Possible Replacement of Wheat Post Herbicides with Soil Herbicide Pendimethalin

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Summary

The experiment was conducted between 2016-17 to evaluate the efficacy of PRE emergence and POST herbicides for effective weed control in wheat crops and analyse if pendimethalin may replace usually spring post-applied herbicides. The applied PRE emergence herbicide was pendimethalin and POST herbicides were prosulfuron, amidosulfuron + iodosulfuron-methyl-natrium + mefenpyr-diethyl, pyroxsulam, amidosulfuron + iodosulfuron-methyl-natrium + mefenpyr-diethyl + fenoxaprop-p-ethyl. The weed population consisted mainly of annual and some perennial weeds. Weediness comprised 31 plants m^{-2} in the control plots and 1.3-9.0 plants m^{-2} in the plots treated with herbicides. The highest numbers of individuals were recorded for *Persicaria maculosa* (8.0 plants m^{-2}), *Chenopodium album* (7.3 plants m^{-2}), *Apera spica-venti* (7.0 plants m^{-2}) and *Convolvulus arvensis* (3.0 plants m^{-2}). Most POST herbicides effectively reduced dominant weeds with the highest efficacy in plots treated with herbicide amidosulfuron + iodosulfuron-metil-natrium + mefenpir-dietil (95.9%). Furthermore, the efficacy of PRE herbicide pendimethalin with two doses was lower compared to POST herbicides, besides amidosulfuron + iodosulfuron-metil-natrium + mefenpir-dietil + fenoxaprop-p-ethyl. The treated plots with herbicides showed a statistically higher wheat yield compared to control plots. The PRE herbicide pendimethalin may replace POST herbicides, but this depends strongly on used dosage, climatic conditions and weeds that germinate in the spring. Wheat yields differed among PRE herbicide pendimethalin applications and POST herbicide, ranging between 5115 and 7003 kg ha^{-1}.

Key words

efficacy, PRE and POST herbicide, weeds, wheat

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Introduction

Weeds have become an increasing problem in wheat crops worldwide. Today, wheat is the predominant crop in arable lands of Kosovo, and is cultivated in about 73.363 ha, with an average yield of 4.0 t/ha ha (Kosovo Agency of Statistics-KAS, 2022). Based on the research conducted on the occurrence of weeds and the effectiveness of herbicides in wheat in Kosovo, the dominant weeds are: *Cirsium arvense* (L.) Scop, *Consolida regalis* Gray, *Polygonum aviculare* L., *Consolida orientalis* (J. Gay) *R.Scrodinger*, *Convolvulus arvensis* L., *Centaurea cyanus* L., *Erodium cicutarium* (L.) L'Her. ex Aiton, *Bifora radians* Bieb., and *Galium aparine* L. (Susuri et al., 2001; Mehmeti et al., 2009; Mehmeti and Demaj, 2010; Mehmeti et al., 2018).

Weeds affect the grain yield through competition (Siddiqui et al., 2010; Hashem et al., 2019) and cause 7-50% losses in wheat annually (Milberg & Hallgren, 2004; Oerke, 2004; Singh et al., 2004 Zand et al., 2007; Rao and Chauhan, 2015). The weed management in wheat is mainly based on the application of herbicides, but also on the cultural practices (Streit et al., 2003; Chachar et al., 2009; Knežević et al., 2012; Choudhary et al., 2016). However, the time of application, the type of herbicides, and the types of weeds present are very important for efficacious weed control in wheat crops.

Traditionally in many countries, herbicides in wheat are applied from the two-leaf stage until the end of tillering and from tillering until booting. At present, the most used herbicides in Kosovo in wheat are from the group of acetolactate synthase (ALS)-inhibiting herbicides and synthetic auxins for broadleaf and acetyl CoA carboxylase (ACCase) inhibitors for annual grasses. Wells, (2008) reported that pyroxsulam combats wild oat (*Avena fatua* L.), brome grass (*Bromus diandrus* Roth), phalaris (*Phalaris minor* Retz. or *paradoxa* L.), annual ryegrass (*Lolium rigidum* Gaudin). Geier et al. (2011) report that pyroxsulam appears to be a practical alternative to the herbicides currently used for brome control in winter wheat.

Taking into consideration the necessity of chemical weed control for stable wheat production, the aim of this study was to investigate the possibility to replace post-emergence herbicides (POST) with pre-emergence herbicide (PRE) pendimethalin for weed control in wheat, as well as the efficacy of PRE and POST herbicides and their influence on wheat yields.

