RESEARCH

Weed management practices for redroot pigweed (*Amaranthus retroflexus* L.) and smooth pigweed (*A. hybridus* L.) control in maize

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ABSTRACT

Redroot (*Amaranthus retroflexus* L.) and smooth pigweed (*A. hybridus* L.) are troublesome weeds in row crops in Serbia. Both species are very competitive, hosts for pathogens and insects, produce pollen which is highly allergenic; and the most recent research reported herbicide resistance in some populations across Serbia. An integrated approach for the control of both *Amaranthus* species must be evaluated and presented in order to reduce their negative potential in agriculture. In this paper, 9 yr results on redroot pigweed and smooth pigweed weed control are presented. In three different experiments, weed density and biomass of redroot and smooth pigweed were recorded: a) Crop rotation, b) row spacing and time of herbicide application, c) influence of nozzles and adjuvants. The influence of crop rotation and PRE herbicide mixture, PRE and POST mixture, and impact of nozzles and adjuvants were evaluated. PRE herbicide mix of *S*-metolachlor and isoxaflutole influenced 98.1% and 100% efficacy in the maize (*Zea mays* L.) continuous and in maize rotated with winter wheat (*Triticum aestivum* L.), respectively. The mixture of two herbicides, applied either in PRE or POST, resulted in 100% of control of both species. Finally, similar results were obtained for nicosulfuron application with extended range (XR) or turbo TeeJet induction (TTI) nozzles, and combined with nonionic surfactant (NIS) or ammonium sulphate (AMS) adjuvants. The novelty of obtained results indicates that only holistic approach based on different weed management practices can contribute to sustainable *Amaranthus* control.

Key words: Adjuvant, cropping systems, herbicides, nozzles, weed control.

INTRODUCTION

Redroot pigweed (*Amaranthus retroflexus* L.) and smooth pigweed (*A. hybridus* L.) are some of the most common species in summer row crops in Serbia (Bozic, 2018). Species from *Amaranthus* genus are C_4 plants, and they are stronger competitors when compared to C_3 plants. Also, these species have large potential for seed production with over 200 000 seeds per plant (Webster and Grey, 2015). *Amaranthus* species have an extended germination period and rapid growth (Bensch et al., 2003). Both redroot and smooth pigweed are self-pollinated, and gene transfer does not occur, like it does with other species (e.g. Palmer amaranth, waterhemp) (Vieira et al., 2018a). However, their management can be a very difficult task, especially if multiple resistance occurs (Whaley et al., 2007). Pigweed density has significant influence on maize growth and yield parameters (Vazin, 2012). As *Amaranthus* species are not easy to control, the research underlined an Integrated Weed Management (IWM) in row crops in order to provide increased efficacy by proper combination of applied measures or practices (Mhlanga et al., 2016).

Recently, redroot pigweed resistance to acetolactate synthase (ALS) herbicides was reported in Serbia (Vrbnicanin, 2020). The same author confirmed the resistance in Johnsongrass (*Sorghum halepense* (L.) Pers.) and common ragweed (*Ambrosia artemisifolia* L.) indicating potential problems in weed management in Serbian fields. An IWM is a holistic approach which leads to sustainable weed management (Swanton et al., 2008). It uses all available measures that will disrupt weed life cycles, and enable good background for better or increased herbicide efficacy (Liebman and Dyck, 1993). Herbicide resistance is a large problem worldwide, and the IWM system acts in order to slow down already present resistance and/or to prevent development of new resistant cases. As most recent literature reported, the application of pre-emergence (PRE) herbicide, as well as herbicide mixtures of two or three active ingredients, with different modes of action (MOA) (Beckie and Harker, 2017), appears to be an efficient method for weed control.

With a lack in new herbicide MOA and economic reality, application techniques that improve herbicide performance must be evaluated. Proper herbicide, nozzle, and adjuvant selection has been suggested as a strategy to maximize herbicide efficacy. Nozzles are some of the most important components of spraying equipment, which determine coverage, drift, and uniformity in herbicide application (Hartzler and Hanna, 2016). Literature reports that using nozzles that produce coarser (compared to medium and fine droplets) droplets does not compromise efficacy (Ferreira et al., 2020), while drift is successfully mitigated. On the other hand, adjuvants are agrochemicals that enhance pesticide efficacy and can reduce drift (Hazen, 2000). By changing the spray solution's physicochemical properties, they can increase the spreading and wetting area of droplets on plants leaves (Castro et al., 2014), interact with plant cuticle (Hess and Foy, 2000), which will lead to a greater absorption and uptake by the targeted weeds.

