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Original Research Article

Bio-efficacy of herbicides with different water volume and spray timing under zero tillage rice residue retention scenario against *Phalaris minor* in wheat

ABSTRACT

Background

Continuous use of the similar modes of ~~action~~ action-based herbicides leads to the development of herbicide resistance in ~~wheat~~ wheat-associated weeds in north-west India. Accelerated development of multiple resistance against most of the available post-emergence herbicides ~~emphasis~~ emphasize the use of pre-emergence herbicides. But, the efficacy of pre-emergence herbicide is a matter of concern as surface retained stubbles and/or straw alter herbicide efficacy associated with a direct interception of herbicide.

Methods

A field study was conducted ~~during~~ for two *rabi* seasons (2018-19 and 2019-20) to optimize spray volume and time of application for improving the bio-efficacy of pre-~~-~~emergence herbicides under a zero tillage full rice residue scenario. The herbicidal treatments (g/ha) included pendimethalin + pyroxasulfone (1000.0+127.5) as pre-emergence (PE), pyroxasulfone (127.5) as PE, pyroxasulfone (127.5) as early post emergence (EPoE), aclonifen+diflufenican (1002+200) EPoE, halauxifen methyl+ fluroxypyr (7.3+233.4) as EPoE, flumioxazin (100) as PE with two different water volumes 500 and 100 liter/ha along with pendimethalin *fb* pinoxaden (1500+50) in 500 l/ha water volume, pendimethalin (1500) as PE in 375 l/ha water volume, weed free and weedy check.

Results

The present study showed that pendimethalin + pyroxasulfone as PE with a higher spray volume of 1000 l/ha and alone application of pyroxasulfone as EPoE produced similar *Phalaris minor* control as with pendimethalin *fb* pinoxaden (PE *fb* Post) under full rice residue scenario in ~~zero~~ zero-till wheat.

Keywords~~:,~~ **:** Herbicide resistance, *Phalaris minor*, ~~Pre~~ Pre-emergence, Residue retention, wheat

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1. INTRODUCTION

Rice-wheat is the most important cropping system in India. Sustainability issues such as depletion of ground water, extensive rice residue burning, deterioration of soil structure, accelerated development of wheat associated weeds and escalating cost of cultivation are halting the potential productivity of this system [1,2,3]. The wheat crop is infested by many weeds which including grasses as well as broadleaf weeds. Among, grassy weeds are *Phalaris minor, Avena ludoviciana*, *Polypogon monspeliensis and Poa annua*, while, important broad leaved weeds are *Chenopodium album*, *C. murale*, *Coronopus didymus*, *Rumex dentatus*, *Rumex spinosus*, *Anagallis arvensis*, *Melilotus indica*, *Medicago denticulata*, *Malva parviflora* and *Convolvulus arvensis* [4]. *Phalaris minor* (littleseed canarygrass) is morphologically similar to wheat plants in its vegetative phase and shows a more competitive nature against wheat in resource acquisition. The problem of *Phalaris minor* is primarily concentrated in the rice-wheat cropping system that is being followed in Indo-Gangetic Plains.

In the rice-wheat system, continuous use of the same herbicides isoproturon to control *P. minor* in wheat has resulted in the development of resistant biotypes in north-west India [2,5]. The first case of resistance in *P. minor* to isoproturon was reported in ~~during~~ 1995 in India [6] and over the years the same has evolved multiple and ~~cross~~ cross-resistance against the used herbicides [7]. The accelerated development of herbicide resistance in ~~wheat~~ wheat-associated weed has become a severe threat to the sustainable production of wheat. Moreover, when initial high populations of *P. minor* were exposed to poor spray techniques, and then it enhanced the probability of development of herbicide resistance by imposing strong selection pressure [8]. In addition to it, overuse of herbicides of the same mode of action has resulted in the evolution of cross and multiple herbicide resistance against most of the available post-emergence herbicides [2,9]. So, there is a need to emphasize ~~emphasis on~~ the use of pre-emergence herbicides along with ~~post~~ post-emergence for better weed control.