Material and Methods

The field experiment was conducted during 2016-2017 in private wheat fields in the central part of Kosovo. The previous crop was maize with beans. The wheat was planted following conventional tillage practices. The soil was tilled with a field cultivator prior to planting. The Euclid wheat cultivar was planted in the last week of October using 190 kg ha^{-1} of seeds, and before planting, 250 kg ha^{-1} of artificial fertilizer NPK 15:15:15 was applied. In spring (27.02.2017), the first supplementary fertilization with UREA (46% N) in doses 150 kg ha^{-1} was applied, followed by a second fertilization (24.04.2017) with ammonium nitrate in doses 150 kg ha^{-1}. Herbicide treatment was carried out using a 20-liter backpack sprayer with a water quantity of 400 l ha^{-1}. The experiment was set up in a randomized block design with four replications and elementary plots of 10 m^2. In the experiment there were seven treatments (Table 1), six herbicide treatments, and one control (untreated). The control plots were left untreated during the entire experimental period. The estimation of weeds was conducted per 1 m^2. The PRE herbicide with different doses was applied immediately after the planting of wheat and POST herbicides were applied at the end of the wheat tillering stage. The number and composition of weeds as well as the efficacy of herbicides were evaluated by comparing treated and control (untreated) plots. The yield of wheat and dry biomass of weeds were evaluated at the end of the experiment for 1 m^2.

The efficacy of herbicides was calculated by the equation (Šarić, 1991a),

$$CE\ \% = ((A \times 100) / B)\ \%$$

where CE % is the coefficient of efficacy, A is the number of destroyed weeds per m^2 and B is the number of weeds in the untreated 1 m^2 plots.

Table 1. Basic data on the applied herbicides

Treatments	Active ingredient	Product	Rate	Time of application
A	pendimethalin	Stomp 330 E	4.0 L ha^{-1}	PRE
B	pendimethalin	Stomp 330 E	6.0 L ha^{-1}	PRE
C	prosulfuron	Peak 75 WG	0.020 kg ha^{-1}	POST
D	amidosulfuron + iodosulfuron-methyl-natrium + mefenpyr-diethyl	Sekator WG	0.150 L ha^{-1}	POST
E	pyroxsulam	Pallas 75 WG	0.25 kg ha^{-1}	POST
F	amidosulfuron + iodosulfuron-methyl-natrium + mefenpyr-diethyl fenoxaprop-p-ethyl	Sekator WG +	0.150 L ha^{-1}	POST
		Furore super EW	0.800 L ha^{-1}	POST
G	Control			

Note: PRE: pre-emergence; POST: post-emergence; A: pendimethalin PRE; B: pendimethalin PRE; C: prosulfuron POST; D: amidosulfuron + iodosulfuron-metihy-natrium + mefenpyr-diethyl POST; E: pyroxsulam POST; F: amidosulfuron + iodosulfuron-metil-natrium + mefenpyr-diethyl + fenoxoprop-p-ethyl POST; G: control

The weeds were determined in the laboratory of the Faculty of Agriculture in Prishtina, Department of Plant Protection, using the atlases (Demiri, 1979; Šarić, 1991b; Mehmeti et al., 2015), and life forms of weeds according to (Ellenberg et al., 1992).

During 2016-17, the temperatures were slightly higher compared to the multiyear temperatures especially during the months of February, March, June and July (Table 2). The precipitation during 2016-17 was lower compared with the multiyear rainfall especially during February, March and July (Table 3).

Statistical Analysis

The data were analyzed using the Analysis of Variance (ANOVA) technique. To test the significance of differences of mean wheat yield and above ground dry biomass of weeds, the mean values were calculated and significant differences were tested using the Tukey HSD test and the statistical computer programme (JMP, 2012).

Results and Discussion

A total number of 19 weed species was recorded, indicating a species-rich weed community in the experimental field. Of the 19 weed species, 17 were broad-leaf species and only two were grass species. This is compared to past studies in two localities of western Kosovo, which documented 15 and 12 weed species, respectively (Susuri et al., 2001). Furthermore, Mehmeti et al. (2018), documented 16 weed species in the wheat crop of central Kosovo.

The number of individual weed species was high in the control plots compared to the herbicide-treated plots (Table 4). The dominant weed species were: *Persicaria maculosa* Gray (8.0 plants m^{-2}), *Chenopodium album* L. (7.3 plants m^{-2}), *Apera spica-venti* (L.) P.Beauv. (6.5 plants m^{-2}) and *Convolvulus arvensis* L. (3.0 plants m^{-2}). This low weed density was due to crop rotation of maize combined with beans and mechanical weed control used for several years before the experiment. The dominance of the weed species *C. arvensis* in the wheat crop was reported in previous studies (Georgiev et al., 2011; Mehmeti et al., 2018).

