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Evaluation of pre- and post-emergence herbicides for weed control in maize (*Zea mays* L.)

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Abstract

A field experiment was conducted during 2014–2015 to investigate the efficacy of herbicides [Merlin flexx (isoxaflutole), pre- and post-emergence; Equip (foramsulfuron), post-emergence; and Maister (foramsulfuron + iodosulfuron-methyl-sodium), post-emergence] in maize (cv NSC 444) crops grown in the Prishtina region of Kosovo. The field experiment was set in a randomised block design with four replications and elementary plots of 10 m^2. A total of 14 weed species were documented in the maize crop in 2014, which increased to 27 in 2015, with the dominant species being *Amaranthus retroflexus* (87 plants/m^2 in 2014 versus 43.3 plants/m^2 in 2015). The most efficient herbicides in both years were pre-emergence (98.1% vs 92.5%; 2014 vs 2015) and isoxaflutole post-emergence (98.8% vs 89.9%; 2014 vs 2015). All plots treated with herbicides significantly influenced the increase of maize yield in comparison with the control plots. In conclusion, the use of isoxaflutole either pre-emergence or post-emergence is recommended in the study region for successful weed control and high maize grain yields.

Keywords: grain yield, herbicide efficacy, maize, weeds

Introduction

Increasing maize yields is achieved, among other things, with effective protection from diseases, pests and weeds. In Kosovo, herbicide application and/or intensive mechanical weed control are common.

The main crops in Kosovo are wheat and maize. Today, in Kosovo maize is produced on about 36.000 ha, with average yield 4.1 t/ha (Kosovo Agency of Statistics, 2018). Weeds have become an increasing problem in maize crops, with species, such as *Amaranthus retroflexus, Echinochloa crus-galli, Chenopodium album, Cirsium arvense, Convolvulus arvensis* and *Hibiscus trionum,* widespread throughout the arable land in Kosovo (Mehmeti et al., 2009; 2011; 2012).

Indeed, yield losses due to weeds of up to 35% have been reported (Oerke, 2006; Dangwal et al., 2010). Mechanical weed control in late spring, which is practised extensively in mostly small plots of maize and bean intercropping, as well as the use of herbicides in cereals and maize monocultures, counteracts the development of species-rich arable weed vegetation. To this day, several studies on the relationships between weed composition on arable land, soil disturbance and herbicide application have been conducted in Kosovo (Kojić and Pejčinović, 1982; Pejčinović, 1987; Susuri et al., 2001; Mehmeti et al., 2008; 2009; 2012).

In maize production, it is necessary to undertake control of weeds which cause losses of maize grain yields. Weed management in maize production is a combination of cultural and chemical tools.

The aim of this two-year study was to control weed species and determine the efficacy of herbicides in maize crop, as well as the influence of herbicides and weeds on the maize grain yield.

Materials and methods

The field experiment was conducted in 2014 and 2015, on a vertisol soil (pH 6.54, pH_{KCL} 6.14, 5.02% $humus_{total}$, 43.02 mg K_2O/100 g, and 50.7 mg P_2O_5/100 g) in a didactic farm of the Agricultural and Veterinary Faculty in Prishtina (a central part of Kosovo). The maize cv NSC 444 was sown at a density of 70 x 25 cm in spring, in good tilled soil and treated with the fertiliser NPK 15:15:15 at a dose of 200 kg/ha. Supplementary fertilisation with 150 kg/ha of ammonium nitrate was applied in summer.

Table 1. Basic data on the applied herbicides

Treatments	Active ingredient	Product	Rate (l/ha)	Application
A	Isoxaflutole	Merlin flexx SC	0.4 l/ha	PRE*
B	Isoxaflutole	Merlin flexx SC	0.4 l/ha	POST*
C	Foramsulfuron	Equip OD	2.5 l/ha	POST
D	Foramsulfuron + iodosulfuron-methyl-sodium	Maister OD	1.5 l/ha	POST
E	Untreated control			

*PRE – Pre-emergence; *POST – Post emergence.

