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Effect of pre and post-emergence herbicides on weed infestation, crop growth and economics of wheat

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Abstract
A field experiment was carried out to study the efficacy of different pre and post-emergence herbicides and microbial inoculation against *Phalaris minor* and on growth, yield and economics of wheat. The experiment was performed in randomized blocked design with three replication and seventeen treatments in *rabi* season 2018-19 at CCS Haryana Agricultural University, Hisar. Significantly minimum weed count (2.4 m^{-2}) and dry weight (2.3 g m^{-2}) and maximum weed control efficiency (92.5%) and visual control of *Phalaris minor* (91%) was recorded with application of pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS while in case of broadleaved weeds lower density and biomass accumulation and higher weed control efficiency (92.4%) was observed under pendimethalin 1000 g ha^{-1} JAS *fb* sulfosulfuron + metribuzin as a tank mix 25 + 105 g ha^{-1} at 35 DAS. In case of plant height at 60 and 90 DAS (54.7 cm and 79.3 cm, respectively), number of tillers per meter row length at 60 and 90 DAS (109.3 and 106.7, respectively), grain yield (5761 kg ha^{-1}), harvest index (41.3%), gross returns (Rs. ha^{-1} 138810), net returns (Rs. ha^{-1} 57266), and B:C (1.70) was recorded higher with application of pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS which was significantly higher than weedy check but at par with the weed free treatment.

Keywords: Post-emergence, herbicides, infestation, economics, wheat

Introduction

Littleseed canary grass (*Phalaris minor* Retz.) is an indigenous weed of the Mediterranean region that is widely dispersed throughout the world, including all continents with the exception of the Polar Regions. It is the most common and troublesome grassy weed of irrigated wheat in rice-wheat cropping systems in India's north western Indo-Gangetic plains. Although *Phalaris minor* infests a variety of winter crops, it has become particularly damaging to wheat due to its comparable morphological and growth requirements. Because of its extremely competitive ability, it emerges with the germinating wheat crop, competes for water and nutrients, and significantly decreases grain output. Farmers readily adopted herbicides to control this dreaded weed. Isoproturon, an urea substituted herbicide, was the sole herbicide used for more than 15 years, providing very effective control of *Phalaris minor* until resistance emerged in Haryana and Punjab in the 1990s (Malik and Singh, 1995; Walia *et al*., 1997) [6, 13]. In 1992, an emergency recommendation for diclofop-methyl was issued, but it was withdrawn two years later due to the evolution of cross resistance in *Phalaris minor* with no history of previous usage of this herbicide in India. Isoproturon resistance in *Phalaris minor* was caused by the indiscriminate and continuous use of isoproturon for more than a decade, with an unbreakable rice-wheat cropping pattern aggravated by poor treatment rates, spray procedures, and timing. Later, four other herbicides, namely clodinafop, fenoxaprop, sulfosulfuron, and tralkoxydim, were recommended to control *Phalaris minor* in 1997-98 (Yadav and Malik, 2005) [16].

Despite their altered mechanism of action in comparison to isoproturon, these herbicides met the same destiny as isoproturon after 8-10 years of continuous usage, and concerns about their poor efficacy began to arise in farmers' fields (Singh *et al*. 2009) [9]. As a result, new herbicide recommendations for the management of *Phalaris minor* were developed, including pinoxaden, mesosulfuron + iodosulfuron (Punia *et al*. 2008) [7]. However, the horrible *Phalaris minor* developed biological resistance to these new herbicides as well. Some *Phalaris minor* populations from Punjab and Haryana have been reported to be insensitive to pinoxaden application without any previous record of exposure, confirming the emergence of cross-resistance. Similarly, exceptionally high GR_{50} values for mesosulfuron + iodosulfuron have been discovered in a few groups. With the continuous evolution of post-emergence (PoE) herbicide resistance, the use of pre-emergence (PRE) herbicides has emerged as a key strategy to managing herbicide resistance. PRE herbicides such as pendimethalin, trifluralin, metribuzin, pyroxasulfone and flufenacet have been reported to be effective against herbicide-resistant weeds in wheat. But, when used alone, PE herbicides are insufficient to fulfil the goal of reducing weed seed bank; however, when used in conjunction with a variety of techniques, they can be especially effective. Some of the advantages of utilising PRE herbicides include providing an alternate mode of action to several PoE herbicides, reducing selection pressure on later PoE herbicide applications, and removing much of the crop's early season weed competitive pressure (Singh 2015) [10]. The purpose of this study was to explore the use of pre-emergence herbicides, microbial combinations followed by post-emergence herbicides for the successful management of multiple herbicide resistant *Phalaris minor* in wheat.

