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Herbicide mixtures for weed control in dual purpose tall wheat and pendimethalin residue in wheat fodder and soil

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ABSTRACT

Weeds are the biological constraints to increase wheat productivity in Asia. A field experiment was conducted during the *Rabi* seasons of 2015-16 and 2016-17 to evaluate the efficacy of pendimethalin, pinoxaden, metsulfuron, sulfosulfuron, clodinafop under sole, mixture and their sequential application against control of mixed weed flora in dual purpose wheat at area of farm CCS HAU Hisar (Haryana). The season-long growth of weeds reduced wheat yield up to 55.4 and 59.3% during 2015-16 and 2016-17, respectively. Before cutting of wheat for fodder, among herbicidal treatments, pre-emergence (PE) application of pendimethalin 1500 g/ha significantly reduced grassy (*P. minor*) and broad-leaf weeds dry weight at 25 and 55 days after sowing (DAS) during both the years. After cutting, weed dry weight at 85, 115 DAS and at harvest was significantly reduced under sequential application of pendimethalin 1500 g/ha *fb* pinoxaden + metsulfuron (50 + 4) at 2 week after cutting (WAC) at 55 DAS, pendimethalin 1500 g/ha *fb* sulfosulfuron + metsulfuron (30 + 2) at 2 WAC and pendimethalin 1500 g/ha *fb* clodinafop + metsulfuron (60 + 4) at 2 WAC as compared to alone application of post-emergence (PoE). Among herbicidal treatments, significantly higher weed control efficiency, plant height, total tillers, grain yield and B:C ratio was observed under sequential application of herbicides than alone application of herbicides during both the years of study. Wheat fodder could be used safely for livestock as no residue was reported.

INTRODUCTION

Wheat can be grown as a dual purpose crop where it provides both grain and forage from the same patch of land (Shuja *et al.* 2010). The net profit or income of this system should be higher as both livestock and wheat commodities are available for market. Many factors could be responsible for low yield in wheat, but weed infestation is one of the major causes. Wheat (*Triticum aestivum* L.) is infested with complex weed flora. In India the average yield losses in wheat due to weeds vary from 20 to 32% across different wheat growing regions (Chhokar *et al.* 2008). Montazeri *et al.* (2005) reported that chemical method is most commonly used to control weeds in wheat fields. All types of weeds are not controlled by a single herbicide and the continuous use of a single herbicide results in weed shifts and evolution of herbicide resistance. The presence of mixed weed flora warrants integrated use of herbicides. More recently, in wheat crop, herbicide resistance has been reported in *Phalaris minor* against pinoxaden (Kaur *et al.* 2015), in *Rumex dentatus* against metsulfuron-methyl (Chhokar *et al.* 2017) and in *Avena ludoviciana* against clodinafop (Singh 2016). In dual purpose wheat, once the crop is cut for fodder, the competition from the weeds could be more as the crop will require time to regenerate and attain some growth. Under such situation, tank mixtures and sequential application of herbicides may play critical role to have a broad-spectrum weed control in dual purpose crop.

Wheat fodder is fed to livestock, the estimation of herbicide residue in wheat fodder need to be examined. Also the study of herbicide persistence in soil is required, as it may affects the yield of next growing crop on same piece of land. Schleicher *et al.* (1995) reported that pendimethalin persistence in the soil is affected by soil temperature and moisture conditions. Although determining the herbicide residues in the soil and crop produce is a challenging task because of very low concentration of analyte, as low as maximum residue limit (MRL) is imposed by the regulatory agencies. Therefore, the present experiment was designed for weed management to get maximum productivity and profitability of dual purpose wheat.

MATERIALS AND METHODS

Field experiments were conducted at the research farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India during winter season of 2015-16 and 2016-17. The experimental soil was sandy loam with organic carbon (0.35%), pH (7.9), EC (0.25 mmhos/cm) and was low in available nitrogen (132 kg N/ha), medium in available phosphorous (17 kg P/ha) and high in available potassium (370 kg K/ha). The experimental field had been under irrigated cluster bean-wheat cropping system. The weekly weather data (maximum and minimum temperature and rainfall) during the two growing seasons are represented in **Figure 1**. During second year (2016-17) mean weekly temperature was relatively 2-3^{0}C higher than first year at initial 7-8 weeks period of crop growth and had an adverse impact on growth parameters and yield of crop. The wheat crop received 33 mm rain in 2015-16 and 47.2 mm in 2106-17.