The field experiment was a randomised block design, with four replications and elementary plots of 10 m^2. There were five treatments: four herbicide treatments and a control treatment without herbicide and cultivation. Herbicides (see Table 1) were applied using a special knapsack sprayer with a capacity of 20 l and the amount of water used was 400 l/ha. The pre-emergence herbicide was applied immediately after sowing of the maize and post-emergence herbicides at the stage of maize 3–5 leaf. Sixty days after pre-emergence herbicide application and forty days after post-emergence herbicide application, the number and structure of weeds, as well as the efficacy of herbicides were estimated by comparing sprayed plots and control plots (untreated).

The weed species were determined in the laboratory of the Faculty of Agriculture and Veterinary in Prishtina, Department of Plant Protection, using the atlases of Šarić (1991a) and life forms according to Ellenberg et al. (1992). The estimation of weeds was conducted for 1 m^2. The number of weed plants and the aboveground dry biomass of the weeds were recorded. The efficacy of herbicides was calculated by the equation (Šarić, 1991b):

$$KE = \frac{A \times 100}{B}\%$$

where, KE is the coefficient of efficacy, A is the number of destroyed weeds per 1 m^2 (number of weeds in the untreated 1 m^2 plots minus number of weeds in the treated 1 m^2 plots), and B is the number of weeds in the untreated 1 m^2 plots.

For the estimation of the aboveground dry biomass of weeds, the samples for each replicate were harvested in October 2014–2015, then the weeds were separated from the maize and other materials were removed before being dried at room temperature.

Statistical analysis

The data were analysed using analysis of variance (ANOVA) technique. To test the significance of differences in the mean maize yield and aboveground dry biomass of weeds, the mean values were calculated and significant differences were tested using the Tukey HSD test and a statistical computer program (SAS Institute Inc. 2012).

Meteorological conditions

Information on air temperature and rainfall near to the maize field under study are given in Tables 2 and 3 respectively.

Average year [mean values for 1951 to 1980 according to Zajmi (1996)] data is given for comparison. The temperatures and rainfall in 2014 and 2015 were different to the average year values, with some months (April, June, July and September) in 2014 experiencing more rainfall than in 2015.

Table 2. Mean air temperature (°C) in Prishtina in 2014 and 2015 in comparison to an average year (1951–1980)

Year	Months							
	IV	V	VI	VII	VIII	IX	X	Average
2014	10.4	14.5	18.5	20.8	21.9	16	11.2	16.2
2015	9.6	16.6	18.6	23.4	22.6	18.5	11.4	17.3
Average 1951-1980	9.8	14.4	18	19.7	19.8	15.8	10.5	15.4

Table 3. Rainfall (mm) in Prishtina in 2014 and 2015 in comparison to an average year (1951–1980)

Year	Months							
	IV	V	VI	VII	VIII	IX	X	Sum
2014	228	71	80.7	75.7	9	152	65.4	682
2015	61.1	53.9	37.4	2.7	86.8	46.3	112.4	401
Average 1951-1980	51.4	75.3	56.9	48.6	46.2	47.5	56.1	382

Results and discussion

The results show that the weed flora in the maize crop during the two-year study was very rich, both floristically (33 species) and with regard to the population size (105 plants/m^2). This is due to the impact of changing agricultural practices on growing maize, and cultivation of maize as a monoculture. The herbicides used had an effect on the reduction of weeds in comparison with the control plots, with higher efficacy in the first year of application in comparison to the second year as shown in Figure 1. This may be due to the significant differences in weather conditions between the two years, as reported by Sulewska et al. (2012).

Of the 33 weed species present, 26 of them were broadleaved, while 7 were grass species. The annual species were more dominant (24 species) than perennials (9 species). Nonetheless, the proportion of annual species was relatively high. In 2014, the dominant weeds were broadleaved, with only one grass species, *Setaria viridis*. However, in 2015, the number of grass weeds was significantly higher compared with 2014, most of the six species identified were annuals, mainly *Setaria glauca* and *Setaria viridis*. It is important to note that the four perennial grass weed species in 2015 were *Elymus repens*, *Cirsium arvense*, *Lolium perenne* and *Sorghum halepense* (Table 4a, 4b, 4c), with *Convolvulus arvensis* being the most frequent perennial species in 2014, while it was *Lolium perenne* in 2015.

