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POST herbicide programme for effective weed control in winter wheat (*Triticum aestivum* L.)

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Abstract. Field experiments were conducted during two winter wheat-growing seasons to evaluate the efficacy of some new POST herbicides and herbicide combinations for those effective controls of weeds in winter wheat crops in the Republic of Macedonia. The weed population consisted mainly of annual winter and spring and some perennial weeds. Weediness comprised 116 and 208 plants m^{-2} in 2012–2013 and 2013–2014, respectively, in the Skopje region, and 93 and 114 plants m^{-2} in 2012–2013 and 2013–2014, respectively, in the Probištip region. All POST herbicides effectively reduced dominant weeds density (> 93%) in the Skopje region in both years, as well as in the Probištip region in 2012–2013, but not in 2013–2014. In this year, lower temperature directly following application decreased efficacy of POST applied herbicides, which provided control of *Lolium perenne* that was between 76 and 84%; control of *A. ludoviciana* was less than 85%; control of *B. radians* was no more than 83% and no one treatment controlled *P. convolvulus* more than 82%. Wheat yields in the Skopje region were not significant among years for the different POST herbicide applications and ranged between 3,580 and 3,720 kg ha^{-1} in 2012–2013, and between 3,760 and 3,910 kg ha^{-1} in 2013–2014. A significant treatment by year interaction resulted in two distinct years for wheat yields in the Probištip region with POST herbicides. In 2012–2013, wheat yields were between 3,230 and 3,390 kg ha^{-1}, but in 2013–2014, wheat yields ranged from 3,060 to 3,490 kg ha^{-1} and weed-free control showed a significant higher wheat yield compared to all evaluated herbicides.

Key words: efficacy, herbicide, weeds, wheat.

INTRODUCTION

Weed-crop competition is a major factor limiting worldwide production of many crops, including wheat. Weeds are one of the major constraints in wheat production, as they reduce productivity due to competition (Khan et al., 2002; Olesen et al., 2004; Siddiqui et al., 2010) and allelopathy (Gao et al., 2009; Bertholdsson, 2012; Zhang et al., 2016), serve as an alternate host for various insects and fungi by providing habitats for pathogens (Capinera, 2005), and increase harvesting costs (Ozpinar, 2006). According to many authors, weeds cause 17–30% losses in wheat annually (Milberg & Hallgren, 2004; Zand et al., 2007; Rao & Chauhan, 2015). Therefore, the control of weeds is a basic requirement and major component of management in the wheat production system (Nazari et al., 2013). Weed management in wheat is a combination of cultural and herbicidal application (Streit et al., 2003; Chachar et al., 2009; Knežević et al., 2012). Chemical control is the most commonly used and reliable method for controlling weeds in wheat. The importance of this control has been emphasised by various authors (Klein et al., 2006; Frihauf et al., 2010; Geier et al., 2011; Sheikhhasan et al., 2012; Mandal et al., 2014; Mehmood et al., 2014; Mehmeti et al., 2018).

Herbicides registered for weed control in winter wheat in the Republic of Macedonia have significantly changed over the past 4–5 years. Acetolactate synthase (ALS)-inhibiting herbicides are primary herbicides for broadleaf and annual grass weed control in winter wheat. They are widely used because of low environmental impact, low mammalian toxicity, and high efficacy (Khaliq et al., 2011; Reddy et al., 2013). Florasulam, metsulfuron-methyl, tritosulfuron, triasulfuron and tribenuron are registered for weed control in wheat (Kostov & Pacanoski, 2004; Pacanoski & Jankuloski, 2012). These herbicides provide good broadleaf weed control efficacy, but have little to no activity on grass weeds. However, the herbicides pyroxsulam, iodosulfuron-methyl-sodium and mesosulfuron-methyl selectively controls both grass and broadleaf weeds in wheat.

Pyroxsulam is a broad-spectrum herbicide and triazolopyrimidine sulphonamide is labelled for grasses and broadleaf weed control in wheat (Wells, 2008) which was registered in 2011. Herbicides, pyroxsulam as well as the mesosulfuron, iodosulfuron and sulfosulfuron controls wild oat (*Avena fatua* L.), bromes (*Bromus* spp. Scoop.) and rigid ryegrass (*Lolium rigidum* Gaudin) (Wells, 2008). Premixed mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican (Alister OD 180) is another ALS and phytoene dehydrogenase-inhibiting herbicide that was registered in 2014. This herbicide controls certain broad-leaved and grass weeds in wheat (Reza, 2013). Pinoxaden is a newly selective herbicide for annual grass weeds in wheat and barley which was registered in 2012. It belongs to the chemical class of phenylpyrazolines. The herbicide acts by inhibiting the enzym e Acetyl-CoA-Carboxylase (ACCase), interrupting the synthesis of fatty acids and as a final consequence impacts the formation of biomembranes (Hofer et al., 2006). Pinoxaden satisfactorily controls (> 92%) common windgrass (*Apera spica-venti* (L.) Beauv.), slender meadow foxtail (*Alopecurus myosuroides* Huds.) and wild oat (*Avena fatua* L.) (Kieloch et al., 2006).