Regarding the biological spectrum of weeds in wheat, therophytes have dominated with 69.0%, followed by hemicryptophytes with 19.0%, geophytes with 9.0%, and least of all, chamaeophytes with 3.0%. The dominance of therophytes in wheat crops was also reported in the research conducted by Nikolic et al. (2012) and Mehmeti et al. (2018).

Although there were differences between treatments, the efficacy of PRE herbicide pendimethalin and POST herbicides in reducing the number of weeds was satisfactory. In the plots where herbicide pendimethalin PRE 6.0 L ha^{-1} was used, the dominant weed was *C. arvensis*; however, in those treated with a dose of 4.0 L ha^{-1}, the dominant weeds were *P. maculosa* and *C. arvensis*. The dominant weed species in plots treated with herbicide pyroxsulam were *C. arvensis* and *Ch. album*.

The highest efficacy achieved from POST herbicides was 95.9% using iodosulfuron-methyl-sodium + amidosulfuron + mefenpir-diethyl, while other herbicides had lower efficacies. Efficacy of pyroxsulam herbicide was 84.8%, some lower efficacy was shown by prosulfuron herbicide, while the combination of herbicides iodosulfuron-methyl-sodium + amidosulfuron + mefenpir-diethyl + fenoxaprop-p-ethyl had 71.5% efficacy. However, the efficacy of the herbicide PRE-em pendimethalin, with two different doses was lower than POST herbicides besides a combination of herbicides iodosulfuron-methyl-sodium + amidosulfuron + mefenpir-diethyl + fenoxaprop-p-ethyl (Table 4).

Table 2. Mean air temperature (°C) in Ferizaj, near the studied field, in the year of the experiment and between 1951-1980 ('average year' according to Zajmi, 1996), (Δ: difference between 2016-17 and the 'average year')

Year	Month											
	IX	X	XI	XII	I	II	III	IV	V	VI	VII	Ave.
2016-17	16.1	10.4	4.6	-1.4	-0.1	3.4	8.6	9.6	14.8	20.9	22.2	9.3
Ave. year	15.7	10.3	5.5	0.6	-1.4	1.1	4.7	9.8	14.5	18.1	19.8	9.0
Δ	+0.4	+0.1	-1.1	-2.0	-1.5	+2.3	+3.9	-0.2	+0.3	+2.8	+2.4	+0.3

Source: Hydrometeorology Institute of Kosovo

Table 3. Rainfall (mm) in Ferizaj, near the studied field, in the year of the experiment and between 1951-1980 ('average year' according to Zajmi, 1996), (Δ: difference between 2016/17 and the 'average year')

Year	Month											
	IX	X	XI	XII	I	II	III	IV	V	VI	VII	Sum
2016-17	65.7	96.9	90.4	2.4	56.1	29.0	26.2	57.3	84.8	72.2	34.2	615.2
Ave. year	52.5	63.7	67.2	55.4	50.1	45.3	46.8	51.3	83.2	70.9	63.0	649.4
Δ	13.2	33.2	23.2	53.0	6.0	16.3	20.6	6.0	1.6	2.3	29.2	+34.2

Source: Hydrometeorology Institute of Kosovo

This can be explained by the higher than average rainfall in October after application of pendimethalin (Table 3), which can result in leaching through the soil profile as was reported in previous studies for PRE herbicides (Ferrell et al., 2004; Pacanoski and Mehmeti, 2019; Tanji and Boutfirass, 2018), and weeds that germinate in the spring cannot be controlled by pendimethalin. The low efficacy of the combination of iodosulfuron-methyl-sodium + amidosulfuron + mefenpir-diethyl + fenoxaprop-p-ethyl can be attributed to the incompatibility of herbicide mixtures (Singh and Singh, 2005), but it also depends on the weed species that occur in certain localities and weed development stage (Faccini and Puricelli, 2007). However, related to the reduction of weed species numbers, all applied herbicides except iodosulfuron-methyl natrium + amidosulfuron + mefenpyr-diethyl showed a low efficacy.

The herbicide prosulfuron showed weak control against the grass species *Apera spica-venti*, while pyroxsulam showed good control. In North Dakota, pyroxsulam controlled wild oat (*Avena fatua* L.) more effectively when applied at the one or three-leaf stages than when applied at the five-leaf stage (Hanson and Howatt, 2007). The dominant broadleaved weed *C. arvensis* was not well controlled in all plots treated with herbicides except for herbicide iodosulfuron-methyl natrium + amidosulfuron + mefenpyr-diethyl. Pendimethalin in both rates of application did not provide good control of *C. arvensis*.