Seedbed preparation consisted of pre-sowing irrigation, ploughing with a disc harrow followed by two passes with a field cultivator followed by planking. Wheat '*C306*' was seeded on October 28, 2015 and October 30, 2016 using seed rate of 100 kg/ha, in 22.5 cm spaced rows. The crop was fertilized by using urea as the source of nitrogen at different doses and in different splits as shown in treatments. Phosphorous was applied at 30 kg P_2O_5/ha through single super phosphate as basal dose. Each year, the experiment was conducted in a randomized complete block design with three replications. Seven treatment combinations consisted of five herbicides *viz*. pendimethalin 1500 g/ha PE alone and followed by (*fb*) post-emergence (PoE) application of pinoxaden 50 g/ha + metsulfuron 4 g/ha, sulfosulfuron + metsulfuron (30 + 2) g/ha and clodinafop + metsulfuron (60 + 4) g/ha at 2 week after cutting (WAC), alone application of pinoxaden 50 g/ha + metsulfuron 4 g/ha, sulfosulfuron + metsulfuron (30+2) g/ha and clodinafop + metsulfuron (60 + 4) g/ha at 2 WAC. A weed-free check and a weedy check were also included for comparison with the herbicide treatments. The plot area was 6.5 × 4.5 m. All herbicides were applied using knapsack sprayer fitted with a flat fan nozzle. The crop was supplied with need based post-sowing irrigations when the soil moisture had declined to one-third of field capacity. All management practices other than the weed control treatments were consistent with the recommended package of practices for the CCS HAU, Hisar. In the weed free treatment, weeds were removed by hand weeding throughout the season. Grassy and broad-leaf weed dry weight was assessed taking, all weeds by using a 0.45 m^2 quadrant placed at two representative locations, in each plot at 25, 55, 85, 115 DAS and at harvest were cut and dried in an oven at 70 ^{o}C for 72 h and then weighed. Weed control efficiency (WCE) was calculated in dual purpose wheat by the formula:

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

After 55 days of sowing, dual purpose wheat crop was harvested for fodder at 5 cm stubble height. Plant height was measured from the ground to the tip of the uppermost leaf from five randomly selected plants in each plot at 55, 85, 115 DAS and at harvest. Total number of tillers was counted in one meter row length in each plot at crop harvest. Spike length from five representative spikes from each plot was measured in cm with scale. The crop was manually harvested at maturity and grain yield was recorded after threshing treatment wise. 1000-grains were counted from the grain yield of each plot and their weight was recorded as test weight of respective treatment. Benefit-cost ratio was calculated.

Data were analyzed using software S.P.S.S version 7.5. to evaluate the differences between treatments. Weed biomass data were square root transformed before performing ANOVA because of high variance. However, non-transformed means are presented with mean separation based on transformed values. Where the ANOVA indicated that treatment effects were significant, means were separated at $p<0.05$ and adjusted with Fisher's Protected Least Significant Difference (LSD) test.

Pendimethalin residue in fodder and soil was carried out at Agrochemicals Residues Testing Laboratory, Department of Agronomy, CCS Haryana Agricultural University, Hisar by GC-MS/MS (Agilent 7890A series).

RESULTS AND DISCUSSION

Weed studies

Before cutting, among herbicidal treatments, application of pendimethalin 1500 g/ha PE, pendimethalin 1500 g/ha PE *fb* pinoxaden +

metsulfuron (50 + 4) at 2 WAC (weeks after cutting), pendimethalin 1500 g/ha PE *fb* sulfosulfuron + metsulfuron (30 + 2) at 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60 + 4) at 2 WAC provided significantly reduced grassy weed (*P. minor*) and broad-leaf weed dry weight, which might be due to efficacy of pendimethalin as a PE herbicide in controlling weed flora in field (**Table 1**).

