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Standardization of spray technique for pre-emergence herbicides in ZT-wheat (*Triticum aestivum*) with surface residue cover

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ABSTRACT

The present study was carried out at Regional Research Station, CCS Haryana Agricultural University, Karnal, Haryana during winter (*rabi*) seasons of 2019–20 and 2020–21. In this experiment, ZT-wheat (*Triticum aestivum* L.) was sown with happy seeder under surface residue load of 6 t/ha (chopped). Fourteen weed control treatments including pre-emergence herbicide (pendimethalin 1500 g/ha), sequential application of pre-emergence *fb* post-emergence (POE) herbicide (pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha), weedy check and weed-free were applied in a randomised block design (RBD) with 3 replications. Pre-emergence (PRE) herbicides were applied on the top of rice (*Oryza sativa* L.) residues using two water volumes (500 and 1000 litre/ha) with 3 types of nozzles (flat-fan, flood-jet and air-injection). Among weed species, *Rumex dentatus* (L.) and *Phalaris minor* (Retz.) showed significantly higher suppression under residue mulch and *Medicago polymorpha* (L). showed least suppression. Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (1000 l/ha) (Flood-jet) was statistically similar to weed-free in terms of grain yield, net returns and B:C ratio during both the years.

Keywords: Herbicides, Nozzle, Rice residue, Water volume, Weeds

Wheat (*Triticum aestivum* L.) is the world's most important food crop and fundamental to human civilization. In India, it is the second most cultivated cereal crop contributing up to 35–40% of the total food grain production. It is grown on approximately 30 million hectares (mha) with total production of around 95 million tonnes (MT) of wheat (Anonymous 2017a). Rice-wheat (RW) is the major cropping system of the country and occupies 10.6 mha spread over Indo-Gangetic Plains (IGPs). The two north-western states of Haryana and Punjab account for about 3 mha of RW cropping land and about 35% of India's wheat production. The major broadleaved weeds (*Rumex dentatus*, *Chenopodium album*, *Melilotus alba*, *Medicago polymorpha*, *Coronopus didymus*, *Anagallis arvensis* and *Lathyrus aphaca*, *R. dentatus*) are reducing the grain yield and quality of wheat. Sole reliance on herbicides has given rise to herbicide resistance (HR) in wheat weeds in India and new resistant species are being confirmed every few seasons. Among the weeds, *Phalaris minor* is the single most dominant grassy weed of wheat in RW system in north-western IGP of India (Brar and Walia 2007, Punia and Yadav 2009, Punia *et al.* 2012a, 2017a). *R. dentatus* and *Polypogon monspeliensis* have evolved resistance to ALS inhibitors (Chhokar *et al.* 2013, 2015, Singh 2016b, Yadav *et al.* 2017) and *Avena ludoviciana* to ACCase inhibitors (Singh 2016a), and *Chenopodium album* to sulfonylureas (Chhokar *et al.* 2017, Singh *et al.* 2017).

There is a need to formulate the conditions for higher efficacy of pre-emergence herbicides in surface retained residue scenario by modifying spray volume, spray nozzles and time of herbicides application. HR weeds in wheat were found susceptible to pre-emergence (PRE) herbicides (Kaur 2007, Chhokar and Sharma 2008, Dhawan *et al.* 2012). PRE herbicides are an effective anti-resistant management strategy that reduce the risk of HR development (Lopes-Ovejero *et al.* 2013, Beckie and Hall 2014). Also, a single PRE application is not sufficient to control all weed cohorts and to evade POE application. Therefore, PRE herbicides need a mixing partner for improved and broad-spectrum control of weeds.

MATERIALS AND METHODS

A field experiment was conducted during winter (*rabi)* seasons of 2019–20 and 2020–21 at the Regional Research Station, CCSHAU, Uchani, Karnal (29º 43' 41" N and

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76º 58' 50" E at an elevation of 243 m amsl), Haryana. The surface (0–15 cm) soil was sandy loam (57.5% sand, 24.3% clay, and 18.2% clay). The maximum temperature is about 45°C during the hot summer (May and June), while during the winter months (December and January) the minimum temperature may be near zero. There average annual rainfall is around 600 mm, 70–80% of which is received during the monsoon period i.e. July–September, and the rest is received in showers of cyclic rains during the winter and spring seasons. The mean relative humidity remains nearly constant at about 75–90% from July–March, steadily decrease in April, and stays around 40–50% during the hot summer months of May and June.