Since the weed control depends on various factors, and herbicide resistance is a great issue in agriculture, a holistic approach is needed for every production system, especially when row crops were considered. A lack of new herbicide mode of action, combined with genetically modified crops and economic reality, crop production and protection will face more challenges than ever. Combination of multiple weed management programs, including cultural measures such as crop rotation, chemical options-rotation of herbicide with different mode of action, and optimization of herbicide performance have to be evaluated in order to maximize weed control and crop production. Also, some weeds will become predominant in fields and will be difficult to control. Therefore, in this paper we presented several possible ways to control *Amaranthu*s species as very troublesome weeds in maize production.

MATERIALS AND METHODS

This paper presents how various cropping practices impact redroot (*Amaranthus retroflexus* L.) and smooth pigweed (*A. hybridus* L.) control across three different cropping systems. The field experiments were conducted at the Maize Research Institute "Zemun Polje", Belgrade (44°52' N, 20°20' E), Serbia. The investigated systems are presented in the Table 1. The same for all three systems was that both species were controlled in maize (*Zea mays* L.) Maize hybrid ZP 606 (FAO 600), Stay-Green with upstanding leaves was planted every year (middle April) in all experiments in a density of approx. 60 000 plants ha^{-1} (except the experiment with different row spacing). In each year the preceding crop was winter wheat and after harvesting and shallow plowing (0.1 m depth) plus deep plowing (in the second half of October) was performed. Herbicide efficacy was evaluated from elementary plots that encompassed eight rows, 5 m long, 28 m^2 in total area, including four replicates. Weed density and biomass were recorded 28 d after herbicide application, with a sampling area of 1 m^2.

Table 1. Weed control in different cropping systems.

Experiment type	1. Impact of rotation	2. Impact of row spacing	3. Impact of adjuvants and nozzles
Factors	Maize-wheat rotation and maize continuous	70 cm row spacing 50 cm row spacing	XR11002 nozzle TTI11002 nozzle
Herbicide applied	Isoxaflutole + *S*-metolachlor	*S*-Metolachlor+mesotrione Nicosulfuron+mesotrione	Nicosulfuron
Year	2013, 2015, 2017, 2019, 2021	2014, 2015, 2016	2020, 2021

The first experiment regarding crop rotation was set in 2009, and results from 2013, 2015, 2017, 2019, and 2021 were presented, when maize was present in the rotation cycle. The herbicide treatment included a mixture of isoxaflutole ((5-cyclopropyl-1,2-oxazol-4-yl)-[2-methylsulfonyl-4-(trifluoromethyl)phenyl]methanone; Merlin 750-WG, 750 g kg^{-1}, Bayer CropScience, Leverkusen, Germany) and *S*-metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-[(2*S*)-1-methoxypropan-2-yl]acetamide), applied as PRE treatment in rates of 105 and 1344 g ai ha^{-1}, respectively. The experiment was established as a split-plot experiment with maize-winter wheat (*Triticum aestivum* L.) crop rotation and a continuous cropping, while subplots were treated with herbicide combination, and one plot was a control.

In the second experiment, two types of herbicide applications were tested in the maize field: a PRE mixture of *S*-metolachlor (Dual Gold 960 EC, Syngenta, Basel, Switzerland) and mesotrione (2-(4-methylsulfonyl-2-nitrobenzoyl)cyclohexane-1,3-dione; Callisto, 480 g ai L^{-1}, Syngenta) was applied at the rates of 1344 and 120 g ai ha^{-1}, respectively, and a POST treatment which included nicosulfuron (2-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoyl]-*N*,*N*-dimethylpyridine-3-carboxamide; Motivell Extra 6 OD, 60 g ai L^{-1}, Londerzeel, Belgium) and mesotrione (Callisto, 480 g ai L^{-1}) at the rates of 60 and 120 g ai ha^{-1}, respectively, was applied when maize plants develop 5-6 leaves (15-16 BBCH). This experiment included row spacing as a factor. It included 70 and 50 cm distance between maize rows. The experiment was established as a split-plot experiment, where row spacing was considered as the main plot, while subplots were treated with herbicides, and one plot was a control.