After cutting of dual purpose wheat for fodder, occurrence of new flush of weeds was observed because of application of irrigation and fertilizer in the field just after cutting of crop. In present experiment, sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50+4) at 2 WAC (week after cutting at 55 DAS), pendimethalin 1500 g/ha PE *fb* sulfosulfuron + metsulfuron (30 + 2) 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60+4) at 2 WAC recorded significantly less dry weight of weeds and higher weed control efficiency (WCE).Weeds under alone application of PE pendimethalin 1500 g/ha, PoE pinoxaden + metsulfuron (50 + 4) at 2 WAC, sulfosulfuron + metsulfuron (30 + 2) at 2 WAC, clodinafop + metsulfuron (60 + 4) at 2 WAC did not show-effective mortality as remaining stubble of weeds after cutting were aged and hardy, thus the alone PoE spray *i.e.* 70 DAS (means 2 weeks after cutting) of herbicides mixtures were less effective against those weeds (**Table 1**). The results are in conformity with Das (2008). But sequential application of PE and POE herbicides provided effective control of weeds. Similarly, sequential application of pendimethalin 1.5 kg/ha PE followed by tank mix pinoxaden + metsulfuron 64 g /ha or mesosulfuron + iodosulfuron 14.4 g/ha or sulfosulfuron + metsulfuron (RM) 32 g/ha PoE provided excellent control of *P. minor* as well as broad-leaf weeds in wheat field (Anonymous, 2015-16). Baghestani *et al.* (2008) also reported that tank-mix or pre-mix use of different herbicide chemistries or sequential application of pre- and post-emergence herbicides at different times showed effective weed control. Dry weight of both grassy and broad-leaf was increased under alone application of pendimethalin 1500 g/ha PE due to emergence of new flush of weeds during the crop season.

A negative relationship was observed between weed dry weight and WCE in the linear regression model (**Figure 2**). The regression model explained about 93.3% of the variation in WCE due to weed biomass and showed a good fit between the WCE and the weed biomass.

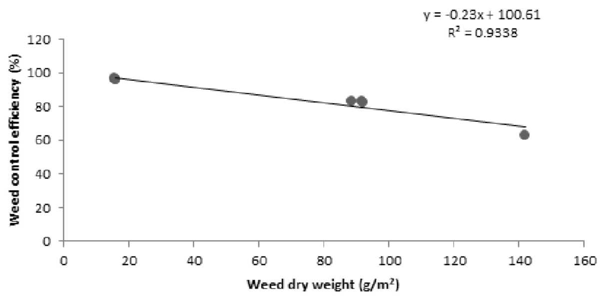


Figure 2. Relationship between weed dry weight and weed control efficiency (WCE). The line represents a linear model fitted to the average data for both the years

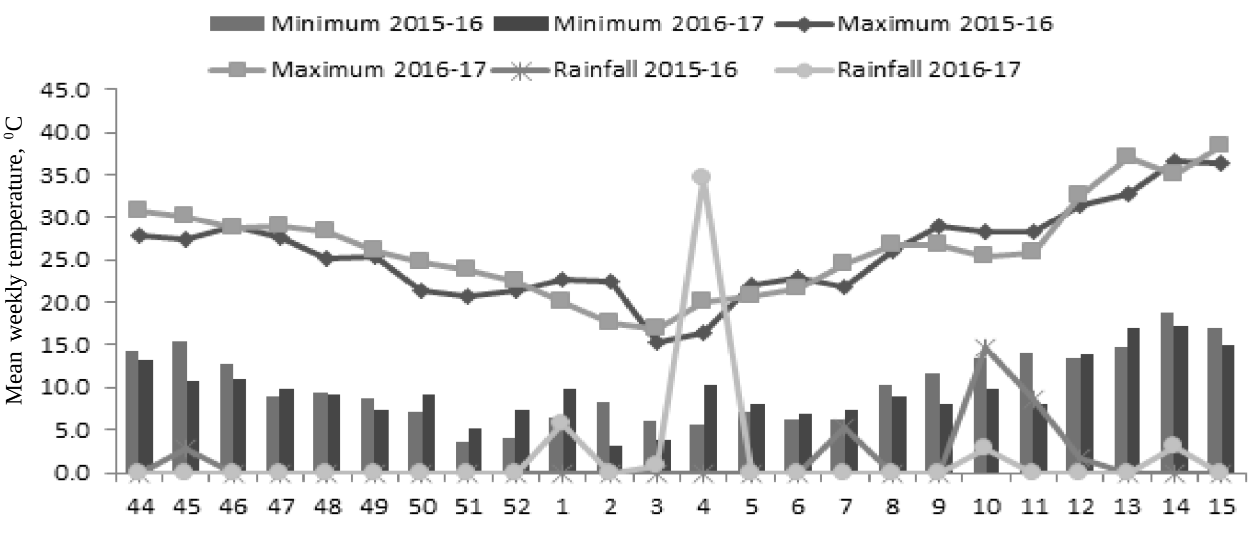
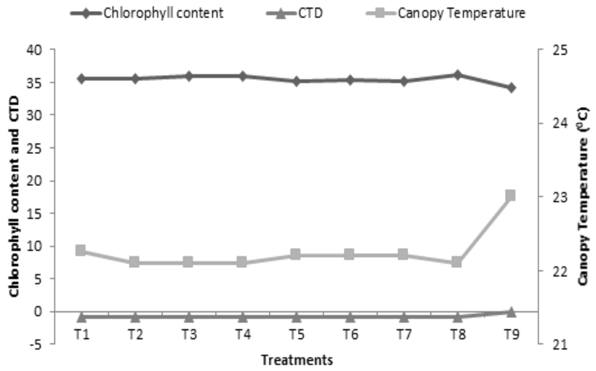