A total of 14 weed control treatments, including PRE herbicide (pendimethalin 1500 g/ha), sequential application of PRE *fb* POE (pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha), weedy check and weed-free checks were arranged in a randomised block design (RBD) with 3 replications. PRE herbicides were applied on the top of rice residues using two water volumes (500 and 1000 l/ha) and three types of nozzles (flat-fan, flood-jet and air-injection).

Wheat variety and plant husbandry: ZT-wheat (var. HD 2967) was sown with happy seeder under surface residue load of 6 t/ha (chopped) on 18th November, 2019, and 25th November 2020. The soil of the field was clay loam in texture, low in organic carbon (0.35%), medium in phosphorus (11 kg P_2O_5/ha) and potassium (284 kg K_2O/ha). Each plot size was 6 m × 2.2 m. The seeding rate was 100 kg/ha at 20 cm row spacing. The pre-emergent herbicide pendimethalin was applied immediately after sowing on chopped residue with a knapsack sprayer fitted with a flat fan, flood jet and air injection nozzle using a spray volume of 500 and 1000 l/ha and post-emergent herbicides were applied at 35 DAS. For experiment, preceding rice was combine harvested, leaving standing stubbles of 20–25 cm height during both the years. Total residues (loose + anchored) were approx. 6 t/ha and, chopper and spreader were used for chopping and uniform residue distribution in the field. The crop was managed according to the standard agronomic practices of the state university. Weed density was determined by the quadrat method suggested by Misra and Puri (1954). Two quadrats of 50 cm × 50 cm were randomly located in each plot 30, 60 and 90 DAS. The weeds inside the quadrat were counted and averaged before converting to numbers/m^2. The original values were subjected to square root transformation ($\sqrt{X+1}$). The weeds in the quadrats selected for determining weed density were taken for recording dry biomass 30 and 60 DAS. These samples were dried under the sun and then kept in an oven at 65±5°C for 48 h. The dried samples were weighed and final dry biomass was expressed as g/m^2. The data were recorded by comparison of each treatment with an unsprayed weedy check (0% control).

Harvesting: Crop was harvested on 24th April 2020 and 25th April 2021. Sampling for grain yield of the crop was done from two random places of 2.0 m × 2.0 m size from each plot at the time of harvesting. An area of 0.2 m on each side of the plot and one border row on both sides of the experimental plots were harvested first, thereafter the net area separately. The grain weight was recorded at 14% moisture after threshing, cleaning and drying. Grain yield was recorded from a harvested area of 6 m × 1.8 m in each plot. Threshing was accomplished with a plot thresher followed by cleaning and grain yield recorded at the 14% level of moisture content. The grain yield was expressed as tonnes/ha.

Statistical analyses: Before statistical analysis, the % data of the weed control efficiency were subjected to angular transformation ($\sin^{-1}\sqrt{X}$) to improve the homogeneity of the variance. The data were subjected to the analysis of variance (ANOVA) (Fisher 1958). 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 was used for statistical analysis (http:/hau.ernet.in/about/opstat.php). The data were analysed separately for each year.

RESULTS AND DISCUSSION

Density of Phalaris minor: The density and biomass showed an increasing trend within the cropping season from 30–90 DAS during both years (Table 1). All over, PRE+POST emergence application of pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha reduced the population and biomass of *P. minor* significantly, relative to the weedy check. At all stages, high water volume (1000 l/ha) with flood jet nozzle reduced the weed density and biomass followed by air injection and flat fan. At 30 DAS, pendimethalin 1500 g/ha (flood jet) (1000 l/ha) performed better and at 60 and 90 DAS, pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (flood jet) (1000 l/ha) recorded lower *P. minor* density and biomass statistically similar to pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (Flood jet) (500 l/ha). Sindhu (2017a) reported that the herbicide mixture of pendimethalin 1.5 + metribuzin 0.14 kg/ha when applied on the top of mulch as pre-emergence with high carrier volume (1000 l/ha) reduced the density and biomass of *P. minor, R. dentatus, M. denticulata, M. indica, L. aphaca* and other weeds as compared to weedy check at harvest. In another tactic, application of pendimethalin 1.5 + metribuzin 0.140 kg/ha (500 l/ha) as early post-emergence i.e. one day before first irrigation to wheat also reduced the weed biomass (Sindhu *et al.* 2016). Only few researchers have evaluated the effectiveness of PRE herbicides applied either above or below mulch, mainly in landscape planting (Somireddy 2011, Chang *et al.* 2013). Yadav *et al.* (2016) found that the sequential application of pendimethalin 1000 g/ha or trifluralin 1000 g/ha just after sowing followed by clodinafop 60 g/ha or sulfosulfuron 25 g/ha at 35 DAS provided 90–100% control of *P. minor* along with broadleaved weeds in wheat, when compared to POST alone. Similar results were also reported by Kaur (2017).