Table 4a. The weed species in maize crop during 2014 and 2015 (plants/m^2) in specific treatments

Life forms	Weed species	Treatments A		B		C		D		E	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
T	*Alopecurus myosuroides* Huds.	0	0.3	0	0	0	0	0	0	0	0.3
T	*Amaranthus retroflexus* L.	0	0	0	0	0.5	7	0.3	0.7	87	43.3
T	*Anagallis arvensis* L.	0	0	0	0.3	0	0	0	0	0	0
T	*Chenopodium album* L.	0	0	0	0	2	12.2	0.8	7.7	15.5	12.8
T	*Chenopodium rubrum* L.	0	0	0	0	0	0	0	0	0.3	0
G	*Cirsium arvense* (L) Scop.	0	0	0	0	0	0.5	0	0	0	0.5
T	*Consolida regalis* S.F.(Gray).	0	0	0	0	0	0	0	0	0	1
G, Hli	*Convolvulus arvensis* L.	1.5	0.5	1.5	0	0.5	0	1.5	0	7.5	3.5
T	*Datura stramonium* L.	0	0	0	0	0	0	0	0	1	0
H	*Daucus carota* L.	0	0	0	0	0	0.2	0	0.3	0	0.3
T	*Echinochloa crus-galli* L.	0	0	0	0	0	0	0	0.2	0	0.2

A - isoxaflutole + cyprosulfamide-protectant - PRE; B - isoxaflutole + cyprosulfamide-protectant - POST; C - foramsulfuron + isoxadifen-ethyl-protectant - POST; D – foramsulfuron + iodosulfuron-methyl-sodium + isoxadifen-ethyl protectant - POST; E – Control.

Table 4b. The weed species in maize crop during 2014 and 2015 (plants/m^2) in specific treatments

Life forms	Weed species	Treatments									
		A		B		C		D		E	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
G	*Elymus repens* L.	0	2	0	0	0	0	0	0	0	0.3
Tli	*Fallopia convolvulus* (L) Å. Löve	0.5	1.2	0	2.2	0.5	2	1	2.3	1.5	1.3
T	*Fumaria officinalis* L.	0	0	0	0.5	0	0	0	0.2	0	0
T	*Geranium dissectum* Jusl.	0	0.2	0	0	0	0	0	0	0	0
T	*Helianthus annuus* L.	0	0	0	0	0	0	0	0	1.3	0
T	*Heliotropium europaeum* L.	0	0	0	0	0	0	0	0	0	0.5
T	*Hibiscus trionum* L.	0	0	0	0	0	0	0	0	0.3	0
T	*Lamium amplexicaule* L.	0	0	0	0	0	0	0	5.3	0	1
T, H	*Lamium purpureum* L.	0	0	0	0	0	0	0	0	0	0.5
G, Hl	*Lathyrus tuberosus* L.	0	0	0	0	0	0	0	0	0.5	0
G, H	*Linaria vulgaris* Müll.	0	0	0	0	0	0	0	0	0	0.2

A - isoxaflutole + cyprosulfamide-protectant - PRE; B - isoxaflutole + cyprosulfamide-protectant - POST; C - foramsulfuron + isoxadifen-ethyl-protectant - POST; D – foramsulfuron + iodosulfuron-methyl-sodium + isoxadifen-ethyl protectant - POST; E – Control.

Table 4c. The weed species in maize crop during 2014 and 2015 (plants/m^2) in specific treatments

Life forms	Weed species	Treatments A 2014	A 2015	B 2014	B 2015	C 2014	C 2015	D 2014	D 2015	E 2014	E 2015
H	*Lolium perenne* L.	0	1.5	0	1	0	0	0	0	0	1
T	*Polygonum aviculare* L.	0.5	0	0	2	1	2.5	0.3	3	1.3	0.8
T	*Setaria glauca* Poir.	0	0	0	0	0	2.7	0	1.5	0	0.3
T	*Setaria viridis* L. (P. Beauv)	0	0.5	0	1.8	0.5	0	0	1.2	7	0.3
T	*Sinapis arvensis* L.	0	0	0	0	0	0	0	0	0.3	2.5
T	*Solanum nigrum* L.	0	0	0	0	0	0	0	0	0.3	0
H	*Sorghum halepense* L. Pers.	0	0	0	0.5	0	0	0	0	0	0
T	*Stachys annua* L.	0	0	0	0	0	4.7	0	0	6.5	10.3
C, H	*Trifolium repense* L.	0	0	0	0	0	0	0	0	0	0.5
T	*Veronica persica* Poir.	0	0	0	0	0	0.7	0	0	0	0.3
T	*Xanthium strumarium* L.	0	0	0	0.3	0	0.2	0	0	0	0.2
Total number of weed species/m^2		3	7	1	8	6	10	5	10	14	23
Total number of weeds/m^2		2.5	6.2	1.5	8.3	5	32.7	3.9	22.4	130.3	82

