use showed adverse effects in direct-seeded and transplanted rice fields (Xu *et al.* 2009) and enhanced risk to environment and human health (Ding *et al.* 2010). In literature, degradation of pyrazosulfuron-ethyl by few bacteria such as *Pseudomonas* sp., *Pseudomonas putida*, *Acinetobacter* sp. and *Rhodopseudomonas* sp. S9-1 by Xu *et al.* (2009) and Yin *et al.* (2011) have been reported. Several fungi are known to produce enzymes that are able to degrade aromatic herbicides and have therefore been suggested as potential candidates for bioremediation (Huang *et al.* 2007, Sondhia *et al.* 2013). A large number of fungal species were found to be efficient to degrade phenylurea herbicides such as *Rhizoctonia solani*, *Bjerkandera adusta* and *Aspergillus* species

(Sondhia *et al.* 2013). Rønhede *et al.* (2005) demonstrated effective degradation of isoproturon by *Alternaria* species. But no information exists on the biodegradation of pyrazosulfuron-ethyl in the soil by *Alternaria alternata*. Therefore, in this study, degradation ability of pyrazosulfuron-ethyl in the soil by *Alternaria alternata* is reported.

Isolation of *Alternaria alternata* from rice field

Degradation experiments were done in sterilized soil under laboratory conditions. Sandy clay loam (67.32% sand, 10.00% silt, and clay 22.68%) soil with pH 7.4 and organic carbon 0.85% was collected in sterilizable polythene bags where pyrazosulfuron-ethyl was applied at a field dose of 25 g/ha continuously for three years. Samples were brought to the laboratory to isolate and identify pyrazosulfuron-ethyl degrading fungi. A commercial available formulation of pyrazosulfuron-ethyl 10% WP and analytical pyrazosulfuron-ethyl (99.5%) was purchased from United Phosphorus Limited Company, Gujarat. Analytical grade chemicals and solvents were obtained from (E Merck, Germany).

Alternaria alternata was identified in the Plant Pathology Department, JNKVV, Jabalpur. Isolation and enumeration of the fungi were done by a standard serial dilution and pour plate method. A dilution of 10^{-5} was used for inoculation of fungal media. Fungal isolates were identified and characterized on the basis of colony morphology and spore structures microscopy (Barnett and Hunter 1972). Seven days old fungal culture was maintained on sterilized potato dextrose agar (PDA) medium at 7±1°C to serve as a source of inoculums.

Degradation study of pyrazosulfuron-ethyl in the soil

The 3 mm sieved control soil (herbicide free) was air-dried and sterilized by autoclaving at 121°C for 25 minutes. For each treatment 1.0 kg of sterile soil was packed separately in sterilized polythene bags and moistened with sterile distilled water to 20% to permit good aeration. One kg of sterilized soil was inoculated with *Alternaria alternata* and incubated at 28°C for 3-days in the dark. After inoculation with fungus, herbicide was applied to the soil surface according to the treatments; soil + *Alternaria alternata* + pyrazosulfuron-ethyl at 4 mg/kg; soil + *Alternaria alternata* + pyrazosulfuron-ethyl at 8 mg/kg; and soil + pyrazosulfuron-ethyl without *Alternaria alternata* at 4 and 8 mg/kg .

Each treatment consisted of three replications. The soil sample from each set of experiments was drawn at 0, 5, 10, 20, 30 and 60 days to determine degradation of pyrazosulfuron-ethyl in the soil.

Determination of pyrazosulfuron-ethyl in soil

For extraction and analysis of the pyrazosulfuron-ethyl, a method of Sondhia *et al.* (2013) was followed. Recovery of pyrazosulfuron from soil at 0.01, 0.5 and 1.0 µg/g levels following this method was found to be 86-92% (**Table 1**). The limit of detection (LOD) of pyrazosulfuron-ethyl was determined as the minimum concentration of pyrazosulfuron-ethyl that was detected with acceptable certainty as described by Sondhia (2008). The LOD and the Limit of Quantification (LOQ) were found to be 0.001 and 0.01 µg/mL, respectively.

Table 1. Recovery of the pyrazosulfuron-ethyl from soil at 0.5 to 1.00 µg/g fortification level with a recovery of 86 to 92% in the soil

Matrix	Fortification (µg/g)	Amount recovered (µg/g)	Recovery (%)
Soil	0.01	0.009±0.002*	90
	0.50	0.46±0.013*	92
	1.00	0.86±0.015	86

*Standard deviation

Degradation products were identified as described by Sondhia *et al.* (2013) using TLC and LC/MS-MS. Pyrazosulfuron residues in the soil were determined by UFLC with Photo Diode Array Detector. A C-18 column (ODS) of 25 mm length and 3.6 mm i.d. was used. The mobile phase acetonitrile: water (70:30) was kept at a flow rate of 0.45 ml/min. The UFLC system was standardized by injecting 20µL of standard solutions of freshly prepared pyrazosulfuron-ethyl in ACN with varying concentrations (0.001 to 10 µg/mL from a stock solution of 1000 ppm) and the detector response was measured in terms of peak areas. Areas under the peak (µV/sec) versus concentrations (µg/mL) were plotted and fit by simple linear regression to obtain an equation for the standard curve. The amount of pyrazosulfuron-ethyl in each sample was thus calculated based on the slope of the standard.