Figure 1. Average weekly temperature and rainfall data during 2015-16 and 2016-17 at CCS Haryana Agricultural University Research Farm, Hisar, India

Crop growth studies and yield

Among different herbicidal treatments, before cutting, significantly more plant height was recorded in all the treatments where pre emergence application of pendimethalin was applied as compared to the alone post-emergence application of herbicides (**Table 2**). After cutting, significantly shorter plants were recorded under alone application of PE pendimethalin 1500 g/ha, PoE pinoxaden + metsulfuron (50 + 4) at 2 WAC, sulfosulfuron + metsulfuron (30 + 2) at 2 WAC and clodinafop + metsulfuron (60 + 4) 2 WAC as compared to sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50 + 4) at 2 WAC, pendimethalin 1500 g/ha PE *fb* sulfosulfuron+ metsulfuron (30 + 2) at 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60 + 4) at 2 WAC at 85 DAS during both the years of study. Chlorophyll content and canopy temperature had not shown any significant difference among different treatments (**Figure 3**).



T1- Pendimethalin 1500 g PE; T2- Pendimethalin 1500 g PE *fb* pinoxadenn + metsulfuron (50 + 4) 2 WAC (weeks after cutting); T3- Pendimethalin 1500 g PE *fb* sulfosulfuron + metsulfuron (30 + 2) 2 WAC; T4- Pendimethalin 1500 g PE *fb* clodinafop + metsulfuron (60 + 4) 2 WAC; T5- Pinoxadenn + metsulfuron (50 + 4) 2 WAC; T6- Sulfosulfuron + metsulfuron (30 + 2) 2 WAC; T7- Clodinafop + metsulfuron (60 + 4) 2 WAC; T8- Weed free; T9- Weedy check

Figure 3. Effect of different herbicides on chlorophyll content (SPAD unit), canopy temperature (^{0}C) and CTD at heading stage of dual purpose wheat

Table 1. Effect of different herbicides on grassy and broad leaf weeds dry weight (pooled data of two years) in dual purpose wheat

Treatment	Dose (g/ha)	Time of application	25 DAS	55 DAS	85 DAS	115 DAS	At harvest
Grassy weed dry weight (g/m^2)							
Pendimethalin	1500	PE	1.3 (0.6)	2.1 (3.4)	2.6 (5.5)	6.3 (37.7)	7.7 (58.4)
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	1.2 (0.5)	2.2 (3.8)	2.3 (4.0)	2.0 (2.9)	2.7 (6.05)
Pendimethalin *fb* sulfosulfuron + metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	1.3 (0.7)	2.2 (3.7)	2.3 (4.3)	2.2 (4.1)	2.8 (6.8)
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE *fb* 2 WAC	1.3 (0.6)	2.3 (3.9)	2.3 (4.4)	2.1 (3.6)	2.8 (7.2)
Pinoxaden + metsulfuron	50 + 4	2 WAC	2.2 (3.5)	5.5 (29.1)	3.5 (11.4)	4.2 (16.4)	5.3 (27.3)
Sulfosulfuron+ metsulfuron	30 + 2	2 WAC	2.2 (3.8)	5.2 (26.0)	3.3 (9.9)	4.2 (16.9)	5.3 (26.4)
Clodinafop + metsulfuron	60 + 4	2 WAC	2.3 (4.2)	5.4 (28.3)	3.5 (10.9)	4.4 (18.5)	5.4 (28.2)
Weed free	-		1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check	-		2.3 (4.25)	5.4 (28.2)	5.8 (32.5)	10.4 (107)	12.6 (157)
LSD (p=0.05)			0.8	1.3	1.5	1.7	1.8
Broad-leaf weed dry weight (g/m^2)							
Pendimethalin	1500	PE	2.0 (2.8)	2.8 (6.9)	3.3 (9.8)	7.7 (58.0)	9.2 (83.8)
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	2.0 (3.0)	2.8 (6.4)	3.5 (10.9)	3.3 (9.8)	3.3 (9.7)
Pendimethalin *fb* sulfosulfuron + metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	1.9 (2.8)	2.5 (5.4)	3.3 (9.7)	2.9 (7.4)	3.2 (9.2)
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE fb 2 WAC	2.2 (2.3)	2.3 (4.3)	3.6 (11.7)	3.1 (8.5)	3.2 (8.8)
Pinoxaden + metsulfuron	50 + 4	2 WAC	3.2 (8.9)	4.6 (19.9)	4.3 (17.6)	6.6 (42.2)	7.9 (62.1)
Sulfosulfuron + metsulfuron	30 + 2	2 WAC	3.0 (7.9)	4.6 (19.5)	4.7 (20.7)	6.5 (41.6)	8.0 (62.5)
Clodinafop + metsulfuron	60 + 4	2 WAC	3.3 (10.1)	4.5 (19.4)	4.5 (19.0)	6.7 (43.1)	8.1 (63.7)
Weed free	-		1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check	-		3.2 (9.2)	5.8 (22.1)	6.7 (44.3)	12.9 (165)	14.5 (210)
LSD (p=0.05)			1.1	1.8	2.5	2.6	2.23