A - isoxaflutole + cyprosulfamide-protectant - PRE; B - isoxaflutole + cyprosulfamide-protectant - POST; C - foramsulfuron + isoxadifen-ethyl-protectant - POST; D – foramsulfuron + iodosulfuron-methyl-sodium + isoxadifen-ethyl protectant - POST; E – Control.

The weather conditions were more favourable for maize in 2014, with a higher rainfall from April to July. Maize plants, although characterised by slow growth, under such conditions grew quickly, significantly reducing the number of weeds. In 2015, the weather conditions were not as favourable for maize growth, with the low rainfall from April to July limiting normal maize development, thereby reducing the effectiveness of herbicides, but favouring the growth of specific weeds. The total number of weed species recorded in 2014 was 14, indicating a species-poor weed community in the experimental field, but in 2015, the number of weed species identified increased to 27 (Table 4a, 4b, 4c). These results are in accordance with Mehmeti et al. (2012), who investigated weed composition in maize crop and reported 23 weed species. However, Mehmeti et al. (2008) showed that the current weed flora in maize crops in Kosovo is species-poor on the field scale (about 8 weed species). Furthermore, in the northern part of Romania, Ciobanu et al. (2008) recorded 26 weed species in maize crop and in Poland, Glowacka (2013), reported 20 weed species. The degree of weed control varied depending on herbicide efficacy (Mehmeti, 2003; Khan and Haq, 2004) and climatic conditions (Bogdan et al., 2007).

The dominant weed species in control plots in 2014 were: *Amaranthus retroflexus* (87 plants/m^2), *Chenopodium album* (15.5 plants/m^2), *Convolvulus arvensis* (7.5 plants/m^2), and *Setaria viridis* (7 plants/m^2), while in 2015, the most dominant species were: *Amaranthus retroflexus* (43.3 plants/m^2), *Chenopodium album* (12.8 plants/m^2), and *Stachys annua* (10.3 plants/m^2). These species were similar to those reported in previous studies of maize fields in Kosovo (Mehmeti et al., 2009; 2012), as well as in other studies (Stanojevič, 2000; Vrbničanin et al., 2006). With respect to species life forms, during the two-year study, therophytes prevailed (71%), followed by hemicryptophytes (17%), geophytes (11%) and chameophytes (1%), in accordance with previous reports (Pejčinović, 1987; Mehmeti et al., 2012).

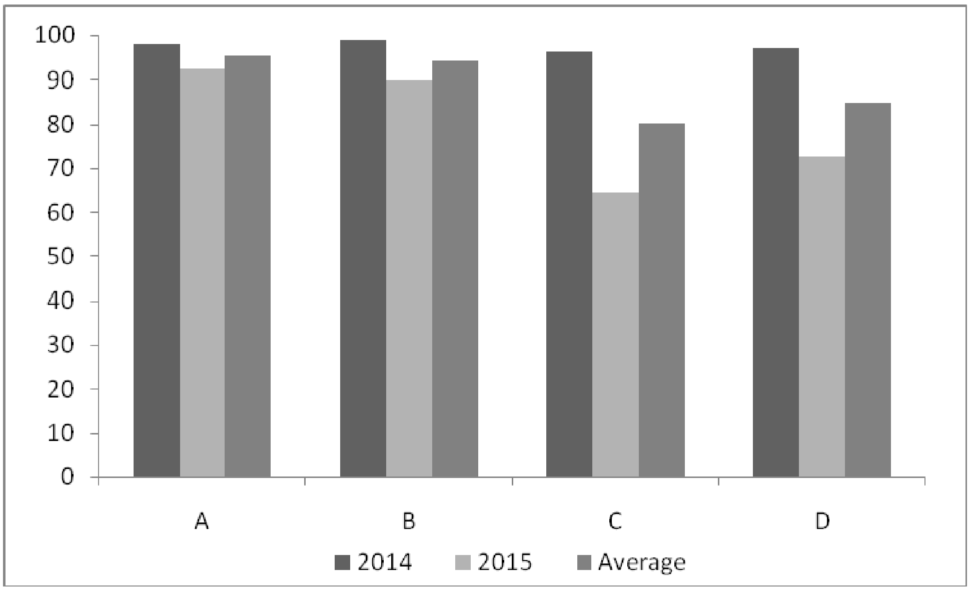

Figure 1. Coefficient of herbicide efficacy in 2014 and 2015 and two-year average