Further, farmers' in north-west India burn~~s~~ both rice and wheat residue in fields resulting in severe losses to ecological health [3]. However, with the development of efficient seeders such as a happy seeder, and rotary disk drill, now it is become feasible to drill wheat seed under partial or full rice residue conditions [10]. The retention of rice residue on the surface provides congenial environment to the succeeding wheat crop with thermo moderating effect, more moisture conservation and prevention of weed emergence~~preventing weed emergence~~ to some extent [3]. However, the tangible effects are varying with the amount of residue, nature of residue and position of residue (retention/incorporation). Further, the efficacy of pre-emergence herbicide is a matter of concern as surface retained stubbles and/or straw alter herbicide efficacy associated with a direct interception of herbicide, accumulation of high organic matter and acceleration of microbial activity under such conditions [11,12]. Earlier, [11] reported only 30% of the applied herbicide reached the soil in the presence of 2.2 t/ha of straw on the surface, whereas less than 10% reached when straw amount raised to 4.48 t/ha and reduced herbicidal action of acetochlor, alachlor, and metolachlor. So, higher doses could be required for effective control of weeds under such scenario. Similarly, [12] reported the effect of trifluralin (~~non~~ non-water-soluble) and pyroxasulfone (water-soluble) on rigid ryegrass improved from 53 to 78% with increasing carrier volume associated with greater coverage resulting in higher weed and chemical contact. Herbicides efficacy under two contrasting conditions ZT and CT is likely to differ enormously due to the presence of stubbles/straw, level of organic matter, variable level of microbial driven metabolism, nature of herbicides (solubility), seeding depth and weed flora [3]. Hence, there is a need to optimize herbicidal dose, formulation, scheduling (pre-planting or before irrigation/early post) and spray volume for adequate weed control in wheat under paddy straw retention conditions [3]. Therefore, this study was planned to screen out herbicides with alternate modes of action and or ~~tank~~ tank-based mixtures for effective weed control in wheat to ensure higher productivity under residue retained conditions. The study was conducted ~~during~~ for two *rabi* seasons (2018-19 and 2019-20) with the objective to optimize spray volume and application time for improving the bio-efficacy of ~~pre~~ pre-emergence herbicides under the zero tillage full rice residue scenario.

2. MATERIALS AND METHODS

The present study was conducted at CCS Haryana Agricultural University Regional Research Station, Uchani, Karnal during *rabi* 2018-19 and 2019-20. The climate of the Karnal region is semi-arid tropical and sub-tropical characterized by hot and dry summer and cold winter. Agro-meteorological data for the ~~of~~ wheat season is provided ~~provided~~ in Figures ~~Figure~~ 1 and 2. The experimental field soil was clay loam and near neutral with low organic carbon, low in available nitrogen, medium in available phosphorus and high in potassium.