*Original data given in parentheses was subjected to square root transformation

Table 2. Effect of different herbicides on plant height (cm) of dual purpose wheat

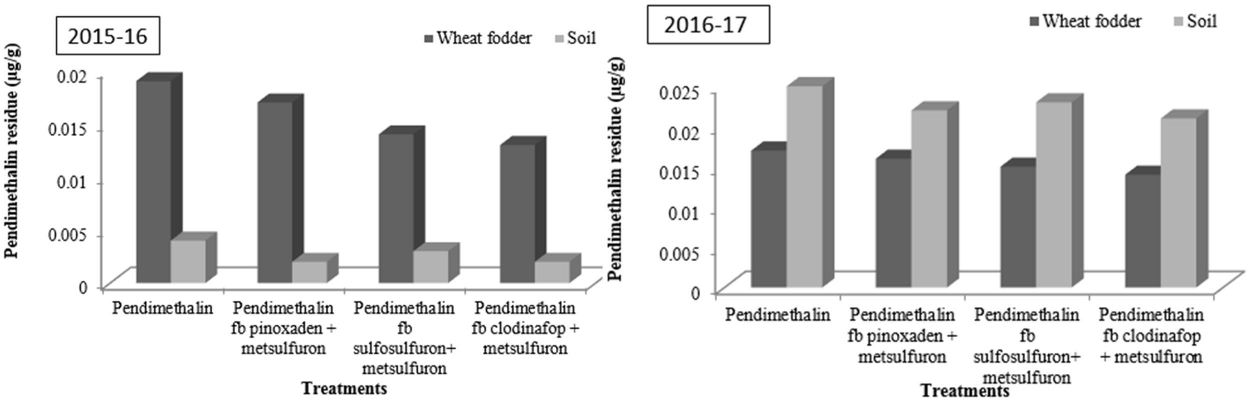
Treatment	Dose (g/ha)	Time of application	Plant height (cm) 2015-16 55 DAS	85 DAS	115 DAS	At harvest	2016-17 55 DAS	85 DAS	115 DAS	At harvest
Pendimethalin	1500	PE	37.2	67.1	98.7	108.9	40.4	71.0	99.7	113.3
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	37.5	71.1	99.9	109.9	40.7	75.4	100.9	114.3
Pendimethalin *fb* sulfosulfuron+ metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	37.3	71.2	100.8	110.9	40.5	75.5	101.8	115.3
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE *fb* 2 WAC	38.3	71.0	100.6	110.7	41.6	75.3	101.6	115.1
Pinoxaden + metsulfuron	50 + 4	2 WAC	35.1	66.8	99.8	109.8	38.1	70.8	100.8	114.2
Sulfosulfuron+ metsulfuron	30 + 2	2 WAC	35.0	66.6	99.6	109.6	38.0	70.7	100.6	113.9
Clodinafop + metsulfuron	60 + 4	2 WAC	34.7	67.0	100.2	110.2	37.7	71.0	101.2	114.6
Weed free	-		39.1	72.9	103.1	113.3	42.4	77.3	104.1	117.8
Weedy check	-		34.5	66.5	97.5	107.3	37.2	70.6	98.5	111.5
LSD (p=0.05)			2.1	1.6	1.8	2.0	2.3	1.7	1.8	2.1