Taking into consideration the necessity of chemical weed control for stable wheat production, the objective of this study was to investigate the effectiveness of some new POST herbicides and herbicide combinations for effective control of weeds in winter wheat crops in the Republic of Macedonia, and, at the same time, to estimate their influence on wheat yields.

MATERIALS AND METHODS

Field experiments were conducted during two winter wheat-growing seasons in 2012–2013 and 2013–2014 in commercial wheat fields in the Skopje and Probištip wheat-growing regions of northern and north-eastern Macedonia on Fluvisol sandy loam and vertisol, respectively (Filipovski, 2006) (Table 1).

Table 1. Soil characteristics in the wheat-growing regions

Region	Soil	Coarse	Fine sand	Clay+silt	Organic matter	pH-water
		(%)				
Skopje	Fluvisol sandy loam	10.50	63.10	26.40	2.66	6.7
Probištip	Vertisol	3.50	30.00	60.30	2.40	7.2

The wheat was grown following conventional tillage practices. The soil was tilled with a field cultivator prior to sowing. Nitrogen, phosphorus and potassium were applied, as recommended by soil test results. Field experiment were carried out with 'Pobeda' and 'Milenka' winter wheat cultivars, which were sown in a well-prepared seedbed at a seeding rate of 230 and 250 kg ha^{-1} on October 15th, 2012 and October 26th, 2013 in the Skopje region and on October 23rd, 2012 and November 1st, 2013 in the Probištip region, respectively. The experiments were conducted in different sites of the same commercial wheat fields. Herbicides were applied with a CO_2-pressurised backpack sprayer CP-3 calibrated to deliver 300 L ha^{-1} of aqueous solution at 220 kPa.

Herbicides were applied at the end of the wheat-tillering stage (BBCH-scale 28-30). Weeds at the time of treatment were in the following growth stages *Asperugo procumbens* BBCH 30, *Avena ludoviciana* BBCH 23-24, *Lolium perenne* BBCH 28-29, *Bifora radians* BBCH 16-18 and *Polygonum convolvulus* 14-16. The experimental design was a randomised complete block with four replicates and elementary plots 25 m^2. Treatments included Lancelot Super (aminopyralid 300 g a.m. kg^{-1} + florasulam 150 g a.m. kg^{-1}) at 33 g ha^{-1} + Pallas 75 WG (75 g a.m. kg^{-1} pyroxsulam) at 0.25 L ha^{-1}; Alister OD 180 (mesosulfuron-methyl 6.0 g a.i. L^{-1} + iodosulfuron-methyl-sodium 4.5 g a.i. L^{-1} + diflufenican 180 g a.i. L^{-1}) at 0.8 and 1.0 L ha^{-1}; Accurate 20 WG (metsulfuron-methyl 200 g a.i. kg^{-1}) at 30 g ha^{-1}; and Axial 100 EC (pinoxaden, 100 g a.i. L^{-1}) at 0.7 L ha^{-1} and Arat WG (water dispersible granules) (tritosulfuron 250 g a.m. kg^{-1} + dicamba 500 g a.m. kg^{-1}) at 170 g ha^{-1} + Pallas 75 WG (75 g a.m. kg^{-1} pyroxsulam) at 0.25 L ha^{-1}. All herbicides were used in recommended rates. Untreated and weed-free controls were included in the studies as well for comparison. The control plots were left untreated during the entire experimental period. Weed-free control was maintained by hand weeding. Hand weeding was initiated at the emergence of weeds and continued to 28th days after application.

Wheat injury and percent weed control were visually evaluated based on a 0–100% rating scale, where 0 is no injury to wheat plants or no weed control and 100 is complete death of wheat plants or complete control of weeds (Frans et al., 1986). Visual estimates of percent wheat injury were estimated 7 and 21 days after application, based on chlorosis and necrosis for each plot, while weed control efficacy was estimated 28 days after application from a one meter square area with the help of quadrat within each plot at both localities during a 2-year experimental period.

At full maturity, wheat was harvested manually at ground level in an area of 1 m^2 per plot. The yield was determined after harvest based on weights of grain containing 13% moisture.

Maximum and minimum temperatures for 5 days after POST treatments were recorded (Table 2). POST treatments in 2013 were applied at times when herbicide applications typically occur in Macedonian wheat production (Table 2) and, thus, are representative of producer practices and label recommendations. Unusually, in 2014, because of a mild winter, the beginning of wheat vegetation started earlier. POST herbicides were applied at the end of the wheat-tillering stage (BBCH 28-30) on March 22nd in Skopje and on March 26th in the Probištip region, respectively. After application, minimum temperatures in the Probištip region varied and such variability was partially attributed to unfavourable environmental conditions associated with cold night-time temperatures of -1 °C and 0 °C, particularly 48 hours after application (Table 2).