Material and Methods

A field experiment was carried out at Research Farm, Dept. of Agronomy, CCS HAU, Hisar (with a latitude of $29^0$10' in the north and a longitude of 75^0 46' in the east), Haryana (India) in the winter seasons of 2018-19 to assess the bio-efficacy of pre (PE) and post-emergence (PoE) herbicides alone and in combination along with microbial inoculation against resistant *Phalaris minor* in wheat. Hisar has a semi-arid climate with hot and dry summers and severe winters. During the crop season 2018-19, the mean weekly maximum and lowest temperatures ranged from 40.7 ^{0}C to 1.9 ^{0}C, respectively. The mean weekly relative humidity ranged from 56 to 99% in the morning and 19 to 66% in the evening. The texture of the soil at the experimental site was judged to be sandy loam, with a slightly alkaline reaction (pH 8.3) and normal electrical conductivity (0.43 dS m^{-1}). Organic carbon (0.26%) and nitrogen (114.5 kg ha^{-1}) were determined to be low in the soil with medium phosphorus (12.6 kg ha^{-1}) and high potassium content (226.4 kg ha^{-1}). The wheat variety WH 1105 was sown in a regularly tilled seed bed using 100 kg seed ha^{-1} in rows 20 cm apart.

The experiment was conducted in randomized complete block design with three replications. Various herbicides treatments were: T_1: clodinafop-propargyl 60 g ha^{-1} at 35 days after sowing (DAS), T_2: pinoxaden 50 g ha^{-1} at 35 DAS, T_3: sulfosulfuron 25 g ha^{-1} at 35 DAS, T_4: clodinafop- propargyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_5: pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_6: sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_7: seed treatment with *Bacillus subtilis* strain SYB 101 (5.0 ml kg^{-1} seed) *fb* clodinafop- propargyl + metribuzin (tank mixed) 60 + 210 g ha^{-1} at 35 DAS, T_8: seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g ha^{-1} at 35 DAS, T_9: seed treatment with *Bacillus subtilis* strain SYB 101 (5.0 ml kg^{-1} seed) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 210 g ha^{-1} at 35 DAS, T_{10}: pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* clodinafop-p-ethyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_{11}: pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_{12}: pendimethalin 1000 g ha^{-1} ((JAS)) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_{13}: metribuzin 210 g ha^{-1} ((JAS)) *fb* clodinafop- propargyl 60 g ha^{-1} at 35 DAS, T_{14}: mertibuzin 210 g ha^{-1} (JAS) *fb* pinoxaden 50 g ha^{-1} at 35 DAS, T_{15}: metribuzin 210 g ha^{-1} (JAS) *fb* sulfosulfuron 25 g ha^{-1} at 35 DAS, T_{16}: weedy check and T_{17}: weed free check. PE herbicides were applied just after sowing in moist soil, while PoE herbicides were applied with a knapsack sprayer at 35 DAS. Visual control of *Phalaris minor* was accessed at 60 DAS on a scale ranging from 0 (no control) to 100% (fully controlled).The densities and dry weight of *Phalaris minor* and broad-leaf weeds were measured. Weed samples were collected using a quadrat from two randomly selected sites in each plot (0.5 x 0.5 m). Each weed sample was split up into different groups: *Phalaris minor* and broadleaf weeds. Each sample was counted for the numbers of *Phalaris minor* and broadleaf weeds, and expressed the density into number m^{-2}. Plants of *Phalaris minor* and broad-leaf weeds from each quadrat were sun-dried before being placed in oven to generate a constant weight at 65^0 C. The dried weed samples were then weighed and the weight was expressed as g m^{-2}. Weed control efficiency was measured as a percentage reduction in weed dry weight under different treatments compared to weedy. The weed control efficiency (WCE) was calculated using the formula (Gupta, 2015) as given below:

$$\text{WCE (\%)} = \frac{\text{Dry weight of weeds in weedy check} - \text{Dry weight of weeds in treatment plot}}{\text{Dry weight of weeds in weedy check}} \times 100$$

Weed index indicates the percent yield reduction in comparison to yield in weed free plot. It was calculated by the formula (Gupta, 2015):

$$\text{WI (\%)} = \frac{\text{Yield from weed free plot (kg ha}^{-1}) - \text{Yield from treated plot (kg ha}^{-1})}{\text{Yield from weed free plot (kg ha}^{-1})} \times 100$$

Visual phytotoxicity of herbicides on wheat was observed at 10, 20 and 30 DAT on a scale of 0 (no mortality) to 100 (complete mortality). From each plot five plants were selected randomly for measurement of plant height and their average was taken at 60 and 90 DAS. For calculation of number of tillers per meter row length (at 60 and 90 DAS), three rows each of 1 meter length were selected randomly in each plot and mean was taken as number of tillers per meter row length. The ratio of economic (kg ha^{-1}) to biological yield (kg ha^{-1}) was worked out for each treatment and expressed as harvesting index (%). Economics of each treatment was calculated based on prevailing market price of inputs on hectare basis. The data collected was analysed with OP STAT software of CCS HAU, Hisar.

Results

Density of *Phalaris minor*

At 60 DAS, Sequential application of pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} as PoE at 35 DAS resulted in minimum density of *Phalaris minor* and it was statistically at par with seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and PoE application of tank mixed pinoxaden + metribuzin 50 + 210 g ha^{-1} or sulfosulfuron + metribuzin 25 + 210 g ha^{-1} at 35 DAS, pendimethalin 1000 g ha^{-1} as pre just after sowing (JAS) *fb* clodinafop-propargyl+ metribuzin as a tank mix (PoE) 60 + 105 g/ha or sulfosulfuron + metribuzin (tank mix) 25 + 105 g ha^{-1} at 35 DAS, metribuzin 210 g^{-1} ha JAS *fb* pinoxaden 50 g ha^{-1} or sulfosulfuron 25 g ha^{-1} at 35 DAS (Table 1.). Better control of *Phalaris minor* was observed with sequential application of herbicides in comparison to their application alone. The combined application of PE and PoE herbicides provide better control of Phalaris minor. Germinating weeds were effectively controlled by pre emergence herbicides and weeds which were emerged latter were kept under check by PoE herbicides. Similar results were reported by Chhokar and Sharma (2008) and Dhawan *et al*. (2012) [2, 1].

Density of Broadleaved weeds

At 60 DAS, pre emergence application of pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mix) 25 + 105 g ha^{-1} at 35 DAS resulted minimum density of broadleaved weeds *i.e. Rumex dentatus, Chenopodium album, Anagalis arvensis* and *Melilotus indica* and it was statistically comparable to application of pendimethalin 1000 g ha^{-1} JAS in combination with post emergence application of either clodinafop-propargyl+ metribuzin (tank mixed) 60 + 105 g ha^{-1} or pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS (Table 1.). However, amongst different herbicides combination lowest density of *Coronopus didymus* was reported from seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and PoE application of tank mixed sulfosulfuron + metribuzin 25 + 210 g ha^{-1} at 35 DAS. Sequential application of pendimethain followed by PoE reported better control of weeds as reported by Chopra and Chopra (2005) and Kumar *et al.* (2013).