In 2014, all applied herbicides showed very high efficiency against weed species compared with 2015 (Figure 1). However, in 2014, the weed *Fallopia convolvulus* was not well controlled in plots treated with isoxaflutole pre-emergence, foramsulfuron post-emergence and foramsulfuron + iodosulfuron-methyl-sodium post-emergence. Furthermore, in 2015, the weed species *Fallopia convolvulus* proved to be resistant to the herbicides used.

Nevertheless, isoxaflutole pre-emergence and post-emergence demonstrated particularly high efficacy against dominant weeds species *Amaranthus retroflexus* and *Chenopodium album,* in agreement with Marković et al. (2012). Isoxaflutol pre-emergence alone and in combination with pendimethanil has been shown to reduce the number of predominant weeds in a maize-bean intercrop (Pacanoski et al., 2014), providing greater control of *Chenopodium album* (Chomas and Kells, 2004). This higher efficacy of isoxaflutole pre-emergence in combination with other herbicides was previously reported by Ciobanu et al. (2008).

The weed species *Chenopodium album* was resistant to the post-emergence herbicides foramsulfuron and foramsulfuron + iodosulfuron-methyl-sodium in 2015. Furthermore, the number of weeds in plots treated with herbicides in 2015 was higher due to the dominance of *Chenopodium album* and *Amaranthus retroflexus*. However, *Amaranthus retroflexus* and *Chenopodium album* have been reported in previous studies as dominant weed species in maize crop Mehmeti et al. (2012), as well as *Chenopodium album* (Skrzypczak et al., 2011). Nurs et al. (2007) reported that the efficacy of foramsulfuron is strongly influenced by weed species sensitivity. Furthermore, there are some studies in which the effect of foramsulfuron was increased with the aid of some adjuvants, including AS (Bunting et al., 2004).

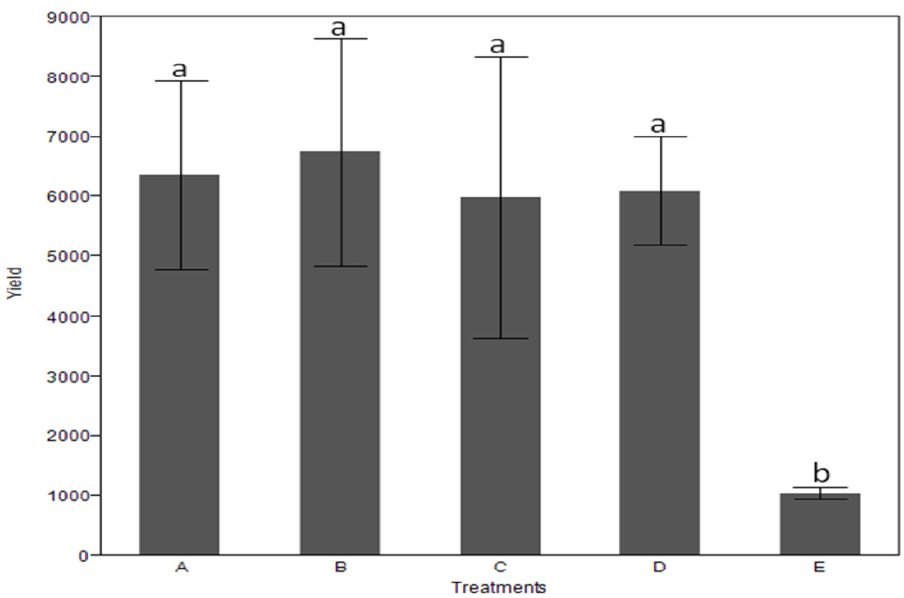

Figure 2. Maize grain yield (kg/ha) depending on herbicide treatment in 2014 (±SD, averages with different letters are significant Tukey's HSD, P<0.05)

In 2014, in comparison to the control plots (1,030 kg/ha), the maize yield in treated plots was higher (Figure 2). These results are in accordance with Abdullah et al. (2007), Munsif et al. (2009) and Mehmeti et al. (2012). However, in 2014, there were comparatively higher maize grain yields in plots treated with isoxaflutole post-emergence (6,737 kg/ha).