Table 2. Temperature data 5 days after treatment in 2013 and 2014 at the experimental locations

Date	Skopje region				Probištip region			
	2013		2014		2013		2014	
	Temperature (°C)				Temperature (°C)			
	min	max	min	max	min	max	min	max
April 4	10	22	-	-	-	-	-	-
April 5	9	24	-	-	-	-	-	-
April 6	12	23	-	-	-	-	-	-
April 7	9	20	-	-	8	22	-	-
April 8	12	23	-	-	12	25	-	-
April 9	-	-	-	-	10	27	-	-
April 10	-	-	-	-	9	21	-	-
March 23	-	-	6	18	-	-	-	-
March 24	-	-	7	20	-	-	-	-
March 25	-	-	5	17	-	-	-	-
March 26	-	-	6	17	-	-	-	-
March 27	-	-	2	19	-	-	-1	16
March 28	-	-	-	-	-	-	0	15
March 29	-	-	-	-	-	-	3	15
March 30	-	-	-	-	-	-	6	19
March 31							5	19

The data were tested for homogeneity of variance and normality of distribution (Ramsey & Schafer, 1997) and were log-transformed as needed to obtain roughly equal variances and better symmetry before ANOVA was performed. Data were transformed back to their original scale for presentation. Means were separated by using an LSD test at 5% of probability.

RESULTS AND DISCUSSION

Weed control. Efficacy of POST herbicides varied among weed species, treatments and years. Inconsistent weather patterns in the 2 years of study likely influenced the weed control. Temperature, particularly minimum temperature following application, may have contributed to the high performance of POST herbicides in both districts in 2013 and in the Skopje region in 2014 (Table 1). Conversely, unfavourable environmental conditions associated with cold night time temperatures of around 0 °C, particularly 48 hours after application, probably were the most likely reason for the lower efficacy of POST applied herbicides in the control of weeds in the Probištip region in 2014 compared to their application in 2013 (Tables 2 and 3).

Asperugo *procumbens*. *Asperugo procumbens* control in the Skopje region was not significant among years for different POST herbicide applications. In this district, regardless of the year, all POST herbicides provided control of *A. procumbens* between

95 and 100%. However, the greatest control (100%) was achieved with aminopyralid + florasulam + pyroxsulam, mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican (applied at 0.8 and 1.0 L ha^{-1}) and tritosulfuron + dicamba + pyroxsulam in 2012–2013, and with aminopyralid + florasulam + pyroxsulam, mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 1.0 L ha^{-1} and tritosulfuron + dicamba + pyroxsulam in 2013–2014, respectively (Table 3). Kostov and Pacanoski (2004) reported 98–100% *A. procumbens* control in winter wheat 30 DAT with amidosulfuron + iodosulfuron–methyl–sodium + mefenpyr–diethyl (Sekator) and tritosulfuron + dicamba (Arat WG).

Lolium perenne. *Lolium perenne* control in the Skopje region was not significant among years for different POST herbicide applications. In this region in 2012–2013, all POST herbicides suppressed *L. perenne* 93–100%. Among the POST treatments, only metsulfuron-methyl + pinoxaden showed significantly higher efficacy in control of *L. perenne* compared to all other evaluated herbicides (Table 3). Similar to the previous year, in 2013–2014 all POST applied herbicides controlled *L. perenne* between 94 and 99%. A significant treatment by year interaction resulted in two distinct years for *L. perenne* control in the Probištip region. All POST applied herbicides in 2012–2013 controlled *L. perenne* 95–100%, but only mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 1.0 L ha^{-1} and metsulfuron-methyl + pinoxaden showed significantly higher efficacy in control of *L. perenne* (99–100%) compared to all other evaluated herbicides (Table 4). In 2013–2014, cold temperature within 48 hours of application could have caused reduced *L. perenne* efficacy. Temperature has been shown to have a large influence on *L. perenne* growth and metabolism (Beevers & Cooper, 1964), and lower temperatures could reduce herbicide uptake. All POST herbicides provided control of this weed between 76 and 84% (Table 4). According to Grey et al. (2012), maximum and most consistent *L. perenne* control (> 90%) occurred with mesosulfuron plus MSO and UAN. Without UAN, control of *L. perenne* with mesosulfuron varied from 44 to 97%. Ellis (2009) reported good POST control of *L. perenne* (> 80%) with pinoxaden, mesosulfuron, flufenacet + metribuzin, and chlorsulfuron + flucarbazone.

Avena ludoviciana. *Avena ludoviciana* control in the Skopje region was not significant among years for different POST herbicide applications. In 2012–2013, all POST herbicides provided control of *A. ludoviciana* between 98 and 100%. Negligible lower efficacy was recorded in 2013–2014. Control of *A. ludoviciana* by POST treatments was above 95%, with only metsulfuron-methyl + pinoxaden providing excellent control (100%) (Table 3). A significant treatment by year interaction resulted in two distinct years for *A. ludoviciana* POST control in the Probištip region In this region in 2012–2013, POST treatments controlled *A. ludoviciana* more than 95%, but the greatest control (100%) was achieved with mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 1.0 L ha^{-1} and metsulfuron-methyl + pinoxaden. In 2013–2014, POST herbicides' efficacy decreased when a decrease in temperature occurred soon after application. However, *A. ludoviciana* control was less than 85% (Table 4). Pyroxsulam controls important winter annual grass weeds, including *Avena* spp. In North Dakota, pyroxsulam controlled *Avena fatua* L. more effectively when applied at the one- or three-leaf stage than when applied at the five-leaf stage (Hanson & Howatt, 2007).