Dry matter accumulation

At 30 DAS, significant lower biomass accumulation of grassy weeds was observed in treatment with sequential application of pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* clodinafop-propargyl+ metribuzin (tank mix) 60 + 105 g ha^{-1} at 35 DAS and it was statistically comparable to pre emergence application of pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* post emergence application of pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} or sulfosulfuron + metribuzin (tank mix) 25 + 105 g ha^{-1} and pre emergence application of metribuzin 210 g ha^{-1} (JAS) along with post emergence application of either clodinafop- propargyl 60 g ha^{-1}, pinoxaden 50 g ha^{-1} or sulfosulfuron 25 g ha^{-1} at 35 DAS. However significant minimum dry matter accumulation of grassy weeds at 60 DAS was recorded from pendimethalin 1000 g ha^{-1} (JAS) with pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS (Table 1.).

In case of broadleaved weeds (at 30 and 60 DAS), application of pendimethalin 1000 g ha^{-1} (JAS) followed by tank mix application of sulfosulfuron + metribuzin 25 + 105 g ha^{-1} at 35 DAS recorded significant lower dry matter accumulation and it was statistically similar with pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* application (PoE) of either clodinafop-propargyl+ metribuzin (tank mix) 60 + 105 g ha^{-1} or pinoxaden + metribuzin (tank mix) 50 + 105 g ha $^{-1}$ at 35 DAS and Metribuzin 210 g $^{-1}$ ha (JAS) *fb* sulfosulfuron 25 g ha^{-1} at 35 DAS. Minimum density of weeds in pre and post emergence herbicides applied treatments resulted in lower biomass accumulation by weeds. These results are in line with Sheoran *et al*. (2013) and Yadav *et al*. (2016).

Table 1: Effect of different herbicides and microbial inoculation on weed count (No. m^{-2}) and dry matter accumulation of weeds in wheat