The data were calculated as mean ± S.D. and analyzed using analysis of variance technique (ANOVA). All statistical analyses were done with Excel 2003. Differences are considered statistically significant when p d” 0.05. Rates of degradation of pyrazosulfuron-ethyl in the soil was calculated by linear regression from the transformed first order rate equation. The time of dissipation of 50 and 90 % (DT_{50}) was calculated from the equation DT_{50}= ln2/K, where K degradation rate constant.

Microbial degradation of pyrazosulfuron-ethyl in soil

After two hours (0-day) of treatment, pyrazosulfuron-ethyl residues were found to be 0.284 and 0.368 µg/g in the soil inoculated with *A. alternata* at 4 and 8 mg/kg doses, respectively. Pyrazosulfuron-ethyl residues degraded successively by the *A. alternata* and concentration decreased to 0.062 and 0.145 ìg/g after 30 days in the soil treated with 4 and 8mg/kg doses, respectively. The difference was found significant at all days and two set of treatments (p=0.05) Dissipation of pyrazosulfuron-ethyl residues by *A. alternata* at various days at different time interval is presented in **Figure 1** and **Table 2**.

Degradation parameters for pyrazosulfuron-ethyl residues were estimated in the soil inoculated with *Alternaria alternata* on the basis of first-order rate kinetics and regression equations. The degradation trends of pyrazosulfuron-ethyl residues on soil surfaces, determination coefficients, regression statistic and half-life times are shown in **Table 2** and **3**. Residues of pyrazosulfuron-ethyl in 4 and 8 mg/kg treatments, respectively degraded in the soil according to equations: y = -0.019x + 1.305 and y = -0.038x + 1.445 (linear) inoculated with *Alternaria alternata*, (**Figure 1**).

Four transformation products with [M+H]+ ions at m/z 234 (I), 198(II), 191(III) and 156 (V) were detected as a result of degradation of pyrazosulfuron-ethyl by *A. alternata* in soil and identified as ethyl 1-methyl-5-sulfamyl-1H-pyrazole-4-carboxylate (I); dimethoxypyrimidin-2-ylcarbamoyl amine (II); amino sulfomyl,1-H pyrazole carboxylic acid (III) and 4,6-dimethoxypyrimidin-2-amine (IV). These were identified as based on mass spectrum data and fragmentation pattern in positive mode. Pyrazosulfuron-ethyl products at m/z 205(III) and 277(IV) were also reported from soil of rice field where pyrazosulfuron-ethyl was applied to control annual weeds (Sondhia et al. 2013). Formation of degradation products II and IV was also demonstrated by Zheng *et al.* (2008), and Wang *et al.* (2012).

Table 2. Degradation of pyrazosulfuron-ethyl in the soil by *Alternaria alternata* under laboratory conditions at two doses

Days after application	Residues (µg/g)			
	Microbial control		Chemical control	
	4 mg/kg	8 mg/kg	4 mg/kg	8 mg/kg
0	0.284±0.012(0.0)	0.368±0.073(0.0)	1.823±0.064(0.0)	2.944±0.071(0.0)
5	0.165±0.011(41.91)	0.237±0.012(35.6)	1.711±0.060 (6.14)	2.762±0.054 (6.16)
10	0.153±0.010(46.13)	0.205± 0.018(44.3)	1.349 ±0.032 (25.87)	2.1987±0.075 (25.33)
20	0.148±0.010(56.36)	0.192 ±0.096(47.83)	0.998±0.027 (45.25)	1.754 ±0.050 (40.42)
30	0.062±0.006(78.17)	0.145±0.008(60.6)	0.796±0.011 (56.33)	1.598±0.063 (45.72)
60	0.037± 0.005(86.97)	0.096±0.015(73.91)	0.679±0.011 (62.79)	1.198±0.063 (59.30)

[a]Mean of three replicates; SD: standard deviation; figures in parentheses indicate % dissipation.

Table 3. First order dissipation equation, R^2, rate constant, DT_{50} and DT_{90} values and regression statistics of pyrazosulfuron-ethyl in the soil under laboratory conditions

Parameter	Treatment			
	4mg/kg*	8mg/kg*	4mg/kg**	8mg/kg**
Rate constant (day^{-1})	3.8 x 10^{-2}	1.9 x 10^{-2}	1.7 x 10^{-2}	1.5 x 10^{-2}
R^2	0.943	0.917	0.859	0.914
DT_{50}	7.92	15.84	17.70	20.06
DT_{90}	60.57	121.15	135.41	153.46
F	28.792	184.20	14.20	27.74
Standard Error	0.006	0.001	0.004	0.003
t Stat	-5.365	-13.57	-3.76	-5.27
P-value	0.013	0.0008	0.032	0.013
K	0.038	0.019	0.017	0.015