Figure 1: Daily weather data of experimental site during *rabi* 2018-19

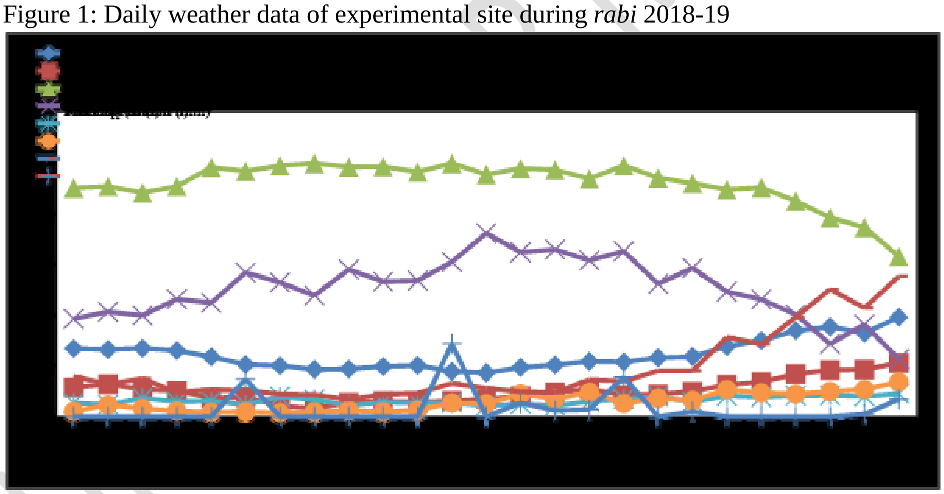

Figure 2: Daily weather data of experimental site during *rabi* 2019-20

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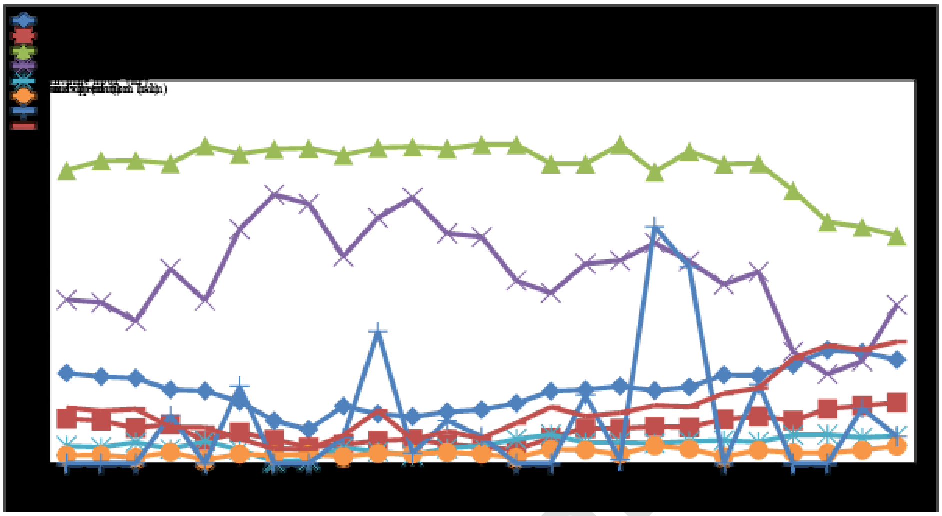

The experiment was laid out in a randomized block design with three replications. The herbicidal treatments (g a.i./ha) included pendimethalin + pyroxasulfone (1000.0+127.5) as pre-emergence (PE), pyroxasulfone (127.5) as PE, pyroxasulfone (127.5) as early post emergence (EPoE), aclonifen+diflufenican (1002+200) EPoE, halauxifen methyl+ fluroxypyr (7.3+233.4) as EPoE, flumioxazin (100) as PE with two different water volumes 500 and 100 liter (L) along with pendimethalin *fb* pinoxaden (1500+50) in 500 L water volume, pendimethalin (1500) as PE in 375 L water volume, weed free and weedy check. During *rabi* 2019-20, mesosulfuron+idosulfuron herbicide (14.4 g/ha) was used in replacement of aclonifen+diflufenican (1002+200). The herbicides were sprayed at ~~pre~~ pre-emergence stage and early ~~post~~ post-emergence stage (one day before first irrigation) with the different spray volumes of water. In weed free treatment, hand weeding was done –whenever required and no weed management practice was taken in weedy check plots. The wheat *cv* 'HD 2967' and 'WH 1105' were ~~was~~ sown on 6 November 2018 and 7
November 2019 and harvested on 17 April and 20 April during 2018-19 and 2019-20, respectively. Wheat was sown using happy seeder with retention of full rice residue about 6-7t/ha after harvesting ~~of~~ the rice. The seed rate was 100 kg/ha and the crop was sown ~~crop sown~~ with a row spacing of 20 cm. All other management practices were followed as per the recommended package and practices by the university. The weed samples were collected at 75 DAS of the crop with the help of a quadrant (0.5 x 0.5m) from two places in a random manner from each plot. Each weed sample was separated as *P. minor* and counted as number of plants/m^2. Weeds -from each plot~~s~~ were first sundried and thereafter kept in the oven at 65ºC until a constant weight was achieved. The crop yield data was recorded at harvest. The statistical analysis was made with the help of OPSTAT software. The significance of the treatments ~~were~~was tested at 5% level of significance.

RESULTS AND DISCUSSION
Weed density and dry weight

The wheat crop was infested primarily by *Phalaris minor* among grassy weeds~~weed~~, while, *Medicago denticulate*, *Rumex dentatus* and *Coronopus didymus* among ~~broad~~ broad-leaved weeds (BLWs) during both the years of study. During 2018-19, significantly lower *Phalaris minor* density was observed with EPoE application of aclonifen +diflufenican which was statistically found ~~at statistically~~ at par with pre application of pyroxasulfone but significantly higher than the~~to rest~~ of the treatments for the original values (Table 1). During 2019-20, minimum *Phalaris minor* density was found with tank mix application of pendimethalin+pyroxasulfone as PE with water volume 1000 L which was statistically at par with EPoE application of pyroxasulfone alone for both water volumes along with pendimethalin *fb* pinoxaden (Table 2).