Weed control efficiency and Weed index: Higher weed control efficiency (WCE) was recorded by pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (flood jet) (1000 l/ha) (99% 2019–20 and 98% 2020–21) followed by pendimethalin

Table 1 Effect of standardization of spraying technique for pre-emergence herbicides in zero-tillage (ZT) wheat with surface residue cover on the density (plants/m^2) and biomass (g/m^2) of *P. minor*

Treatment	Nozzle type	Water volume for PRE herbicide (l/ha)	Density (plants/m^2)						Biomass (g/m^2)					
			30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
			2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
Pendimethalin 1500 g/ha	Flat fan	500	3.86 (14)	4.19 (16.7)	5.63 (30.7)	5.86 (33.3)	5.80 (32.7)	5.80 (32.7)	7.4	8.5	16.8	16.5	17.7	15.8
Pendimethalin 1500 g/ha	Flat fan	1000	3.20 (9.3)	3.68 (12.7)	5.00 (24)	5.32 (27.3)	5.2 (26)	5.51 (29.3)	5.5	7.2	13.1	14.1	13.7	15.0
Pendimethalin 1500 g/ha	Flood jet	500	3.69 (12.7)	4.03 (15.3)	5.13 (25.3)	5.38 (32)	5.45 (28.7)	5.74 (32)	6.8	8.4	12.9	14.8	15.9	16.0
Pendimethalin 1500 g/ha	Flood jet	1000	2.88 (7.3)	3.40 (10.7)	4.73 (21.3)	5.07 (26.7)	5.00 (24)	5.26 (26.7)	4.5	6.6	12.5	12.8	12.4	13.7
Pendimethalin 1500 g/ha	Air injection	500	3.78 (13.3)	4.11 (16)	5.39 (28)	5.63 (30.7)	5.51 (29.3)	5.74 (32)	7.4	8.5	15.4	16.1	16.4	16.2
Pendimethalin 1500 g/ha	Air injection	1000	2.99 (8.0)	3.49 (11.3)	4.65 (20.7)	4.93 (23.3)	4.86 (22.7)	5.20 (26)	4.6	6.2	11.2	11.9	11.8	13.3
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Flat fan	500	3.77 (13.3)	4.00 (15.3)	3.19 (9.3)	3.68 (12.7)	3.7 (12.7)	4.20 (16.7)	7.5	8.1	5.6	6.8	6.8	9.8
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Flat fan	1000	3.28 (10)	3.66 (12.7)	3.15 (8.4)	3.50 (10)	3.21 (9.3)	3.60 (12)	5.3	7.4	5.4	6.5	5.3	6.4
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Flood jet	500	3.87 (14.7)	4.19 (17.3)	3.41 (8.7)	3.87 (11.3)	3.11 (8.7)	3.6 (12)	7.6	9.1	4.7	6.3	4.8	6.8
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Flood jet	1000	2.99 (10.7)	3.5 (15.3)	3.31 (6.7)	3.78 (9.3)	3.5 (7.3)	3.87 (10.7)	6.1	6.6	4.1	6.1	4.3	6.8
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Air injection	500	3.96 (14)	4.26 (16.7)	3.11 (10.7)	3.51 (14)	3.11 (8.7)	3.6 (12)	7.6	7.6	6.1	7.1	5.2	7.3
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Air injection	1000	3.4 (8)	4.02 (11.3)	2.76 (10)	3.21 (13.3)	2.87 (11.3)	3.41 (14)	4.8	6.5	5.4	7.5	5.7	8.0
Weed free	--	--	1 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	0.0	0.0	0.0	0.0	0.0	0.0
Weedy check	--	--	4.51 (19.3)	5.00 (24)	6.30 (38.2)	6.53 (41.5)	7.05 (48.7)	7.05 (48.7)	14.0	16.5	23.2	23.9	29.1	28.8
CD (P=0.05)			0.55	0.50	0.37	0.36	0.32	0.36	2.33	1.40	1.99	1.23	1.75	2.24

