Indian Journal of Weed Science (2023) **55**(3): 244–248
http://dx.doi.org/10.5958/0974-8164.2023.00045.X

RESEARCH ARTICLE

Halauxifen plus fluroxypyr pre-mix herbicide as a post-emergent against broad-leaf weeds in wheat

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Received: 1 April 2023 | Revised: 24 July 2023 | Accepted: 27 July 2023

ABSTRACT

Broad-leaf weeds are known to pose a severe challenge to wheat in the rice-wheat cropping system in North-West India. A field studies were conducted at Research Farm of Department of Agronomy, Punjab Agricultural University, Ludhiana during 2017-18 and 2018-19 in randomized complete block design replicated four times to evaluate the efficacy of herbicide with an alternative mechanism of action for the control of broad-leaf weeds in wheat. Treatments comprised of halauxifen-methyl 1.21% + fluroxypyr-methyl 38.9% EC at 160.4 (4.8+155.6), 200.6 (6.1+194.5) and 240.66 (7.3+233.4) g/ha, halauxifen 10.42% WG at 7.3 g/ha + PG 26-2 N surfactant at 750 ml/ha, fluroxypyr-methyl 48% EC at 233.4 g/ha, metsulfuron 20% WP at 4 g/ha+ surfactant, metsulfuron 10% + carfentrazone 40% DF at 25 g/ha + surfactant, weed free check and weedy check. The results indicated that post-emergence application of halauxifen + fluroxypyr at 200.6 and 240.66 g/ha effectively controlled broad-leaf weeds namely *Medicago denticulata, Rumex dentatus* and *Coronopus didymus* and gave wheat grain yield of 5.25 and 5.34 and 5.15 & 5.25 t/ha during 2017-18 and 2018-19, respectively. The current study demonstrated that halauxifen + fluroxypyr at 200.6-240.66 g/ha would be a suitable option for controlling broad-leaf weeds in wheat in Punjab.

Keywords: Broad-leaf weeds, Fluroxypyr, Halauxifen, Ready-mix, Weed management, Wheat

INTRODUCTION

Wheat is infested with diverse weed flora of grasses as broad-leaf weeds. In irrigated wheat, many broad-leaf weeds namely *Rumex dentatus* L., *Medicago denticulata* L., *Anagallis arvensis* L., *R. spinosus, Convolvulus arvensis* L., *Malva parviflora, Chenopodium album, Vicia sativa, Lathyrus aphaca, Circium arvense* (L.) Scop., *Melilotus alba, Coronopus didymus, Polygonum plebeium* and *Spergula arvensis* are of major concern in rice-wheat system in the North-Western part of India. Due to the continuous use of graminicides like clodinafop, fenoxaprop, pinoxaden *etc*., the weed spectrum started changing from grass to broad-leaved weeds and increased to the extent that weeds like *Rumex* and *Medicago* are alarmingly dominating the wheat fields. Thus, controlling broad-leaf weeds is essential for sustaining wheat productivity, as these are also becoming a major problem in conservation agriculture.

The wheat crop should be weed free during the critical period of 30-40 days of sowing otherwise, it may cause drastic yield reduction under heavy weed infestation. The yield losses depend on weed species, density, time of emergence, wheat variety, row spacing, soil, environmental factors and management factors *viz.* irrigation, fertilizer use, soil type, weed control practices and cropping sequences (Chhokar *et al*. 2007a,b). In wheat, 2,4-D, metsulfuron, carfentrazone and a pre-mix of metsulfuron plus carfentrazone are recommended to control broad-leaf weeds in Punjab. For control of broad-leaved weeds, 2,4-D is less preferred herbicide by the farmers due to its efficacy on limited broad-leaf weed species. After 2,4-D, metsulfuron was widely used herbicide but again is ineffective against weeds like *Malva parviflora* (Chhokar *et al*. 2002) and *S. nigrum* (Mukherjee *et al.* 2011) and provides poor control of *Rumex* due to resistance (Dhanda *et al.* 2020). Then, carfentrazone-ethyl was also recommended to control hardy weeds like *Malva* spp., *Solanum nigrum* and *Convolvulus arvensis* and other broad-leaf weeds. But, it does not control the subsequent weeds emerging after application due to lack of its residual activity (half-life of carfentrazone is 2-5 days) in soil (Lyon *et al.* 2007, Willis *et al.* 2007). Pre-mix of metsulfuron + carfentrazone has been recommended to control hardy and all other broad-leaf weeds, but its availability is a major challenge.