Treatments	*Phalaris minor*	*Rumex dentatus*	*Chenopodium album*	*Anagallis arvensis*	*Melilotus indica*	*Coronopus didymus*	Dry matter accumulation (g m^{-2}) at 30 DAS		Dry matter accumulation (g m^{-2}) at 60 DAS	
							Grassy	BLW	Grassy	BLW
T1: Clodinafop-propargyl 60 g/ha at 35 days after sowing (DAS)	4.8 (22.7)	6.1 (36.0)	5.2 (26.6)	3.5 (11.7)	4.3 (17.3)	5.1 (25.3)	6.9	8.5	12.8	56.2
T2: Pinoxaden 50 g/ha at 35 DAS	3.2 (9.7)	6.1 (36.0)	5.3 (27.3)	3.7 (13.3)	4.1 (16.0)	5.0 (24.0)	6.6	7.9	5.5	53.1
T3: Sulfosulfuron 25 g/ha at 35 DAS	3.6 (12.3)	5.4 (28.7)	4.4 (18.7)	2.9 (7.3)	3.1 (8.7)	4.0 (15.3)	6.5	8.1	8.8	26.0
T4: Clodinafop-propargyl + metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	4.5 (19.3)	3.8 (13.7)	3.7 (13.0)	3.2 (9.3)	3.4 (10.7)	3.4 (10.7)	6.7	8.5	10.9	27.9
T5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	2.9 (7.3)	3.9 (14.3)	3.5 (11.7)	3.1 (8.7)	3.6 (12.0)	3.2 (9.3)	6.4	8.0	4.5	24.5
T6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	3.4 (11.0)	3.5 (11.7)	3.2 (9.3)	2.7 (6.7)	2.9 (7.3)	3.1 (8.7)	6.5	8.1	7.4	17.3
T7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and clodinafop-propargyl + metribuzin (tank mixed) 60 + 210 g/ha at 35 DAS	4.2 (17.0)	3.5 (11.0)	4.1 (15.7)	3.0 (8.0)	3.4 (10.7)	3.2 (9.3)	6.9	8.2	7.7	24.7
T8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g/ha at 35 DAS	2.9 (7.3)	3.7 (13.0)	4.2 (16.3)	2.6 (6.0)	3.2 (9.7)	3.0 (8.0)	6.6	7.9	4.1	25.5
T9: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g/ha at 35 DAS	2.8 (7.0)	3.3 (10.3)	3.4 (10.7)	2.6 (6.0)	3.1 (9.0)	2.7 (6.7)	6.5	7.8	7.5	16.1
T10: Pendimethalin 1000 g/ha just after sowing (JAS) *fb* clodinafop-propargyl+ metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	2.8 (7.0)	1.2 (0.7)	1.2 (0.7)	1.5 (1.3)	2.0 (3.3)	3.7 (12.7)	2.7	2.4	5.3	9.3
T11: Pendimethalin 1000 g/ha (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	2.4 (4.7)	1.2(0.7)	1.6 (2.0)	1.6 (2.0)	1.8 (2.7)	3.5 (11.3)	2.8	2.2	2.3	9.5
T12: Pendimethalin 1000 g/ha (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	2.6 (6.0)	1.0 (0.0)	1.0 (0.0)	1.2 (0.7)	1.6 (2.0)	3.0 (8.0)	2.9	2.2	4.5	4.4
T13: Metribuzin 210 g/ha (JAS) *fb* clodinafop-propargyl 60 g/ha at 35 DAS	3.2 (10.0)	2.4 (5.0)	3.4 (11.0)	2.3 (4.7)	2.7 (6.3)	4.0 (15.3)	3.6	3.6	7.7	11.8
T14: Metribuzin 210 g/ha (JAS) *fb* pinoxaden 50 g/ha at 35 DAS	2.6 (5.7)	2.3 (5.6)	3.2 (9.6)	2.1 (4.0)	2.9 (7.7)	4.1 (16.0)	3.7	3.6	4.3	12.3
T15: Metribuzin 210 g/ha (JAS) *fb* sulfosulfuron 25 g/ha at 35 DAS	3.0 (8.3)	2.2 (4.0)	2.3 (4.6)	1.9 (2.7)	2.4 (4.7)	3.3 (10.0)	3.5	3.3	6.9	7.7
T16: Weedy check	8.0 (62.3)	6.3 (39.3)	5.3 (27.3)	3.9 (14.3)	4.2 (17.3)	5.2 (26.0)	6.9	8.3	30.8	57.9
T17: Weed free check	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	0.0	0.0	0.0	0.0
S.Em (±)	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.5	0.4	1.9
CD at 5%	0.7	0.4	0.5	0.6	0.6	0.5	1.5	1.3	1.3	5.6

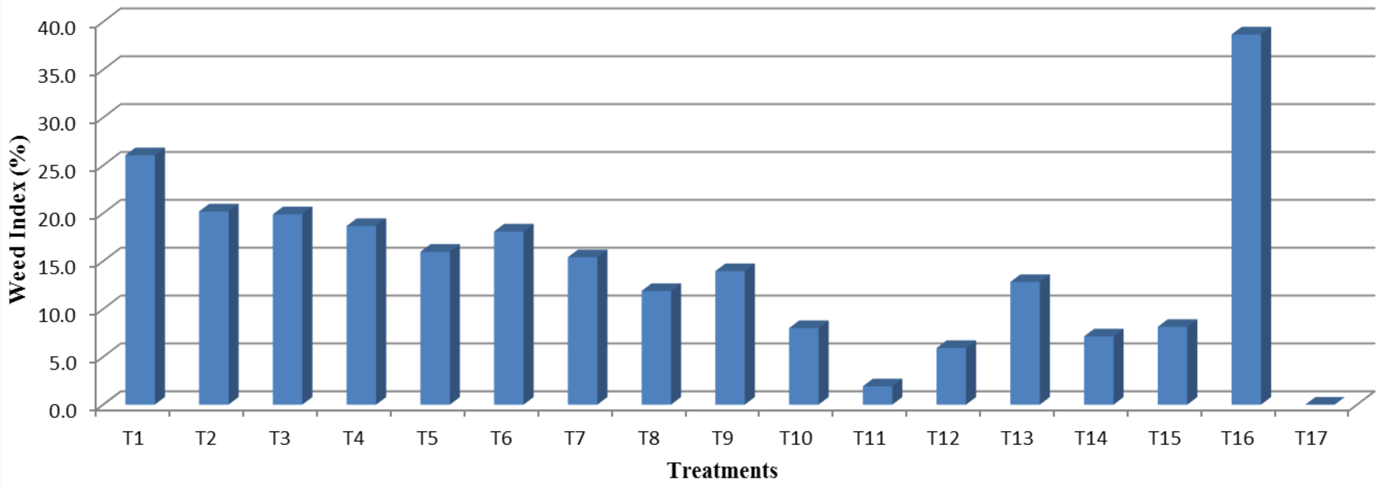
Original data given in parenthesis was subjected to square root($\sqrt{x+1}$) transformation before analysis