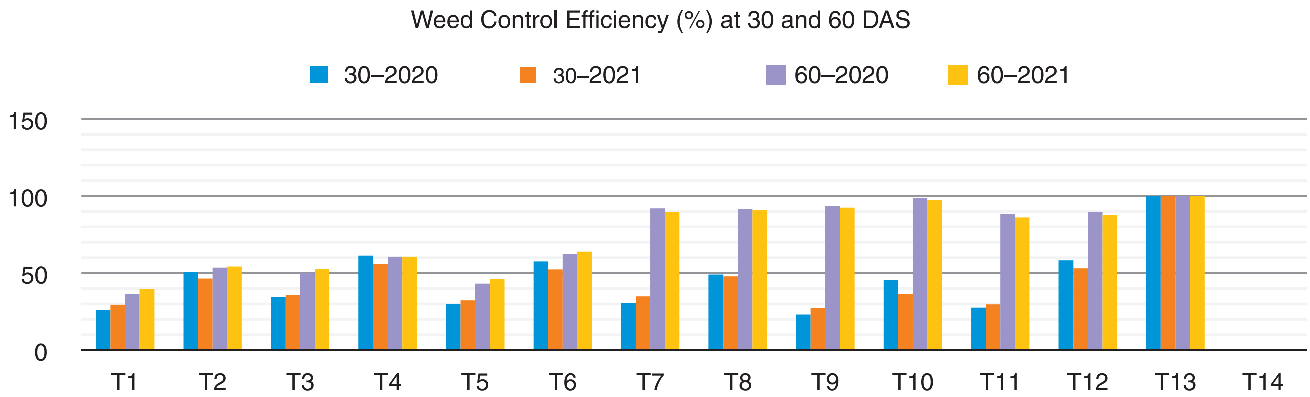

Fig 1 Effect of standardization of spraying technique for pre-emergence herbicides in zero-tillage wheat with surface residue cover on WCE (%) at 30 and 60 DAS

1500 g/ha *fb* pinoxaden 50 g/ha (flood-jet) (500 l/ha) (93% 2019–20 and 93% 2020–21) and pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (air injection) (500 and 1000 l/ha) (92% 2019–20 and 90, 91% 2020–21) (Fig 1). The lowest WCE was achieved under pendimethalin 1500 g/ha (flat-fan) (500 l/ha). Lower weed index (WI) was recorded by pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (flood-jet) (1000 l/ha) (4.83 2019–20 and 6.40 2020–21) and pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (air-injection) (1000 l/ha) (5.26 2019–20 and 7.90 2020–21). Whereas, the higher WI was recorded under pendimethalin 1500 g/ha (flat-fan) (500 l/ha) (Fig 2). The application of herbicidal treatments significantly reduced the growth and development of *P. minor* and recorded the highest weed control efficiency as compared to weedy. In the case of chopped residue application, interception of herbicides would probably be more due to increased surface area of the mulch material and complete covering of soil surface and more weed control efficiency.

Yield attributing characters and yield: The benefits of residue mulching were also reflected in wheat grain yield, and harvest index (HI). Data pertaining to grain yield and HI wheat presented in Table 2 show that significant variations existed in grain yield and HI of wheat due to the effects of different treatments. Maximum grain yield and HI was recorded in weed free plots that were on par with pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (Flood jet) (1000 l/ha) (6387 kg/ha in 2019–20 and 5932 kg/ha in 2020–21) followed by pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (Flood jet) (500 l/ha) and pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (Air injection) (1000 l/ha). Weedy check plot recorded lowest grain yield and HI (4504 kg/ha in 2019–20 and 4087 kg/ha in 2020–21). Better efficacy of pendimethalin applied with flood-jet nozzle with higher water volume of 1000 l/ha in terms of suppression of weeds emergence could be the main reason for better growth and development of wheat crop. Better efficacy of pendimethalin applied with flood-jet air-injection nozzles with higher water volume of 1000 l/ha in terms of suppression of weeds emergence could be the main reason for better growth and development of wheat crop. Higher or similar wheat yield under rice residue mulch was also reported in other studies in the same environment (Chakraborty *et al.* 2008, Sharma *et al.* 2008, Balwinder-Singh *et al.* 2011b, Ram *et al.* 2013).

Economics: PRE + POST application of pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (Flood jet) (1000 l/ha) provided highest net returns and B:C ratio (₹65712/ha, 1.80 in 2019–20 and ₹58204/ha, 1.71 in 2020–21, respectively) (Table 2) followed by pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha (Flood jet) (500 l/ha). Lowest net returns and B:C ratio were obtained under sole application of pre-emergence herbicide i.e. pendimethalin 1500 g/ha (Flat-fan) (500 l/ha). In contrast, pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha with 6 t/ha residue mulch in combination with high water volume and suitable nozzle type (Flood-jet), a longer-acting treatment affected the second and third weed cohorts at 60 and 90 DAS.