Table 3. *Asperugo procumbens, Lolium perenne* and *Avena ludoviciana* control (%) 28 days after POST herbic 2012–2013 and 2013–2014 in Skopje region[a-d]

Treatments	Rate (g L ha^{-1})	Skopje region			
		A. procumbens		*L. perenne*	
		2012–2013	2013–2014	2012–2013	2013–20
Untreated control	------	0	0	0	0
Aminopyralid + florasulam + pyroxsulam	33 + 0.25	100[a]	100[a]	96[b]	95[ab]
Mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican	0.8	100[a]	95[b]	93[c]	94[b]
Mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican	1.0	100[a]	100[a]	97[b]	97[ab]
Metsulfuron-methyl + pinoxaden	30 + 0.7	97[b]	96[b]	100[a]	99[a]
Tritosulfuron + dicamba + pyroxsulam	170 + 0.25	100[a]	100[a]	97[b]	95[ab]
LSD 0.05		2.81	3.05	2.97	4.41
Random effect interactions POST herbicides treatment x year		NS		NS	

[a] Abbreviation: POST – posteemergence; NS – not significant; [b] POST treatments were applied at wheat BBCH 28-30, *Asp* *ludoviciana* BBCH 23-24, and *Lolium perenne* BBCH 28-29; [c] Weed control efficacy was estimated 28 DAA; [d] Means followe are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

Table 4. *Lolium perenne* , *Avena ludoviciana, Bifora radians* and *Polygonum convolvulus* control (%) 28 days a
winter wheat in Probištip region in 2012–2013 and 2013–2014

Treatments	Rate (g L ha^{-1})	Probištip region					
		L. perenne		*A. ludoviciana*		*B. radians*	
		2012–2013	2013–2014	2012–2013	2013–2014	2012–2013	201
Untreated control	------	0	0	0	0	0	0
Aminopyralid + florasulam + pyroxsulam	33 + 0.25	97[b]	78[ab]	97[b]	80[ab]	100[a]	83[a]
Mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican	0.8	95[b]	76[b]	95[b]	78[b]	97[b]	80[a]
Mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican	1.0	99[a]	82[ab]	100[a]	85[a]	100[a]	82[a]
Metsulfuron-methyl + pinoxaden	30 + 0.7	100[a]	84[a]	100[a]	85[a]	100[a]	79[b]
Tritosulfuron + dicamba + pyroxsulam	170 + 0.25	95[b]	80[ab]	98[ab]	82[ab]	100[a]	82[a]
LSD 0.05		2.77	7.07	2.08	6.23	1.55	3.6
Random effect interactions POST herbicides x year		*		*		*	

[a] Abbreviation: POST – posteemergence; * Significant at the 5% level according to a Fisher's protected LSD test at $P < 0.05$; [b] P
BBCH 28-30, *Lolium perenne* BBCH 28-29 *Avena ludoviciana* BBCH 23-24, *Bifora radians* BBCH 16-18, *Polygonum convo*
was estimated 28 DAA; [d] Means followed by the same letter within a column are not significantly different according to Fisher'

Excellent control of *Avena fatua* with pinoxaden + cloquintocet metyl (5–1.25%), at doses ranging from 20 to 60 g a.i. pinoxaden ha^{-1} applied to two to three leaves and at the beginning of tillering of *Avena fatua*, was reported by Scursoni et al. (2011). Similar results were reported by Hofer et al. (2006). Othello 6% OD (diflufenican 5% + mesosulfuron methyl 0.75% + iodosulfuron–methyl–sodium 0.25% + mefenpyr-diethyl 2.25%) controlled *Avena ludoviciana* more than 95% (Reza, 2013). The same herbicide provided 95% control of *Apera spica-venti* (Vanaga et al., 2010).

***Bifora radians*.** A significant treatment by year interaction resulted in two distinct years for *B. radians* control in the Probištip region with POST herbicides. In this region in 2012–2013, POST treatments provided control of *B. radians* between 97 and 100% (Table 4). In 2013–2014, lower temperature directly following application decreased the likelihood of POST herbicides' efficacy. All POST herbicides provided no more than 83% control of *B. radians* (Table 3). Kostov & Pacanoski (2004) reported 93–98% *B. radians* control in winter wheat 30 DAT with amidosulfuron + iodosulfuron–methyl–sodium + mefenpyr–diethyl (Sekator) and tritosulfuron + dicamba (Arat WG). Florasulam + flumetsulam applied at 50 and 70 mL ha^{-1} provided 92 and 98% control of *B. radians,* respectively (Kostov & Pacanoski, 2007). Effective control of *B. radians* with metsulfuron methyl in winter wheat was reported by Markovic et al. (2005) as well.

***Polygonum convolvulus*.** A significant treatment by year interaction resulted in two distinct years for *P. convolvulus* control in the Probištip region with POST herbicides, as well. In 2012–2013, all POST herbicides suppressed *P. convolvulus* 98–100% (Table 4). No one treatment controlled *P. convolvulus* more than 82% in 2013–2014. In investigations of Sulewska et al. (2012), tritosulfuron + dicamba (Mocarz 75 WG) provided 100% control of *Polygonum* (*Fallopia*) *convolvulus* in maize. Very good control of *Polygonum convolvulus* was observed after application of half of the rate of tribenuron-methyl with adjuvant and amidosulfuron + iodosulfuron in spring barley (Domaradzki & Kieloch, 2009).