Table 2: Effect of different herbicides and microbial inoculation on weed control efficiency, visual control of *Phalaris minor*, Phyto-toxicity on crop and plant height of wheat

Treatments	Weed control efficiency (%) at 60 DAS			Visual control of *Phalaris minor* (%)	Phyto-toxicity on crop (%)			Plant height (cm)	
	Grassy	BLW	Total	60 DAS	10 DAT	20 DAT	30 DAT	60 DAS	90 DAS
T1: Clodinafop-propargyl 60 g/ha at 35 days after sowing (DAS)	58.4	0.0	22.2	70	0	0	0	50.0	74.3
T2: Pinoxaden 50 g/ha at 35 DAS	82.1	0.0	33.9	85	0	0	0	50.5	76.0
T3: Sulfosulfuron 25 g/ha at 35 DAS	71.4	55.1	60.8	60	0	0	0	47.9	74.0
T4: Clodinafop-propargyl + metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	64.6	51.8	56.3	77	2	0	0	53.3	78.7
T5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	85.4	57.7	67.3	87	2	0	0	53.8	79.3
T6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	76.0	70.1	72.2	78	4	0	0	52.7	77.7
T7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and clodinafop-propargyl + metribuzin (tank mixed) 60 + 210 g/ha at 35 DAS	75.0	57.3	63.5	83	5	0	0	53.3	77.7
T8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g/ha at 35 DAS	86.7	56.0	66.6	88	5	0	0	54.2	78.7
T9: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g/ha at 35 DAS	75.6	72.2	73.4	83	8	0	0	52.7	75.7
T10: Pendimethalin 1000 g/ha just after sowing (JAS) *fb* clodinafop-propargyl+ metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	82.8	83.9	83.5	82	2	0	0	54.4	79.0
T11: Pendimethalin 1000 g/ha (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	92.5	83.6	86.7	91	3	0	0	54.7	79.3
T12: Pendimethalin 1000 g/ha (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	85.4	92.4	90.0	87	5	0	0	52.3	78.0
T13: Metribuzin 210 g/ha (JAS) *fb* clodinafop-propargyl 60 g/ha at 35 DAS	75.0	79.6	78.0	87	7	7	0	49.3	75.7
T14: Metribuzin 210 g/ha (JAS) *fb* pinoxaden 50 g/ha at 35 DAS	86.0	78.8	81.3	88	6	6	0	51.0	77.7
T15: Metribuzin 210 g/ha (JAS) *fb* sulfosulfuron 25 g/ha at 35 DAS	77.6	86.7	83.5	73	7	6	0	49.0	75.3
T16: Weedy check	0.0	0.0	0.0	0	0	0	0	46.3	70.7
T17: Weed free check	100.0	100.0	100.0	100	0	0	0	55.1	79.7
S.Em (±)								1.8	1.6
CD at 5%								5.1	4.7

Table 3: Number of tillers per meter row length, grain yield, harvest index and economics of wheat as influenced by various herbicides and microbial inoculation treatments