As many broad-leaf weeds germinate in flushes, the application stage is very important with respect to the herbicide used. All these herbicides are effective

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only at 2-4 leaf stage. Most of the times, farmers delay herbicide application due to foggy weather, field not coming to field capacity especially when heavily irrigated or in heavy textured soil. Therefore, if the weeds germinate after the spray window or sometimes weather prevents application at appropriate crop growth stage window, then the benefits of using herbicides which can control weeds at 4-8 leaf stage can serve as a useful tool for management of weeds.

Continuous dependence on a single herbicide, besides developing resistance in weeds, also causes a shift in weed flora. Hence, to address these problems, evaluating alternative herbicides with new mode of action becomes imperative. Halauxifen-methyl is the first active ingredient of the new arylpicolinate group (Epp *et al*. 2016) and belongs to the synthetic auxin mechanism of action. It is absorbed and translocated by the xylem and phloem, and accumulates in the meristematic tissue. Herbicide is rapidly degraded in soil and provides effective control of several important broad-leaf weeds (EFSA, 2014). Symptoms are similar to the herbicide 2,4-D, i.e., epinasty, deformation, necrosis, induces uncontrollable cell division and subsequent death (Epp *et al.* 2016). So, there is dire need to check the possibility of new mode of action herbicide halauxifen + fluroxypyr to control the broad-leaf weed flora in wheat.

MATERIALS AND METHODS

A field experiment was conducted to investigate the effect of new pre-mix halauxifen + fluroxypyr herbicide against broad-leaf weeds in wheat for two consecutive years 2017-18 and 2018-19 at Research Farm of Department of Agronomy, Punjab Agricultural University (PAU), Ludhiana, Punjab. The soil of the experimental site was sandy loam in texture, normal in reaction (pH 7.2) and electrical conductivity (0.11dS/m), low in organic carbon (0.42%) and available nitrogen (222.2 kg/ha) and high in available phosphorus (16.9 kg/ha) and potassium (201.43 kg/ha). The experiment was conducted in a randomized complete block design with four replications comprising nine treatments, which includes halauxifen 1.21% + fluroxypyr 38.9% EC at 160.4 (4.8+155.6), 200.6 (6.1+194.5) and 240.66 (7.3+233.4) g/ha, halauxifen 10.42% WG at 7.3 g/ha + PG 26-2 N surfactant at 750 ml/ha, fluroxypyr-methyl 48% EC at 233.4 g/ha, metsulfuron 20% WP at 4 g/ha + surfactant, metsulfuron 10% + carfentrazone 40% DF at 25 g/ha + surfactant, weed free check and weedy check. Herbicides were applied as post-emergence at 40 days after sowing (4-8 leaf stage) except metsulfuron and metsulfuron + carfentrazone, which were applied at 30 days after sowing (2-4 leaf stage). A knapsack sprayer (Aspee V-Dyut Delux VBD09) fitted with a flat-fan nozzle (FFPB/85/630) was used for herbicide application using 375 L/ha of water. A uniform spray of pinoxaden at 35 DAS at recommended rate was done to control *Phalaris minor* in the experiment.

Wheat varieties '*PBW 725*' and '*PBW 677*' were sown on 20 November, 2017 and 14 November, 2018 using 100 kg seed per hectare in 20 cm spaced rows with a seed cum fertilizer drill. The recommended doses of fertilizers were applied (125 kg N per ha, 50 kg P per ha and 30 kg K per ha) to the crop. The source of NPK used was urea, DAP and muriate of potash, respectively. Half of the recommended dose of N and whole of phosphorus and potassium were applied at the time of sowing and remaining half dose of N was applied as top dressing at the time of first irrigation. All the recommended plant protection measures were carried out as per the local recommendations of the state.