Wheat yields for each treatment generally reflected overall weed control. Wheat yields differ among PRE herbicide pendimethalin and POST herbicides applications. Compared to the control plots, all herbicides used have influenced grain yield (Fig. 1), and results are in accordance with previous studies (Abbas et al., 2009; Khalil et al., 2010; Mehmeti et al., 2018; Pacanoski and Mehmeti, 2018). The highest grain yields were found in plots treated with iodosulfuron-methyl-natrium + amidosulfuron + mefenpyr-diethyl (7003 kg ha^{-1}) and herbicide pyroxsulam (6900 kg ha^{-1}).

In the two plots treated with pendimethalin after planting of wheat, the yield has been lower compared to POST herbicides. This is consistent with the low yield in plots treated with pendimethalin reported by Kaur et al. (2018). In addition, it is characteristic that plots treated with POST herbicides have shown statistically significant differences with herbicide pendimethalin PRE at a dose of 6.0 L ha^{-1} (Fig. 1). The lower yield in plots treated with PRE herbicide pendimethalin 6.0 L ha^{-1} is likely a result of the herbicides phytotoxicity on the wheat crop. This can be explained by the fact that pendimethalin applied after planting of wheat causes visible damage to wheat seedlings and this depends on concentrations (Ismaili, 2016). The wheat injury from PRE herbicide depends on the application rate, e.g., of pyroxasulfone, but this early-season injury did not negatively affect winter wheat yield (Hulting et al., 2012). However, some research shows that using pendimethalin followed by another herbicide or removing weeds by hand result in higher efficiency and higher yield (Rahaman and Mukherjee, 2009; Choudhary et al., 2016; Barla et al., 2017; Kaur et al., 2018).

The PRE herbicide pendimethalin and POST herbicides reduce the above ground dry biomass of weeds in comparison with control plots. The highest effects in reduction of above ground dry biomass of weeds were with herbicide iodosulfuron-methyl natrium + amidosulfuron + mefenpyr-diethyl 11.3 g/m^2 and pyroxsulam 13.5 g m^{-2}.

Herbicide prosulfuron reduced the above ground dry biomass of weeds (23.8 g m^{-2}). The pendimethalin used PRE with a dose of 4.0 L ha^{-1} reduced above ground dry biomass of weeds, but less than with a dose of 6.0 L ha^{-1}. Furthermore, the combination of iodosulfuron-methyl-natrium + amidosulfuron + mefenpyr-diethyl + fenoxaprop-p-ethyl herbicides had the lowest effect on the dry biomass of weeds (45.0 g m^{-2}). In control plots, the above ground dry biomass of weeds was 188.8 g m^{-2} (Fig. 2). The impact of herbicides on the dry biomass of weeds has also been reported by other researchers (Chopra et al., 2001; Shehzad et al., 2012). The PRE and POST herbicides have significant differences from the control plots for the above ground dry biomass of weeds, beside pendimethalin PRE with doses 4.0 L ha^{-1} (Fig 2).

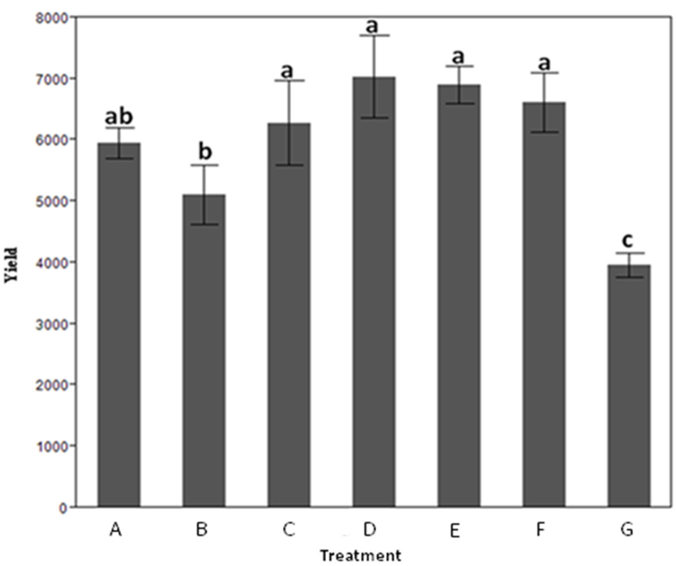

Figure 1. Yield of grain wheat (kg ha^{-1}) depending on herbicide treatment (mean ± SD, average with different letters are significant according toTukey's HSD test, $P \leq 0.05$)