Wheat injury. POST herbicides were applied at times when herbicide applications commonly used in Macedonian wheat production system (Table 2) and, thus, are representative of producer practices and label recommendations. However, in 2014 in the Probištip region, minimum temperature varied and such variability was partially attributed to unfavourable environmental conditions associated with cold night time temperatures of -1 °C and 0 °C, particularly 48 hours after application (Table 2). Lower temperatures generally slow crop growth, which results in prolonged herbicide exposure (Rouse & Dittmar, 2013). Negative temperatures directly following POST application caused wheat injury, which ranged from 12–29% across POST treatments 7 days after application (DAA) (Table 5). Wheat injury with tritosulfuron + dicamba + pyroxsulam was more serious (29%). Injuries caused by aminopyralid + florasulam + pyroxsulam, mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican and metsulfuron-methyl + pinoxaden significantly decreased by 7 and 21 DAA (Table 5). However, wheat injury with tritosulfuron + dicamba + pyroxsulam was still evident 21 DAA. Crooks et al. (2004) reported 7–19% injury for mesosulfuron combinations with thifensulfuron when applied at a spray solution rate of 140 L ha^{-1} at Feekes stage 3.0. Bailey et al. (2003) reported 9–24% wheat injury when mesosulfuron was applied at the 2–3 LF (two- to three-leaf wheat at Feekes stage), 2–3 (two- to three-tiller wheat stage) and 4–5 TILL stages (four- to five-tiller wheat stage). Sosnoskie et al. (2009) noted severe wheat injury (up to 40%) when UAN was combined with mesosulfuron application.

Table 5. Wheat plant injury (%) as influenced by POST applied herbicides, and grain yield as influenced by POST a
in Skopje and Probištip region in 2012–2013 and 2013–2014[a-c]

Treatments	Rate (g L ha^{-1})	Skopje region						Probištip region		
		Wheat injury				Grain yield (kg ha^{-1})		Wheat injury		
		2012–2013		2013–2014				2012–2013		2013
		7 DAA	21 DAA	7 DAA	21 DAA	2012–2013	2013–2014	7 DAA	21 DAA	7 DA
Weed-free control	------	0	0	0	0	3,690[ab]	3,870[a]	0	0	0
Aminopyralid + florasulam + pyroxsulam	33 + 0.25	0	0	0	0	3,650[ab]	3,850[ab]	0	0	15
Mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican	0.8	0	0	0	0	3,580[b]	3,760[b]	0	0	12
Mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican	1.0	0	0	0	0	3,700[a]	3,880[a]	0	0	17
Metsulfuron-methyl + pinoxaden	30 + 0.7	0	0	0	0	3,720[a]	3,910[a]	0	0	17
Tritosulfuron + dicamba + pyroxsulam	170 + 0.25	0	0	0	0	3,670[ab]	3,840[ab]	0	0	29
LSD 0.05						112.8	100.53			
Random effect interactions POST herbicides x year						NS				

[a] Abbreviations: POST – posteemergence; DAA – days after application; NS–not significant; * Significant at the 5% level acco
at P<0.05; [b] Herbicide POST treatments included Aminopyralid + florasulam at 33 g ha^{-1} plus Pyroxsulam at 0.25 L ha^{-1}, Mesosu
sodium + diflufenican at 0.8 and 1.0 L ha^{-1}, Metsulfuron-methyl at 30 g ha^{-1} plus Pinoxaden at 0.7 L ha^{-1}, Tritosulfuron + dica
0.25 L ha^{-1}; [c] Means followed by the same letter within a column are not significantly different according to Fisher's Protected

Hofer et al. (2006) reported 1.5% average wheat phytotoxicity after pinoxaden treatment at the recommended rate. Spring-applied pyroxsulam caused 5–10% wheat injury 5–14 DAT. However, injury was always transient and not detectable by the end of the season (Geier et al., 2011).