Data on weed density and biomass were recorded at 30 and 60 days after application (DAA) by placing quadrat (50 × 50 cm) at two representative spots in each plot. Weed samples were oven dried at 70 °C for constant dry biomass. Data were analyzed using analysis of variance (ANOVA) to evaluate the differences among treatments while the means were separated using the least significant difference (LSD) test at the 5% significance level. Weed density and biomass data were subjected to square root transformation.

RESULTS AND DISCUSSION

Predominant weed species in the experimental field consisted of *Rumex dentatus*, *Coronopus didymus*, *Medicago denticulata* among broad-leaf weeds. One broad-leaved weed *viz. Oenothera* spp., was also recorded but with very low densities (<2%), hence not included.

During both years, all the herbicide treatments recorded significantly lower weed density and weed biomass than weedy check. At 30 days after application (DAA), halauxifen + fluroxypyr at 200.6 and 240.66 g/ha recorded effective control of *Rumex dentatus*, *Medicago denticulata* and *Coronopus didymus*. Halauxifen 10.42% WG at 7.3 g/ha gave moderate control of *R. dentatus* and *Medicago denticulata* and poor control of *C. didymus* during both years. Fluroxypyr-methyl at 233.4 g/ha provided good control of *Coronopus didymus*, however significantly higher weed density of *M. denticulata* was recorded as compared to other herbicide treatments. Fluroxypyr gave poor control of *Medicago* as compared to other broad-leaf weeds (**Table 1**). At 60 DAA, all the three doses (240.66, 200.6 and 160.4 g/ha) of halauxifen + fluroxypyr were statistically at par for the control of *R. dentatus, C. didymus* and *M. denticulata* during both the years. Significantly more density of *C. didymus* was recorded in lower dose of halauxifen + fluroxypyr at 160.4 g/ha as compared to its higher doses. Metsulfuron + carfentrazone + surfactant at 25 g/ha provided good control of all broad-leaf weeds in both years. However, metsulfuron alone recorded *Rumex* and *Medicago* density in 2018-19 (**Table 2**).

All the herbicide treatments recorded significantly lower weed biomass as compared to weedy check during both years. The halauxifen + fluroxypyr at 240.66 g/ha recorded significantly lower weed biomass at 30 and 60 DAA (**Table 3**) during 2017-18 while during 2018-19, halauxifen + fluroxypyr at 200.6 and 240.66 were statistically at par with each other for biomass accumulation of weeds. Metsulfuron + carfentrazone provided good control of all weeds hence did not accumulate any weed biomass. Chhokar *et al.* (2007b) also reported effective control of *M. parviflora* with carfentrazone-ethyl. Moreover, it has also been reported that ready-mix combination of metsulfuron

Table 1. Effect of weed control treatments on weed density at 30 DAA in wheat

Treatment	Dose (g/ha)	Weed density (no./m^2)**							
		Rumex dentatus		*Medicago denticulata*		*Coronopus didymus*		Total	
		2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Halauxifen + fluroxypyr	160.4	1.24 (0.7)	1.00(0)	1.00(0)	1.67(2)	1.41(1)	2.37(5)	1.55(2)	2.78(7)
Halauxifen + fluroxypyr	200.6	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Halauxifen + fluroxypyr	240.66	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Halauxifen 10.42% WG +PG	7.3	1.55(2)	3.78(13)	2.37(5)	1.00(0)	4.93(23)	1.96(3)	5.57(30)	4.18(16)
Fluroxypyr-methyl 48% EC	233.4	2.38(5)	2.38(5)	2.88(7)	3.31 (10)	1.00(0)	1.00(0)	3.60(12)	3.95(15)
Metsulfuron 20% WP + surfactant	4	1.00(0)	1.90(3)	1.00(0)	1.41(1)	1.67(3)	1.00(0)	1.00 (0)	2.15(4)
Metsulfuron + carfentrazone + surfactant	25	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.67 (3)	1.00(0)
Weed free check	-	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Weedy check	-	3.08(9)	4.70(21)	3.20(9)	3.78(13)	5.19(26)	4.03(15)	6.70(44)	7.13(49)
LSD (p=0.05)		0.68	0.44	0.29	0.75	0.80	0.59	0.94	0.79