*With fungi;**: without fungi

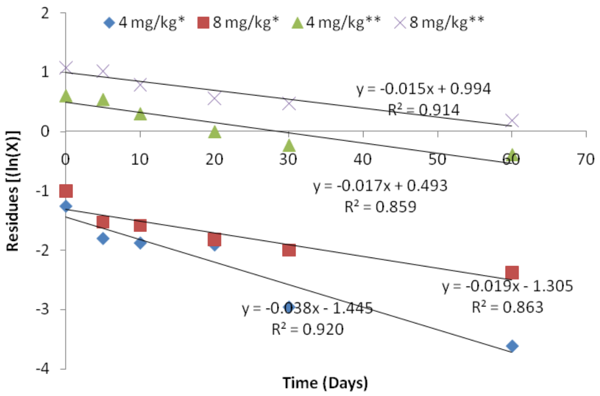

Figure 1. Dissipation kinetics of pyrazosulfuron-ethyl by *Alternaria alternata* under laboratory conditions at two doses in fungal assited tretatments, 4 mg/kg* (K, -0.038, P=0.013) and 8 mg/kg* (k, 0.019, P=0.0008) than in without fungal assited tretatments 4 mg/kg (k, 0.017, P=0.032) and 8 mg/kg** (k, 0.015, P=0.013)**

Chemical degradation of pyrazosulfuron-ethyl in the soil

In chemical degradation experiment, pyrazosulfuron-ethyl residues ranged from 1.823 to 2.944 µg/g in the soil at 4 and 8 mg/kg treatments, respectively after two hours (0-days) of treatment. Residues degraded slowly in the chemical control soil in comparison to the fungi assisted degradation experiment and reached to a concentration of 0.679 and 1.198 µg/g after 60 days in the soil treated with 4 and 8 mg/kg of pyrazosulfuron-ethyl, respectively. The difference was found significant at all days and two set of treatments (p=<0.05) Dissipation of pyrazosulfuron-ethyl residues without *A. alternata* at various days at different time interval is presented in **Table 2**.

Degradation of pyrazosulfuron-ethyl residues on soil surfaces, determination coefficients, and half-life times are shown in **Table 2**. Pyrazosulfuron-ethyl residues dissipated according to first order kinetics [(y = -0.017x + 0.493 and y = -0.015x + 0.994 (linear)] in the soil treated with 4 and 8 mg/kg of pyrazosulfuron-ethyl, respectively (**Figure 1**). The half-life of pyrazosulfuron-ethyl at 4 and 8 mg/kg of doses without fungal inoculation was found to be 17.7 and 20.06 days, however it was 7.92 and 15.84 days, respectively in the soil inoculated with *Alternaria alternata* in these treatment, which was lower in comparison to chemical assisted degradation.

Chu *et al*. (2002) reported the movement of pyrazosulfuron-ethyl in the bottom layer of soil. In addition to this, herbicide can also be lost through the process of photolysis and uptake by the plants. Under laboratory conditions, some factors such as leaching to the bottom layer, photodegradation, plant uptake *etc*, did not play any role in pyrazosulfuron-ethyl degradation and this may results in a higher half-life in the soil than the field soils.

Degradation of pyrazosulfuron-ethyl was slow in the chemical control treatments in comparison to the soil inoculated with *A. alternata* and only 62.7 and 59.3% dissipation was achieved by 60 days in both the doses. However, rapid degradation of pyrazosulfuron-ethyl (86.9 to 73.6%) was found in the treatment having *A. alternata* along with this herbicide at two doses (**Table 2**). A two-tailed test (α2=5%) was analyzed to the data using the T-Test for measuring differences in degradation of pyrazosulfuron-ethyl in soil with *A. alternata* and without fungi (**Table 3**). A significant difference (T-statistic -5.36, p=<0.05 and 0.05%).) was found between two sets of degradation of pyrazosulfuron-ethyl experiments in the soil. This study demonstrated potential of *Alternaria alternata* to degrade higher concentration of pyrazosulfuron-ethyl in the treated soil. Degradation products were formed as a result of cleavage and hydrolysis of the sulfonylurea bridge. It has been well demonstrated that low pH values accelerate the hydrolysis of the sulfonylurea bridge, but at pH 10, contraction of the sulfonylurea bridge may be the concise pathway. Similar findings have been demonstrated by Xu *et al.* (2009).

Microbial degradation is found to be an important mechanism of pyrazosulfuron-ethyl degradation in the soil. Soil fungi, *Alternaria alternata* was found effective to degrade pyrazosulfuron-ethyl up to 87% in the soil at tested dose under laboratory conditions. Degradation of pyrazosulfuron-ethyl was found rapid in the soil inoculated with *A. alternata* than chemical degradation. The main degradation pathway was the sulfonylurea bridge cleavage and hydrolysis. The results demonstrated that *A. alternata* used in the study can be effectively used for the enhanced degradation of pyrazosulfuron-ethyl in agricultural soil or may be mixed with other microbial consortia for rapid degradation. The feasibility of using *A. alternata* alone or in combination with other microbial consortia to detoxify pyrazosulfuron-ethyl contamination in practice needs to be investigated in detail in the future.

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