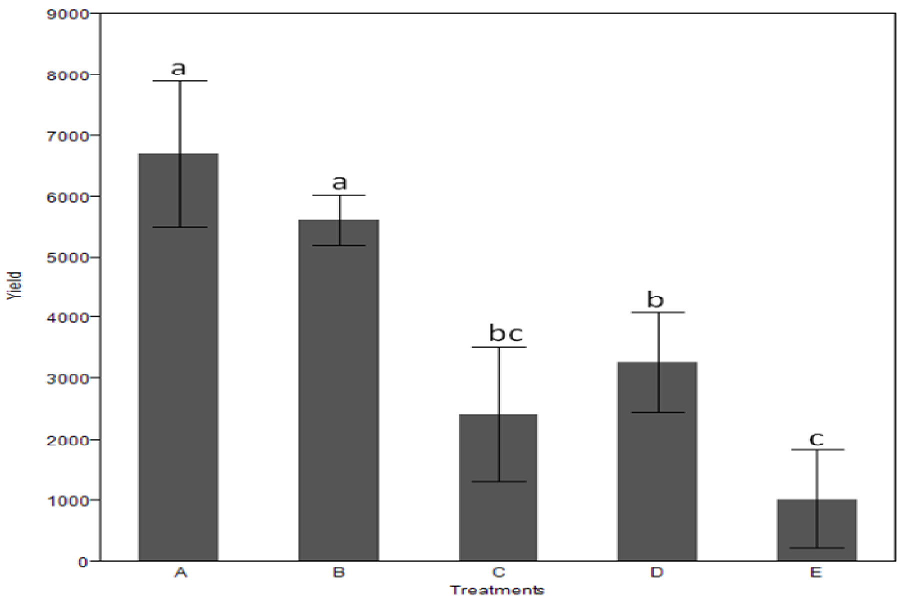

Figure 3. Maize grain yield (kg/ha) depending on herbicide treatment in 2015 (±SD, averages with different letters are significant Tukey's HSD, P<0.05)

In comparison to the control plots, all herbicide treatments showed a significant increase in maize grain yields. In contrast, the maize grain yields were lower in 2015 than in 2014, with the highest yields recorded in plots treated with herbicide isoxaflutole pre-emergence (6,694 kg/ha), while yields were lower in herbicide treatments, except isoxaflutole post-emergence (Figure 3).

In comparison to the control plots, three herbicides showed a significant increase in maize grain yields, but not the plots treated with foramsulfuron post-emergence. In both years of the trial, the dominant weed species was *Amaranthus retroflexus*, which was reported by Dogaru et al. (2012) to have an impact on the maize grain yield.

In the control plots in 2014, the mean aboveground dry biomass of weeds was 480.4 g/m^2, while in the experimental field with weed control, i.e. herbicide-treated plots with isoxaflutole post-emergence, the average dry biomass of weeds was 2.5 g/m^2, followed by isoxaflutole pre-emergence (3.1 g/m^2) and foramsulfuron + iodosulfuron-methyl-sodium post-emergence (4.5 g/m^2).