*DAA- days after application; **Data subjected to square root transformations; figures in parenthesis are means of original values

Table 2. Effect of weed control treatments on weed density at 60 DAA in wheat

Treatment	Dose (g/ha)	Weed density (no./m^2)**							
		Rumex dentatus		*Medicago denticulata*		*Coronopus didymus*		Total	
		2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Halauxifen + fluroxypyr	160.4	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.41(1)	2.16(4)	1.41(1)	2.16(4)
Halauxifen + fluroxypyr	200.6	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Halauxifen + fluroxypyr	240.66	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Halauxifen 10.42% WG +PG	7.3	3.31(10)	4.28(17)	2.62(6)	1.24(0.7)	4.65(21)	2.88(7)	6.13(37)	5.13(25)
Fluroxypyr-methyl 48% EC	233.4	2.44(5)	2.64(6)	2.62(6)	3.85(14)	1.79(3)	2.85(7)	3.79(14)	5.31(27)
Metsulfuron 20% WP + surfactant	4	1.00(0)	2.57(6)	1.00(0)	2.93(8)	1.55(2)	1.00(0)	1.55(2)	3.77(14)
Metsulfuron + carfentrazone + surfactant	25	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Weed free check	-	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Weedy check	-	3.37(10)	5.44(29)	4.34(18)	4.03(15)	5.25(27)	4.58(20)	7.47(55)	8.06(64)
LSD(p=0.05)		0.23	0.25	0.43	0.45	0.93	0.35	0.92	0.36

*DAA- days after application; **Data subjected to square root transformations; figures in parentheses are means of original values

Table 3. Effect of weed control treatments on weed biomass at 30 and 60 DAA in wheat

Treatment	Dose (g/ha)	Weed biomass (g/m^2)**			
		30 DAA		60 DAA	
		2017-18	2018-19	2017-18	2018-19
Halauxifen + fluroxypyr	160.4	3.04 (8)	3.60 (12)	2.16 (6)	4.37 (18)
Halauxifen + fluroxypyr	200.6	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Halauxifen + fluroxypyr	240.66	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Halauxifen 10.42% WG +PG	7.3	6.25 (38)	6.26 (38)	7.03 (49)	7.38 (54)
Fluroxypyr-methyl 48% EC	233.4	5.15 (26)	4.74 (22)	4.00 (15)	6.57 (42)
Metsulfuron 20% WP + surfactant	4	2.08 (4)	3.14 (9)	2.98 (9)	3.92 (14)
Metsulfuron + carfentrazone + surfactant	25	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weed free check	-	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weedy check	-	11.45 (130)	12.47 (155)	13.76 (188)	15.99 (256)
LSD (p=0.05)		0.83	0.57	1.30	0.90

*DAA- days after application; **Data subjected to square root transformations; figures in parentheses are means of original values

+ carfentrazone is better against the diverse weed flora than sole metsulfuron (Singh *et al.* 2011, Chhokar *et al.* 2007b). Among all the herbicide treatments, halauxifen at 7.3 g/ha recorded the highest weed biomass from 2017-18 to 2018-19.

Effect on plant height of wheat was found to be non-significant under different herbicide treatments during both years. The highest grain yield was recorded with halauxifen + fluroxypyr at 240.66 g/ha, which was statistically at par with its lower dose at 200.6 g/ha during both years (**Table 4**). The halauxifen at 7.3 g/ha and fluroxypyr at 233.4 g/ha recorded less tillers and grain yield as compared to pre-mix halauxifen + fluroxypyr during both years. Compared to weedy check, all the weed control treatments resulted in significantly higher wheat grain yield due to effective control of broad-leaf weeds. The grain yield in pre-mix of halauxifen + fluroxypyr produced was significantly more than the sole application of halauxifen and fluroxypyr. This was mainly attributed to improved growth and yield attributes (height and tillers) due to effective weed control.