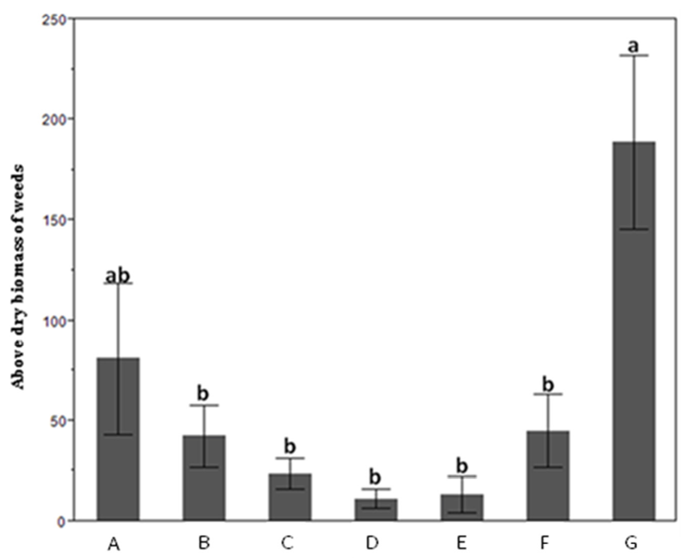

Figure 2. Impact of herbicides in above ground dry biomass of weeds (g m^{-2}) (mean ± SD, average with different letters are significant according toTukey's HSD test, $P \leq 0.05$)

Table 4. Species life forms, number of individuals and coefficient of herbicide efficacy (CE)

Life forms	Weed species	Treatments						
		A	B	C	D	E	F	G
T	*Anagallis arvensis* L.	0.3	0	0	0	0	0	0.5
T	*Apera spica-venti* L.	0	0	4.0	0.5	0	0	7.0
H, C	*Artemisia vulgaris* L.	0	0	0	0	0	0.3	0
T	*Centaurea cyanus* L.	0	0	0	0	0	0	0.3
T	*Chenopodium album* L.	0.5	0	0.8	0.8	1.3	3.7	7.3
G, Hli	*Convolvulus arvensis* L.	3.0	4.3	0.5	0	2.0	2.0	3.0
H	*Daucus carota* L.	0	0.3	0	0	0	0	0
G	*Equisetum arvense* L.	0.5	0.8	0.5	0	0	0	0
T	*Galisonga parviflora* Cav.	0	1.0	0	0	0	0	0
Tli	*Galium aparine* L.	0	0	0	0	0	0	0.5
T, H	*Lamium purpureum* L.	0	0	0.3	0	0	0	0.8
T	*Papaver rhoeas* L.	0	0	0	0	0.8	0	1.3
T	*Polygonum persicaria* L.	3.7	2.0	0	0	0	2.7	8.0
T	*Ranunculus arvensis* L.	0	0	0	0	0.3	0	0
T	*Setaria viridis* L.	0	0	0.3	0	0	0	0.5
T	*Stellaria media* L.	0	0	0	0	0.5	0.3	0.5
H	*Taraxacum officinale* Web.	0	0	0.3	0	0	0	0.5
T	*Veronica persica* Poir.	0	0	0	0	0	0	0.3
/	*Viola arvensis* Murr.	0	0.3	0	0	0	0	1.0
Number of weeds/m^2		8.0	8.7	6.7	1.3	4.8	9.0	31.5
CE (%)		74.6	72.4	78.7	95.9	84.8	71.5	0
Number of weed species/m^2		5.0	6.0	7.0	2.0	5.0	5.0	14.0

Conclusions

In the past but even today, the use of herbicides after planting wheat is quite limited as herbicides for the control of weeds in wheat are mainly used after the germination of wheat. Therefore, the earliest possible control of weeds in wheat is important for the competition between plants and weeds, as the newly germinated plants must win this battle against the weeds. However, it should be considered that the use of higher doses of soil herbicides after planting wheat could cause phytotoxic effects to the plants and, as well as the high amount of rainfall and drought after the use of herbicides, may have an impact on herbicide efficacy. Based on the results, pendimethalin can be used as a PRE herbicide in wheat for weed control, but this depends strongly on used dosage, climatic conditions and weeds that germinate in the spring. Nevertheless, to achieve higher efficiencies and yields of wheat, the use of PRE followed by POST herbicide may need to be recommended in the future.

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