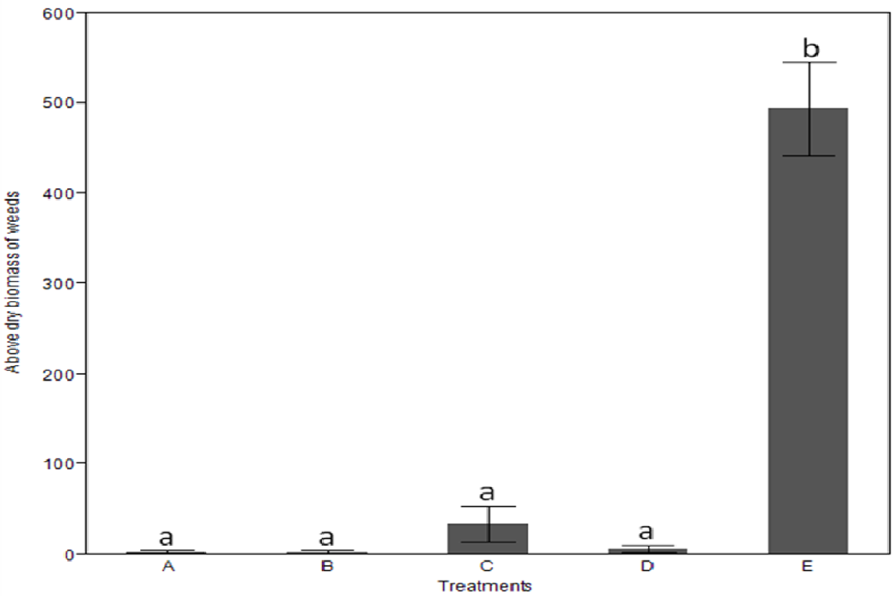

Figure 4. Impact of herbicides in above dry biomass of weeds in 2014 (g/m^2) (±SD, averages with different letters are significant Tukey's HSD, P<0.05)

However, significant differences were recorded with all herbicides in comparison to the control plots. In contrast, the aboveground dry biomass of weeds was lower (410 g/m^2) in the control plots in 2015, with the lowest aboveground dry biomass of weeds in plots treated with isoxaflutole post-emergence (4.75 g/m^2).

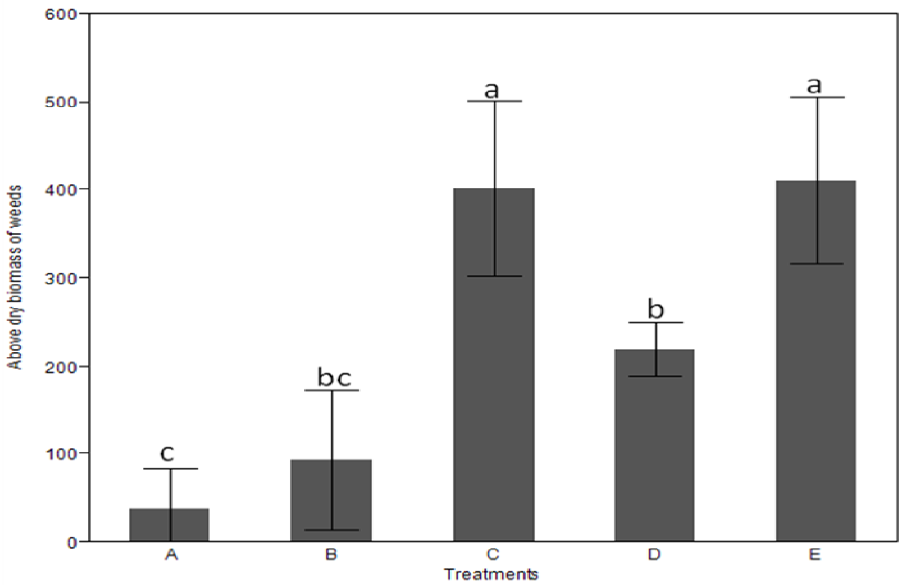

Figure 5. Impact of herbicides in above dry biomass of weeds (g/m^2) in 2015 (±SD, averages with different letters are significant Tukey's HSD, P<0.05)

Nonetheless, the herbicides tested negatively affected the aboveground dry biomass of weeds in comparison to the control plots (Figure 4 and 5). These results are in agreement with Bogdan et al. (2007), who reported a larger weed biomass in the control plots, similar to other studies (Kir and Dogan, 2009; Mehmeti et al., 2014), who concluded that the weed biomass of *Amaranthus retroflexus* and *Chenopodium album* was significantly reduced by different herbicidal treatments, as compared to the control plots.

Conclusions

This study showed that the maize crop in the test plots consisted of 14 weed species in 2014 and 27 weed species in 2015, with the dominant species being *Amaranthus retroflexus* and *Chenopodium album* in both years. The most effective herbicide tested was isoxaflutol pre-emergence in 2014 and post-emergence in 2015, as evidenced by the comparatively higher maize grain yields in plots treated with isoxaflutole post-emergence and pre-emergence in both years of the study. Taking into consideration the differences in weed occurrence and herbicide efficiency between the years due to climatic conditions, a combination of pre-emergence and post-emergence herbicides is recommended for the efficient control of weeds.

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