Treatment	Tillers per meter row length		Grain yield (kg ha^{-1})	HI (%)	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B:C
	60 DAS	90 DAS						
T1: Clodinafop-propargyl 60 g/ha at 35 days after sowing (DAS)	94.3	87.9	4343	38.8	79425	107279	27854	1.35
T2: Pinoxaden 50 g/ha at 35 DAS	99.3	93.0	4688	39.4	79950	115159	35209	1.44
T3: Sulfosulfuron 25 g/ha at 35 DAS	100.3	94.0	4705	38.7	79515	116328	36813	1.46
T4: Clodinafop- propargyl + metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	102.0	97.7	4777	39.0	79730	117781	38051	1.48
T5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	105.7	100.3	4935	39.3	80255	121240	40985	1.51
T6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	105.7	101.7	4811	38.8	79820	118894	39074	1.49
T7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and clodinafop- propargyl + metribuzin (tank mixed) 60 + 210 g/ha at 35 DAS	104.3	103.3	4969	39.1	80035	122354	42319	1.53
T8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g/ha at 35 DAS	112.3	105.3	5176	40.3	80560	125866	45306	1.56
T9: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g/ha at 35 DAS	106.0	105.0	5054	40.4	80125	122778	42653	1.53
T10: Pendimethalin 1000 g/ha just after sowing (JAS) *fb* clodinafop-propargyl+ metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	107.7	104.0	5404	40.9	81281	130710	49429	1.61
T11: Pendimethalin 1000 g/ha (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	109.3	106.7	5761	41.3	81544	138810	57266	1.70
T12: Pendimethalin 1000 g/ha ((JAS)) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	109.3	103.7	5526	40.5	81326	134210	52884	1.65
T13: Metribuzin 210 g/ha ((JAS)) *fb* clodinafop- propargyl 60 g/ha at 35 DAS	101.7	98.0	5121	40.8	80735	123950	43215	1.54
T14: Mertibuzin 210 g/ha (JAS) *fb* pinoxaden 50 g/ha at 35 DAS	104.7	101.0	5455	40.9	81260	131872	50612	1.62
T15: Metribuzin 210 g/ha (JAS) *fb* sulfosulfuron 25 g/ha at 35 DAS	103.3	94.0	5396	40.0	80825	131702	50877	1.63
T16: Weedy check	90.0	82.7	3602	36.3	78000	91585	13585	1.17
T17: Weed free check	110.7	107.3	5873	41.1	99000	141695	42695	1.43
S.Em ±	2.9	1.9	171	1.4				
CD at 5%	8.3	5.5	496	NS				



T_1: Clodinafop-propargyl 60 g ha^{-1} at 35 days after sowing (DAS), T_2: Pinoxaden 50 g ha^{-1} at 35 DAS, T_3: Sulfosulfuron 25 g ha^{-1} at 35 DAS, T_4: Clodinafop- propargyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and clodinafop- propargyl + metribuzin (tank mixed) 60 + 210 g ha^{-1} at 35 DAS, T_8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g ha^{-1} at 35 DAS, T_9: Seed treatment with *Bacillus subtilis* strain SYB 101 (5.0 ml kg^{-1} seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g ha^{-1} at 35 DAS, T_{10}: Pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* clodinafop-p-ethyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_{11}: Pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_{12}: Pendimethalin 1000 g ha^{-1} ((JAS)) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_{13}: Metribuzin 210 g ha^{-1} ((JAS)) *fb* clodinafop- propargyl 60 g ha^{-1} at 35 DAS, T_{14}: Mertibuzin 210 g ha^{-1} (JAS) *fb* pinoxaden 50 g ha^{-1} at 35 DAS, T_{15}: Metribuzin 210 g ha^{-1} (JAS) *fb* sulfosulfuron 25 g ha^{-1} at 35 DAS,; T_{16}: Weedy check and T_{17}: Weed free check