Wheat yield. Wheat yields for each treatment in both regions generally reflected overall weed control (Table 5). Wheat yields in the Skopje region were not significant among years for different POST herbicide applications. The lowest yield in 2012–2013 was obtained in plots treated with mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 0.8 L ha^{-1}. Same herbicide applied at 1.0 L ha^{-1} and metsulfuron-methyl + pinoxaden treatments yielded higher than did the weed-free control, 3,700 and 3,720 kg ha^{-1} respectively. Wheat yields obtained in 2012–2013 from plots treated with aminopyralid + florasulam+ pyroxsulam and tritosulfuron + dicamba + pyroxsulam yielded lower than did the weed-free control, averaging 3,650 and 3,670 kg ha^{-1} respectively (Table 5). In 2013–2014, similar results were obtained. There were significant results in wheat yields between weed-free control and the plots treated with mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 0.8 L ha^{-1}, averaging 3,870 and 3,760 kg ha^{-1}, respectively. In the same year, wheat yields from plots treated with mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 1.0 L ha^{-1} and metsulfuron-methyl + pinoxaden yielded higher than did the weed-free control, averaging 3,880 kg ha^{-1} or greater (Table 5). A significant treatment by year interaction resulted in two distinct years for wheat yields in the Probištip region with POST herbicides. In 2012–2013, wheat yields were greater than 3,360 kg ha^{-1} (weed-free control) when mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican and metsulfuron-methyl + pinoxaden were applied at 1.0 L ha^{-1} and 30 g ha^{-1} + 0.7 L ha^{-1}, respectively (3,390 and 3,430 kg ha^{-1}). The wheat yield following mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican application at 0.8 L ha^{-1} was significantly lower (-130 kg ha^{-1}) than that of the weed-free control. Wheat yields in 2012–2013 were not significantly lower for plots treated with aminopyralid+florasulam+pyroxsulam and tritosulfuron + dicamba + pyroxsulam, which yielded lower than did the weed-free control, averaging 3,290 and 3,340 kg ha^{-1} respectively (Table 5). In 2013–2014 wheat yields were more closely related to percent of weeds control, than wheat injury. Only the weed-free control showed a significantly higher wheat yield compared to all evaluated herbicides. However, wheat yields ranged from 3,060 to 3,490 kg ha^{-1}. mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 0.8 L ha was the lowest-yielding herbicide treatment with 3,060 kg ha^{-1}, whereas metsulfuron-methyl + pinoxaden and mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 1.0 L ha^{-1} were the highest-yielding herbicide treatments. Yield for these treatments ranged from 3,180–3,210 kg ha^{-1}, and was not significant (Table 5). The same yield was obtained from plots treated with aminopyralid + florasulam + pyroxsulam and tritosulfuron + dicamba + pyroxsulam: 3,120 kg ha^{-1}. A significant negative linear relationship between the winter wheat yield and the numbers of *Apera spica-venti* flowered panicles was reported in a study of Vanaga et al. (2010). According to their results, Alister Grande provided control of *Apera spica-venti* greater than 95% and was the highest-yielding herbicide treatment with 5,596 and 4,732 kg ha^{-1} respectively. Conversely, poor weed control of iodosulfuron + mesosulfuron applied at 18 g a.i. ha^{-1} decreased the grain yield by 42.81 and 51.62% as compared to the weed-free check during both growing seasons, respectively (Malekian et al., 2013). In an investigation of

Dalga et al. (2014) the highest grain yields of 4,700 and 4,455 kg ha^{-1} were obtained in weed-free treatment, followed by that of Pallas 20 g ha^{-1}, which gave grain yields of 4,455 and 4,031 kg ha^{-1} in both experimental localities.

CONCLUSIONS

- Both sites were naturally infested with a high population of *Asperugo procumbens* L., *Lolium perenne* L, *Avena ludoviciana* Dur., *Bifora radians* M.B. and *Polygonum convolvulus* L.
- Weed density in non-treated control plots was 116 and 208 plants m^{-2} in 2012–2013 and 2013–2014, respectively, in the Skopje region, and 93 and 114 plants m^{-2} in 2012–2013 and 2013–2014, respectively, in the Probištip region.
- Efficacy of POST herbicides varied among weed species, treatments and years, respectively. Inconsistent weather patterns in the 2 years of study likely influenced the weed control.
- All investigated POST herbicides effectively reduced dominant weeds in both regions, but mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican (applied at 1.0 L ha^{-1}) and metsulfuron-methyl + pinoxaden showed significantly higher efficacy in control of some weeds compared to the other evaluated herbicides.
- Wheat yields for each treatment in both regions generally reflected overall weed control. Mesosulfuron-methyl + iodosulfuron-methyl-sodium + diflufenican applied at 1.0 L ha^{-1} and metsulfuron-methyl + pinoxaden treatments yielded higher than did the weed-free control and other herbicides, respectively.

REFERENCES

Bailey, W.A., Wilson, H.P. & Hines, T.E. 2003. Influence of AE F13006003 Application Timing on Italian Ryegrass Control. *Weed Tech.* **17**, 842–853.

Beevers, L. & Cooper, J.P. 1964. Influence of Temperature on Growth and Metabolism of Ryegrass Seedlings. *Crop Sci.* **4**, 139–143.

Bertholdsson, N.O. 2012. Allelopathy–A Tool to Improve the Weed Competitive Ability of Wheat with Herbicide-Resistant Black-Grass (*Alopecurus myosuroides* Huds.) *Agronomy* **2**, 284–294.

Capinera, J.L. 2005. Relationships Between Insect Pests and Weeds: An Evolutionary Perspective. *Weed Sci.* **53**(6), 892–901.

Chachar, Q.I., Chachar, M.A. & Chachar, S.D. 2009. Studies on Integrated Weed Management in Wheat (*Triticum aestivum* L.). *J. Agri. and Tech.* **5**, 405–412.

Crooks, H.L., York, A.C. & Jordan, D.L. 2004. Wheat Tolerance to AE F130060 00 plus AE F115008 00 Affected by Time of Application and Rate of the Safener AE F107982. *Weed Tech.* **18**, 841–845.

Dalga, D. Sharma, J.J. & Tana, T. 2014. Evaluation of Herbicides and Their Combinations for Weed Management in Bread Wheat (*Triticum aestivum* L.) in Southern Ethiopia. *Int. J. Nat. Res. Lif. Sci.* **1**(1), 31–47.

Domaradzki, K. & Kieloch, R. 2009. Possibilities of Weed Control in Spring Cereals by Herbicides Applied at Reduced rates. *Polish J. Agr.* **1**, 9–14.