Correlation studies

There was positive correlation between wheat tillers with grain yield. However, weed density and weed biomass were negatively correlated during both years. Highest positive correlation was recorded between tillers and grain yield of wheat (0.990**) during 20017-18. Grain yield also had positive relationship with WCE (0.974**) at 30 days after application (DAA) and (0.971**) at 60 DAA, respectively during 2017-18. Correlation coefficient was negative between grain yield and weed density (-0.878** and -0.886** at 30 and 60 DAA) and weed biomass (-0.974** and -0.971** at 30 and 60 DAA), respectively during 2017-18. The highest positive correlation was recorded in grain yield with wheat tillers (0.970**) during 2018-19. Correlation coefficient was negative between grain yield and weed density (-0.976** and -0.947** at 30 and 60 DAA) and weed biomass (-0.977** and -0.979**at 30 and 60 DAA), respectively during 2018-19 (**Table 5**).

Correlation between grain yield of wheat and total biomass of weeds

The linear regression equation describes the relationship between the biomass of total weeds and wheat grain yield (**Figure 1** and **2**). There is linear close relationship between grain yield and biomass with R^2=0.948, 0.943, 0.963 and 0.962 at 30 and 60 DAA, respectively during 2017-18 and 2018-19. The results revealed significant response of weed control treatments to wheat grain yield and weed biomass. Maximum wheat grain yield (5.34 t/ha) was recorded in higher dose of halauxifen + fluroxypyr at 240.66 g/ha. The grain yield of wheat decreased as the biomass of weeds increased. The minimum grain yield (4.10 and 3.78 t/ha) was obtained in weedy check during 2017-18 and 2018-19.

Table 4. Effect of weed control treatments on yield attributes and yield of wheat

Treatment	Dose (g /ha)	Tiller count (no./m^2)		Plant height (cm)		Grain yield (t/ha)	
		2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Halauxifen + fluroxypyr	160.4	326.67	324.30	111.20	106.40	5.06	5.01
Halauxifen + fluroxypyr	200.6	333.17	326.13	109.27	108.13	5.25	5.15
Halauxifen + fluroxypyr	240.66	336.67	331.43	113.00	106.70	5.34	5.25
Halauxifen 10.42% WG +PG	7.3	326.23	324.30	109.13	108.07	4.98	4.89
Fluroxypyr-methyl 48% EC	233.4	326.40	321.57	111.40	108.60	5.05	4.89
Metsulfuron 20% WP + surfactant	4	337.63	322.97	110.20	107.20	5.16	5.14
Metsulfuron + carfentrazone + surfactant	25	330.77	323.33	111.27	105.60	5.25	5.11
Weed free check	-	337.57	333.13	109.53	106.93	5.33	5.43
Weedy check	-	283.33	249.17	111.47	106.27	4.14	3.78
LSD (p=0.05)		24.82	8.47	NS	NS	0.14	0.11

Table 5. Correlation coefficient between weed density, biomass, tillers and grain yield of wheat

	Grain yield	Weed density 30 DAA	Weed density 60 DAA	Weed biomass 30 DAA	Weed biomass 60DAA	Tillers	Grain yield	Weed density 30 DAA	Weed density 60 DAA	Weed biomass 30 DAA	Weed biomass 60 DAA	Tillers
	2017-18						2018-19					
Grain yield	1	-.878**	-.886**	-.974**	-.971**	.990**	1	-.976**	-.947**	-.977**	-.979**	.970**
Weed density 30 DAA	-.878**	1	.997**	.935**	.915**	-.863**	-.976**	1	.981**	.985**	.984**	-.938**
Weed density 60 DAA	-.886**	.997**	1	.938**	.921**	-.870**	-.947**	.981**	1	.951**	.952**	-.897**
Weed biomass 30 DAA	-.974**	.935**	.938**	1	.992**	-.980**	-.977**	.985**	.951**	1	.999**	-.974**
Weed biomass 60 DAA	-.971**	.915**	.921**	.992**	1	-.976**	-.979**	.984**	.952**	.999**	1	-.979**
Tillers	.990**	-.863**	-.870**	-.980**	-.976**	1	.970**	-.938**	-.897**	-.974**	-.979**	1