Fig 1: Effect of various herbicidal treatments on weed index of wheat

Weed control efficiency and Visual control of *Phalaris minor*

Maximum weed control efficiency (92.5%) of grassy weeds and visual control of *Phalaris minor* (at 60 DAS) were recorded from sequential application of pendimethalin 1000 g ha^{-1} (JAS) with pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS followed by metribuzin 210 g/ha (JAS) *fb* pinoxaden 50 g/ha (86%) at 35 DAS. Weed control efficiency of broadleaved was higher (92.4%) under pendimethalin 1000 g ha^{-1} just after sowing *fb* sulfosulfuron + metribuzin as tank mix 25 + 105 g ha^{-1} at 35 DAS followed by pre emergence application (JAS) of metribuzin 210 g ha^{-1} *fb* sulfosulfuron 25 g ha^{-1} (86.7%) at 35 DAS (Table 2.). Sequential application of pendimethalin followed by PoE reported minimum dry matter of weeds hence highest weed control efficiency. Similar results were reported by Sheoran *et al.* (2013) and Kumar (2018).

Weed index and grain yield

Lowest weed index and highest grain yield was recorded under pendimethalin 1000 g ha^{-1} (JAS) with pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS and it was closely followed by pre emergence application of pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS (Fig. 1. and Table 3.). Among herbicide treatments maximum weed index was reported from single application of clodinafop-propargyl 60 g ha^{-1} as PoE at 35 DAS. Application of pre and post emergence herbicides (sequentially) provide effective weed control which provide competitive advantage to crop (Chopra and Chopra (2005) and Kumar *et al.* (2013) [3, 4].

Phytotoxicity on crop

Application clodinafop-propargyl 60 g ha^{-1}, pinoxaden 50 g ha^{-1} and sulfosulfuron 25 g ha^{-1} does not show any phyto toxic effect when applied alone but the tank mix of these herbicides with metribuzin *i.e.* clodinafop-propargyl + metribuzin 60 + 105 g ha^{-1}, pinoxaden + metribuzin 50 + 105 g ha^{-1} and sulfosulfuron + metribuzin 25 + 105 g ha^{-1} showed some (2-5%) phyto toxic effects which were recovered at 30 DAS (Table 2.). Application of metribuzin alone 210 g ha^{-1} resulted in some (6-7%) phyto-toxicity at 10 and 20 DAT which was recovered at 30 DAT. Different wheat varieties were sensitive to higher doses of metribuzin as reported by Singh *et al.* (2004) [12].

Plant height, number of tillers per meter row length and harvest index

Plant height and number of tillers was significantly affected by various herbicides combination as compared to weed check. Maximum plant height and number of tillers per meter row length was recorded with application of pendimethalin 1000 g ha^{-1} (JAS) *fb* tank mix application of pinoxaden + metribuzin (PoE) 50 + 105 g ha^{-1} at 35 DAS and it was statistically comparable with weed free (Table 2. and Table 3.).

No significant effect of various herbicide combination was observed on harvesting index although maximum value was reported from pendimethalin 1000 g ha^{-1} (JAS) *fb* tank mix application of pinoxaden + metribuzin (PoE) 50 + 105 g ha^{-1} at 35 DAS. Better utilization of available resources by crop due to minimum crop-weed competition resulted in higher crop growth parameters. Similar results were reported by Walia *et al*. (2011) and Singh *et al.* (2011) [14, 11].

Economics

Among the various herbicidal treatments, highest gross returns, net returns and B:C was recorded by pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin as a tank mix 50 + 105 g ha^{-1} at 35 DAS (Rs. ha^{-1} 138810, 57266 and 1.70, respectively) followed by pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS (Rs. ha^{-1} 134210, 52884 and 1.65, respectively) (Table 3.). Lowest returns and B:C was reported from weedy check. Due to better weed control minimum loss of yield was reported from plots where pre and post emergence herbicides were applied sequentially and that was reflected in higher net return and B:C. Higher net return were repoted by Kumar *et al.* (2013) [4] due to herbicides application.

Conclusion

Sequential application of pre and post-emergence provide effective control of *Phalaris minor* in comparison to their application alone. Based on the experiment it can be concluded that application of pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS provide better weed control, plant growth and higher net returns.

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