Phalaris minor dry weight (g/m^2) was observed significantly lower with EPoE application of aclonifen +diflufenican (2.6-4.5 g/m^2) which was found at statistically at par with pendimethalin+pyroxasulfone as PE (5.2-6.5g/m^2), alone application of pyroxasulfone as PE (4.7-5.5 g/m^2) along with pendimethalin *fb* pinoxaden (7.1 g/m^2) during *rabi* 2018-19. Application of pyroxasulfone as alone or in combination with pendimethalin provided effective control of *P. minor* as compared to halauxifenmethyl+fluroxypyr (23.3-28.3 g/m^2), flumioxazin (17.1-22.6 g/m^2), alone pendimethalin (16.3 g/m^2) and effects were more pronounced at higher water volume (Table 1). During *rabi* 2019-20, significantly lowest *P. minor* dry matter was recorded with pyroxasulfone (3.03 g/m^2) as EPoE, being at par with PE application of pendimethalin+pyroxasulfone (3.13 g/m^2), alone application of pyroxasulfone as PE (4.1-4.8 g/m^2) along with along with pendimethalin *fb* pinoxaden (4.0 g/m^2). Overall pyroxasulfone application (Table 2) either alone (3.0-4.8 g/m^2) or in tank mix with pyroxasulfone (3.1-4.1 g/m^2) significantly reduced *Phalaris minor* infestation as compared halauxifen methyl+fluroxypyr (19.3-20.5 g/m^2) and weedy check (25.80 g/m^2). These results were found in line with the earlier findings of [12] as spray coverage significantly increased with increasing carrier volume from 4.8% for 30 L/ha to 23% for 150 L/ha. Pyroxasulfone is a new herbicide and acts as a root/shoot growth inhibitor in germinating seedlings- of susceptible weeds [13]. Besides -spray volume, the nature of nozzle also matters for obtaining desired efficacy of herbicides. [14] investigated that 61.3% of farmers reported low weed infestation when they used recommended flood jet and flat fan types of nozzles are the most used nozzles for high volume spray.

Yield

During *rabi* 2018-19 (Table 1), the highest wheat grain yield (5719-5728 kg/ha) was recorded with PE application of pendimethalin + pyroxasulfone spray volume of 500-1000 l/ha which was found at par with sole application of pyroxasulfone as early PoE as either 500 l/ha (5588 kg/ha) or EPoE (5498 kg/ha), but significantly higher to halauxifen methyl+ fluroxypyr as EPOE (5018-5067 kg/ha), flumioxazin (5162-5214 kg/ha), alone pendimethalin (5200 kg/ha) and alone application of pyroxasulfone as PE (5247-5441 kg/ha), but at par with pendimethalin *fb* pinoxaden (5666 kg/ha). Aclonifen+diflufenican treatments were superior to the rest of the treatments in reducing *P. minor* dry weight (2.6-4.5 g/m^2), but showed some phyto-toxicity on the wheat crop (20-25%) at the initial stage which was recovered later and the same was reflected in its yield (5220-5473 kg/ha).

During *rabi* 2019-20, significantly highest grain yield (Table 2) was observed with pendimethalin *fb* pinoxaden (5966 kg/ha), which was found statistically at par with pendimethalin + pyroxasulfone with PE (5717-5867 kg/ha) and alone application of pyroxasulfone as EPoE (5700 kg/ha) with higher water volume. While, significantly lower grain yields were observed with halauxifen methyl+ fluroxypyr (4600-4616 kg/ha) as EPoE and flumioxazin (5116-5383 kg/ha) as PE.

[15] also reported pyroxasulfone at 127.5 g/ha had provided effective control of *P. minor* and resulted in the highest wheat grain yield (4.80-5.43 t/ha) ~~at~~ in farmer's fields. Similar results were also reported by [16] to manage resistant and susceptible rigid ryegrass in Australia. The results from the present study showed that pendimethalin + pyroxasulfone as PRE with higher spray volume 1000 l/ha and alone application of pyroxasulfone as EPoE produced similar *Phalaris minor* control as with pendimethalin *fb* pinoxaden (PRE *fb* Post) under full rice residue scenario in wheat.