Ellis, A.T. 2009. Control of Italian Ryegrass (*Lolium perenne* L. spp. multiflorum Lam. Husnot) in Wheat (Triticum spp.) and Evaluation of Resistance to Acetyl-CoA Carboxylase Inhibiting Herbicides. *Doctoral thesis,* University of Tennessee.

Filipovski, G. 2006. Soil Classification of the Republic of Macedonia. *MASA*, pp. 313–323.

Frans, R.E., Talbert, R., Marx, D. & Crowley, H. 1986. Experimental Design and Techniques for Measuring and Analyzing Plant Responses to Weed Control Practices. In N. D. Camper ed. Research Methods in Weed Science. 3rd ed. Champaign, IL: *Southern Weed Science Society*, pp. 37–38.

Frihauf, J.C., Stahlman, P.W. & Geier, P.W. 2010. Winter Wheat and Weed Response to Postemergence Saflufenacil Alone and in Mixtures. *Weed Tech.* **24**, 262–268.

Gao, X., Li, M., Gao, Z., Li, C. & Sun, Z. 2009. Allelopathic Effects of *Hemistepta lyrata* on the Germination and Growth of Wheat, Sorghum, Cucumber, Rape, and Radish Seeds. *Weed Bio. Man.* **9**, 243–249.

Geier, P.W., Stahlman, P.W., Peterson, D.E. & Claassen, M.M. 2011. Pyroxsulam Compared with Competitive Standards for Efficacy in Winter Wheat. *Weed Tech.* **25**, 316–321.

Grey, T.L., Cutts, G.S., Sosnoskie, L. & Culpepper, A.S. 2012. Italian Ryegrass (*Lolium perenne*) Control and Winter Wheat Response to POST Herbicides. *Weed Tech.* **26**(4), 644–648.

Hanson, L.K. & Howatt, K.A. 2007. Pyroxsulam Efficacy to Wild Oat Influenced by Application Timing or Adjuvants. *Proceedings of the 62nd North Central Weed Science Society Annual Meeting*. St Lois, MO: NCWSS, pp. 89.

Hofer, U., Muehlebach, M., Hole, S. & Zoschke, A. 2006. Pinoxaden – for Broad Spectrum Grass Weed Management in Cereal Crops. *J. Pla. Dis. and Prot.* **20**, 989–995.

Khaliq, A., Matloob, A., Tanveer, A., Areeb, A., Aslam, F. & Abbas, N. 2011. Reduced Doses of a Sulfonylurea Herbicide for Weed Management in Wheat Fields of Punjab, Pakistan. *Chilean J. Agri. Res.* **71**(3), 424–429.

Khan, I., Hassan, G. & Marwat, K.B. 2002. Efficacy of Different Herbicides for Controlling Weeds in Wheat Crop – II Weed dynamics and herbicides. *Pak. J. Weed Sci. Res*. **8**, 41–47.

Kieloch, R., Domaradzki, K. & Górniak, J. 2006. Pinoxaden – A New Active Ingredient for Grass Weed Control in Cereals of South-West Poland. *J. Pla. Dis. and Prot. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz Sonderheft* **XX**, 1067–1072.

Klein, R.N., Martin, A.R. & Lyon, D.J. 2006. Annual Broadleaf Weed Control in Winter. Wheat University of Nebraska, *Linkoln Extension, Institute of Agriculture and Natural Resources* NebGuide G1241.

Knežević, M., Baličević, R., Ravlić, M. & Ranogajec, L.J. 2012. Effects of Reduced Herbicide Doses on Annual Weeds and Winter Wheat Yield by Two Tillage System. *Herbologia* **13**(1), 37–46.

Kostov, T. & Pacanoski, Z. 2004. Results of Examinations of Some New Herbicides in Wheat. *Yearbook for Plant Protection* **XV**, 141–152.

Kostov, T. & Pacanoski, Z. 2007. Results of Biological Examinations of Derby-175 in Wheat. *Yearbook for Plant Protection* **XVIII**, 97–100.

Malekian, B., Ghadiri, H., Kazemeini, S.A. & Edalat, M. 2013. Efficacy Evaluation of Sulfosulfuron, Metsulfuron-methyl plus Sulfosulfuron, Mesosulfuron-methyl plus Iodosulfuron-methyl and Iodosulfuron plus Mesosulfuron Herbicides in Winter Wheat (*Triticum aestivum* L.). *Journal Biol. and Env. Sci.* **7**(21), 177–182.

Mandal, M.S.H., Ali, M.H., Amin, A.K.M.R., Masum, S.M. & Mehraj, H. 2014. Assessment of Different Weed Control Methods on Growth and Yield of Wheat. *Int. Agr. and Agr. Res*. **5**(5), 65–73.

Markovic, M., Protic, N., Protic, R. & Jankovic, S. 2005. New Possibilities of Weed Control in Wheat. *Romanian Agri. Res.* **22**, 41–47.

Mehmeti, A., Pacanoski, Z., Fetahaj, R., Kika, A. & Kabashi, B. 2018. Weed Control in Wheat with Post-emergence Herbicides. *Bul. J. Agric. Sci.* **24**(1), 74–79.