** Correlation significant at 0.01 level (2-tailed); DAA- Days after application

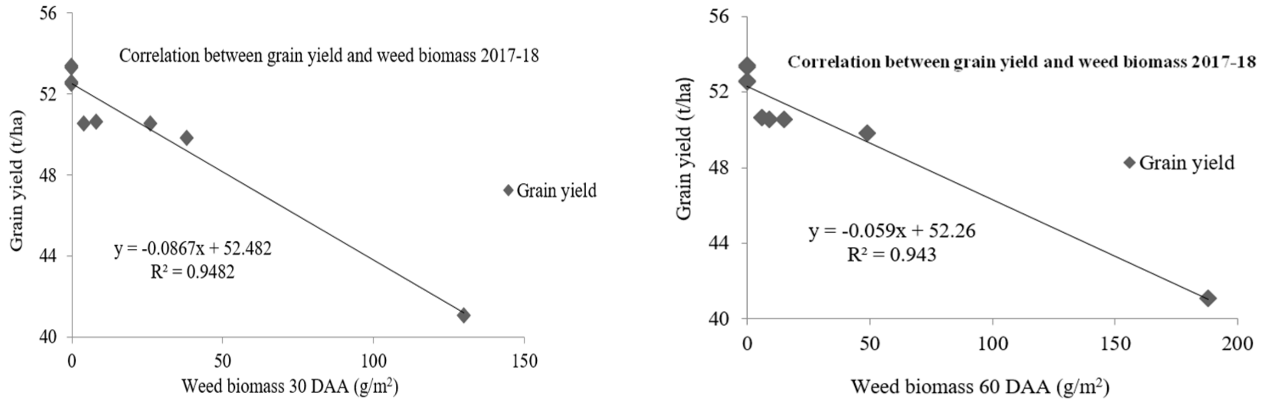

Figure 1. Correlation between grain yield and weed biomass at 30 and 60 DAA during 2017-18

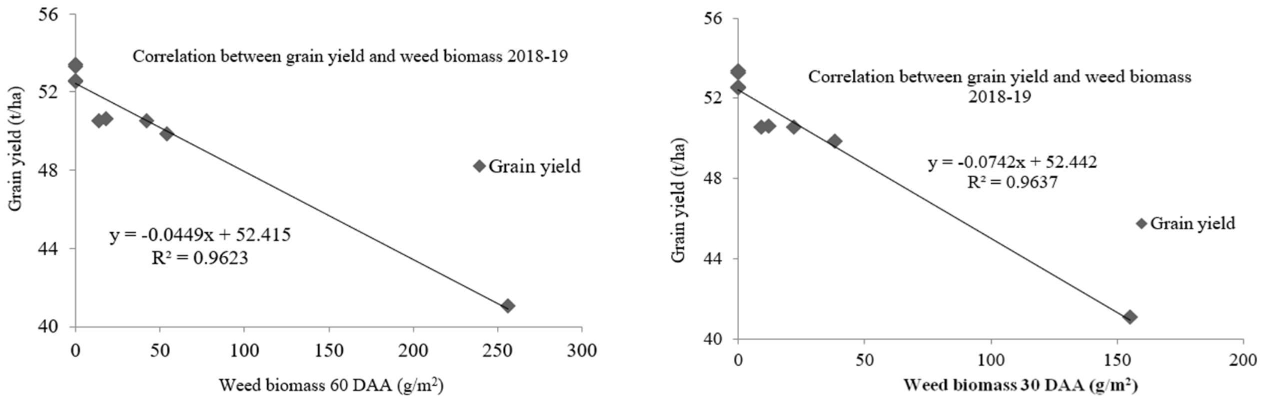

Figure 2. Correlation between grain yield and weed biomass at 30 and 60 DAA during 2018-19

Conclusion

The two-year study concluded that pre-mix of halauxifen + fluroxypyr at 200.6 to 240.66 g/ha may be used for management of broad-leaf weeds in wheat. The present study demonstrates that fields with diverse weed infestation require pre-mix herbicide combination. However, future studies need to be directed towards evaluating the compatibility of this pre-mix herbicide with recommended grass herbicides in wheat.

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