CONCLUSIONS

Herbicide resistance is a worldwide phenomenon and the number of resistant biotypes of weeds is increasing at an alarming rate. From the results of this experiment, it can be concluded that alternate herbicides such as sole application of pyroxasulfone either as PE and EPoE along with its combined application with pendimethalin as pre-emergence with higher water volume may be integrated with other weed management practices under rice residue retention scenario in wheat.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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Table 1: Effect of herbicides spray volume and time of application on weed density, weed dry matter (g/m^2) and grain yield (kg/ha) in wheat during *rabi* 2018-19

Treatments	Dose (g/ha)	Time	Water vol. (L/ha)	*P. minor* density (no./m^2) 75 DAS	*P. minor* dry weight (g/m^2) 75 DAS	Grain yield (Kg/ha)
Pendimethalin + pyroxasulfone	1000.0+127.5	PE	500	2.96(8.0)	6.5	5719
Pendimethalin + pyroxasulfone	1000.0+127.5	PE	1000	3.21(9.3)	5.2	5728
Pyroxasulfone	127.5	PE	500	2.76(6.7)	11.6	5441
Pyroxasulfone	127.5	PE	1000	3.08(8.7)	11.4	5247
Pyroxasulfone	127.5	*EPoE	500	3.36(10.7)	5.5	5588
Pyroxasulfone	127.5	EPoE	1000	3.21(9.3)	4.7	5498
Aclonifen+diflufenican	1002+200	EPoE	500	2.20(4.0)	4.5	5220
Aclonifen+diflufenican	1002+200	EPoE	1000	1.73(2.0)	2.6	5473
Halauxifen methyl+ fluroxypyr	7.3+233.4	EPoE	500	6.29(38.7)	23.3	5067
Halauxifen methyl + fluroxypyr	7.3+233.4	EPoE	1000	6.03(35.3)	28.3	5018
Flumioxazin	100	PE	500	4.65(20.7)	17.1	5162
Flumioxazin	100	PE	1000	3.63(12.7)	22.6	5214
Pendimethalin *fb* Pinoxaden	1500+50	PE *fb* PoE	500	3.62(12.7)	7.1	5666
Pendimethalin	1500	PE	375	3.31(10.0)	16.3	5200
Weed free				1.00(0.0)	0.00	6048
Weedy check				6.34(39.3)	64.9	4784
LSD (p=0.05)				0.75(5.13)	4.9	220

* EPoE spray before first irrigation; PRE- Just after sowing

Table 2: Effect of herbicides spray volume and time of application on weed density, weed dry matter (g/m^2) -at 75 DAS and grain yield (kg/ha) in wheat during rabi 2019-20

Treatments	Dose (g/ha)	Time	Water vol. (L/ha)	*P. minor* density (no./m^2)	*P. minor* dry weight (g/m^2)	Grain yield (kg/ha)
Pendimethalin + pyroxasulfone	1000.0+127.5	PE	500	10.00 (3.3)	4.07	5717
Pendimethalin + pyroxasulfone	1000.0+127.5	PE	1000	5.33 (2.5)	3.13	5867
Pyroxasulfone	127.5	PE	500	14.67 (3.9)	4.27	5367
Pyroxasulfone	127.5	PE	1000	15.33 (4.0)	4.13	5516
Pyroxasulfone	127.5	*EPoE	500	12.00 (3.6)	4.40	5483
Pyroxasulfone	127.5	EPoE	1000	10.67 (3.4)	3.03	5700
Mesosulfuron+idosulfuron	14.4	EPoE	500	33.33 (5.8)	10.27	4950
Mesosulfuron+idosulfuron	14.4	EPoE	1000	18.00 (4.3)	7.53	5266
Halauxifen methyl+ Fluroxypyr	7.3+233.4	EPoE	500	68.00 (8.3)	20.53	4600
Halauxifen methyl + Fluroxypyr	7.3+233.4	EPoE	1000	50.67 (7.1)	19.27	4616
Flumioxazin	100	PE	500	38.67 (6.3)	9.73	5116
Flumioxazin	100	PE	1000	18.67 (4.3)	5.53	5383
Pendimethalin *fb* Pinoxaden	1500+50	PE *fb* PoE	500	8.67 (3.0)	3.93	5966
Pendimethalin	1500	PE	375	30.00 (5.5)	9.67	4650
Weed free				0.00 (1.0)	0.00	6017
Weedy check				55.33 (7.5)	25.80	3633
LSD (p=0.05)				9.11 (0.8)	6.89	386

*EPoE spray before first irrigation; PRE- Just after sowing