Mehmood, Z., Ashiq, M., Noorka, I.R., Ali, A., Tabasum, S. & Iqbal, M.S. 2014. Chemical Control of Monocot Weeds in Wheat (*Triticum aestivum* L.). *American J. Pla. Sci.* **5**, 1272–1276.

Milberg, P. & Hallgren, E. 2004. Yield Loss due to Weeds in Cereals and its Large-Scale Variability in Sweden. *Field Cro. Res.* **86**, 199–209.

Nazari, A.J, Amiri, H., Javadi, M. & Gohlami, M. 2013. Efficiency of Different Herbicides Application for Weed Control in Wheat under Rain Fed Conditions in Iran. *International Journal Agri. and Cro. Sci.* **5**(5), 445–449.

Olesen, J.E., Hansen, P.K., Berntsen, J. & Christensen, S. 2004. Simulation of Above-Ground Suppression of Competing Species and Competition Tolerance in Winter Wheat Varieties. *Field Cro. Res.* **89**, 263–280.

Ozpinar, S. 2006. Effects of Tillage Systems on Weed Population and Economics for Winter Wheat Production under the Mediterranean Dryland Conditions. *Soil and Till. Res.* **87**(1), 1–8.

Pacanoski, Z. & Jankuloski, L. 2012. Response of Winter Wheat Cultivars to 2,4-D + Florasulam Applied at Three Different Growth Stages. *Herbologia* **13**(1), 47–59.

Ramsey, F.L. & Schafer, D.W. 1997. The Statistical Sleuth: A Course in Methods of Data Analysis. Belmont, CA: *Duxbury*. pp. 91–97.

Rao, A.N. & Chauhan, B.S. 2015. Weeds and Weed Management in India – A Review. *Chapter 4 Weed Science in the Asian-Pacific Region*, pp.87–118.

Reddy, S.S., Stahlman, P.W. & Geier, P.W. 2013. Downy Brome (*Bromus tectorum* L.) and Broadleaf Weed Control in Winter Wheat with Acetolactate Synthase-Inhibiting Herbicides. *Agronomy* **3**, 340–348.

Reza, J.M. 2013. Investigatig Efficacy of Othello New Herbicie (Mesosulfuron methyl+Iodosulfuron methyl sodium+ Diflufenican) on Weeds of Wheat Fields. Agricultural Scientific Information and Documentation Centre, *Agricultural Research and Education Organization*. http://agris.fao.org/agris-search/search.do?recordID=IR2015001263 (it is only abstract).

Rouse, C.E. & Dittmar, P.J. 2013. Factors Affecting Herbicide Use in Fruits and Vegetables. Horticultural Sciences Department, Florida Cooperative Extension Service, *Institute of Food and Agricultural Sciences*, University of Florida, pp. 1–5.

Scursoni, J.A., Martín, A., Catanzaro, M.P., Quiroga, J. & Goldar, F. 2011. Evaluation of Post-Emergence Herbicides for the Control of Wild Oat (*Avena fatua* L.) in Wheat and Barley in Argentina. *Crop Protection* **30**(1), 18–23.

Sheikhhasan, M.R.V., Mirshekari, B. & Farahvash, F. 2012. Weed Control in Wheat Fields by Limited Dose of Post-Emergence Herbicides. *World App. Sci. J.* **16**(9), 1243–1246.

Siddiqui, I., Bajwa, R., Huma, Z.E. & Javaid, A. 2010. Effect of Six Problematic Weeds on Growth and Yield of Wheat. *Pak. J. Bot.* **42**(4). 2461–2471.

Sosnoskie, L.M., Culpepper, A.S., York, A.C., Beam, J.B. & Macrae, A.W. 2009. Sequential applications for mesosulfuron and nitrogen needed in wheat. *Weed Tech.* **23**, 404–407.

Streit, B., Rieger, S.B., Stamp, P. & Richner, W. 2003. Weed Populations in Winter Wheat as Affected by Crop Sequence, Intensity of Tillage and Time of Herbicide Application in a Cool and Humid Climate. *Weed Research* **43**, 20–32.

Sulewska, H., Koziara, W., Śmiatacz, K., Szymańska, G. & Panasiewicz, K. 2012. Efficacy of Selected Herbicides in Weed Control of Maize. *Fragm. Agron.* **29**(3), 144–151.

Vanaga, I., Mintale, Z. & Smirnova, O. 2010. Control Possibilities of *Apera spica-venti* (L.) P.Beauv. in Winter Wheat with Autumn and Spring Applications of Herbicides in Latvia. *Agronomy Research* **8** (Special Issue II), 493–498.

Wells, G.S. 2008. Pyroxsulam for Broad-Spectrum Weed Control in Wheat. *Proceedings of the 16th Australian Weeds Conference*. Cairns, Australia: Queensland Weeds Society, pp. 297–299.

Zand, E., Baghestani, M.A., Soufizadeh, S., Eskandari, A., Azar, R.P. & Veysi, M. 2007. Evaluation of Some Newly Registered Herbicides for Weed Control in Wheat (*Triticum aestivum* L.) in Iran. *Crop Protection* **26**, 1349–1358.

Zhang, S.Z., Li, Y.H., Kong, C.H. & Xub, X.H. 2016. Interference of Allelopathic Wheat with Different Weeds. *Pest Man. Sci.* **72**, 172–178.