Table 3. Effect of different herbicides on yield attributes and yield of dual purpose wheat

Treatment	Dose (g/ha)	Time of application	Fodder yield (t/ha)	Total tillers (no./m.r.l)	Spike length (cm)	Grain yield (t/ha)	Test weight (g)
2015-16							
Pendimethalin	1500	PE	3.80	83.2	8.4	2.26	42.6
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	3.84	83.1	8.8	2.93	43.2
Pendimethalin *fb* sulfosulfuron+ metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	3.82	84.4	8.8	2.99	43.8
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE *fb* 2 WAC	3.80	83.9	8.7	2.90	43.2
Pinoxaden + metsulfuron	50 + 4	2 WAC	3.70	79.1	8.6	2.60	42.2
Sulfosulfuron+ metsulfuron	30 + 2	2 WAC	3.75	79.3	8.6	2.70	42.7
Clodinafop + metsulfuron	60 + 4	2 WAC	3.72	78.7	8.6	2.64	42.2
Weed free	-		3.84	85.0	8.8	3.09	43.9
Weedy check	-		3.69	75.5	7.9	1.99	40.4
LSD (p=0.05)			NS	2.9	NS	0.19	NS
2016-17							
Pendimethalin	1500	PE	3.62	81.3	8.0	2.01	38.2
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	3.61	80.9	8.4	2.68	39.4
Pendimethalin *fb* sulfosulfuron+ metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	3.62	81.4	8.5	2.75	39.7
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE *fb* 2 WAC	3.64	81.1	8.4	2.65	39.3
Pinoxaden + metsulfuron	50 + 4	2 WAC	3.51	77.4	8.3	2.41	38.6
Sulfosulfuron + metsulfuron	30 + 2	2 WAC	3.49	77.3	8.3	2.49	38.8
Clodinafop + metsulfuron	60 + 4	2 WAC	3.51	77.0	8.3	2.40	38.7
Weed free	-		3.62	81.7	8.5	2.79	39.7
Weedy check	-		3.47	73.1	7.8	1.75	37.9
LSD (p=0.05)			NS	2.5	NS	0.14	NS

m.r.l- meter row length

Maximum number of total tillers, higher grain yield and B: C ratio were observed with weed free which were statistically at par with sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50 + 4) at 2 WAC, pendimethalin 1500 g/ha PE *fb* sulfosulfuron+ metsulfuron (30 + 2) at 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60 + 4) after 2 WAC which might be due to the reason that weed control by sequential application of herbicides and their mixture helped in reducing the competition of crop plants with weeds. The results corroborates with the findings of Anonymous, (2015-16). Sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50 + 4) 2 WAC, pendimethalin 1500 g/ha PE *fb* sulfosulfuron+ metsulfuron (30 + 2) 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60 + 4) 2 WAC recorded 32.18%, 33.5% and 31.4%, higher grain yield, respectively than weedy check.



Limit of detection (LOD) - 0.001 µg; Limit of quantification (LOQ) - 0.003 µg; Maximum residue limit (MRL) of 0.05 µg/g

Figure 4. Pendimethalin residue (µg/g) in wheat fodder and soil

However, weed control treatments had no significant effect on fodder yield of dual purpose wheat at 55 DAS during both years of experimentation (**Table 3**).

Residue of pendimethalin in wheat fodder and soil

The detected residue of pendimethalin in wheat fodder and soil during both the crop seasons were below the maximum residue limit (MRL) of 0.05 µg/g set by European Food Safety Authority (EFSA) that won't affect the livestock and next succeeding crop (**Figure 4**). During second crop season, slightly high residue of pendimethalin was reported in soil which might be due to less microbial activity because of increase in 2-3^{0}C temperature in initial crop period during second year (**Figure 1**). But, the residue was below the maximum residual limit and succeeding crop won't be affected. This result corroborates with Gasper *et al.* (1994) that cultivation, soil temperature and moisture conditions had affected pendimethalin persistence in soil and it adsorbs rapidly and strongly to soil because of its high potential for hydrogen bonding.

Based on this study, it can be concluded that without any residual effect on fodder sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50 + 4) g/ha or sulfosulfuron + metsulfuron (30 + 2) g/ha or clodinafop + metsulfuron (60 + 4) g/ha at 2 WAC provided effective management of weeds and higher crop productivity of dual purpose wheat.

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