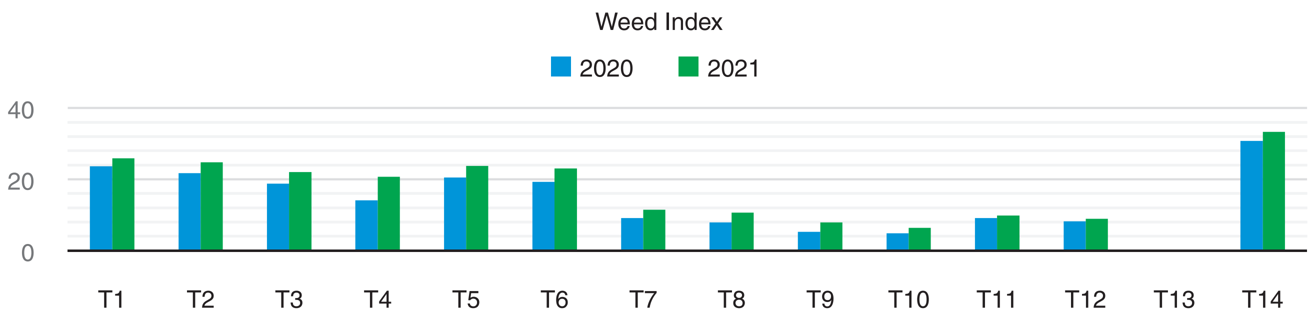

Fig 2 Effect of standardization of spraying technique for pre-emergence herbicides in zero-tillage wheat with surface residue cover on Weed index.

Table 2 Effect of standardization of spraying technique for pre-emergence herbicides in zero-tillage wheat with surface residue cover on yield and economics

Treatment	Nozzle type	Water volume for PRE herbicide (l/ha)	Grain yield (kg/ha)		Harvest index		Net returns (₹/ha)		B:C ratio	
			2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
Pendimethalin 1500 g/ha	Flat fan	500	4964	4539	43.63	40.30	41203	34264	1.51	1.43
Pendimethalin 1500 g/ha	Flat fan	1000	5092	4607	44.08	40.47	43853	35761	1.55	1.45
Pendimethalin 1500 g/ha	Flood jet	500	5279	4776	44.60	41.12	47845	39310	1.60	1.49
Pendimethalin 1500 g/ha	Flood jet	1000	5582	4854	45.33	40.81	54442	41628	1.68	1.52
Pendimethalin 1500 g/ha	Air injection	500	5166	4668	43.79	40.32	45972	37483	1.57	1.47
Pendimethalin 1500 g/ha	Air injection	1000	5249	4713	43.97	40.31	47784	38610	1.60	1.48
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Flat fan	500	5909	5421	46.40	43.16	59011	50853	1.72	1.62
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Flat fan	1000	5989	5475	46.38	43.13	60932	52232	1.74	1.64
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Flood jet	500	6259	5840	46.54	43.36	64807	55973	1.79	1.68
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Flood jet	1000	6387	5932	46.32	43.41	65712	58204	1.80	1.71
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Air injection	500	5906	5525	45.86	43.13	59523	53455	1.73	1.65
Pendimethalin 1500 g/ha *fb* pinoxaden 50 g/ha	Air injection	1000	6068	5775	45.58	42.92	61339	54905	1.75	1.67
Weed free	--	--	6501	6124	47.06	44.62	67946	60839	1.82	1.75
Weedy check	--	--	4504	4087	42.78	39.26	32965	26120	1.42	1.34
CD (P=0.05)			475	522	1.68	1.57	-	-	-	-

Given the dearth of new herbicides and concurrent break out of herbicide resistance in India, it is now obligatory to conserve the existing herbicides resources while maintaining the productivity and profitability of wheat. Rice residues as mulch in wheat suppressed most of the weeds by reducing their weed and growth. ZT-wheat sowing with happy seeder with chopped rice residues (6 t/ha), application of pendimethalin 1500 g/ha as pre-emergence *fb* pinoxaden 50 g/ha as post-emergence with flood-jet nozzle and high carrier volume (1000 l/ha) improved herbicide penetration through mulch and provided satisfactory control of *P. minor* ultimately resulting into grain yield similar to weed-free.

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