For both experiments, herbicide applications were made with a CO_2 backpack sprayer with a four-nozzle boom using extended range nozzles (XR11002, TeeJet Spraying Systems, Wheaton, Illinois, USA) calibrated to deliver a spray volume of 140 L ha^{-1} solution at 275.8 kPa.

In the third field experiment, nicosulfuron (Motivell Extra 6 OD, 60 g ai L^{-1}) was applied with two adjuvants: Non-ionic surfactant (NIS) in a rate of 0.5 v/v (Dash, BASF, Germany) and ammonium sulphate (AMS; 20%N +24%S, Zorka Šabac, Serbia) at a rate of 5 v/v. In this research, herbicide solution was sprayed through extended range (XR11002) and turbo TeeJet induction (TTI11002) nozzles (TeeJet Technologies, Glendale Heights, Illinois, USA) using a CO_2 backpack sprayer with a four-nozzle boom, calibrated to deliver a spray volume of 140 L ha^{-1} solution at 275.8 kPa, when maize plants develop 5-6 leaves (15-16 BBCH). The experiment was established as a split-plot experiment, where nozzles were considered as the main plot, while subplots were treated with herbicides. Besides the efficacy examination, the progress of efficacy is presented by visual estimation of injuries 7, 14, and 21 d after treatment. Visual assessments of injury were made on a scale of 0-100, where 0 represented no injury and 100 was plant death.

All data were subjected to ANOVA using Sisvar Statistical Software, version 5.6 (Ferreira, 2011) and differences between means were tested by Tukey's test ($\alpha = 0.05$). Meteorological data were presented for each year in Table 2. For all seasons, low precipitation levels were reported in April (less than 15 mm), while following years also had a lower level of precipitation in May: 2014, 2015, 2019, and 2020.

RESULTS AND DISCUSSION

Experiment 1. Impact of rotation

According to obtained data, *S*-metolachlor and isoxaflutole mixture applied as PRE herbicide suppressed both *Amaranthus* species, and high efficacy was obtained. In maize rotated with winter wheat, 100% efficacy of applied herbicides on redroot and smooth pigweed was reported, opposite of continuous cropping where the *Amaranthus* biomass reduction was 98%, indicating that *Amaranthus* species control was not affected by the cropping system. The highest weed density in the control treatment (without herbicide application) in rotation was in 2015 and 2017, the years with the lowest

Table 2. Air temperatures (average) and precipitation (totals) during April, May, and June in Zemun Polje, Serbia for 2013-2021 (except 2018).

Month	Variable	2013	2014	2015	2016	2017	2019	2020	2021
April	°C	14.6	13.7	12.9	15.3	12.4	14.6	10.6	11.4
	mm	14.9	84.8	19.7	43.3	47.1	14.0	4.7	45.9
May	°C	17.3	17.4	19.1	17.6	18.6	15.7	16.1	17.4
	mm	89.6	192.5	97.8	60.7	49.2	42.3	79.9	73.0
June	°C	21.9	21.1	22.1	23.1	24.4	24.2	20.9	22.0
	mm	37.8	71.2	31.1	151.6	39.0	150.1	125.9	19.5

precipitation level. However, applied herbicides had an excellent efficacy. When herbicide mixtures were applied in maize continuous cropping rotations similar results were noticed, with 99.3% of redroot pigweed efficacy and 100% efficacy in smooth pigweed control averaged for all years (Table 3). Lower density of both species in 2013 and 2019 could be the consequence of low precipitation amounts in those years (Table 1), what could indicate that meteorological factors played important role in *Amaranthus* species emergence in regard to other applied measure such as herbicides application.

Both species participation in total weed population (weed biomass) is presented in Figure 1. In the maize continuous cropping, the highest percentage was reported in 2015, with 24.6% in total weed population. Opposite of this, in maize grown in the rotation with winter wheat, more than 50% of weed population was recorded in 2013 and 2015 (53.2% and 53.6%, respectively), while the lowest percentage was in 2019, with 25.2%.

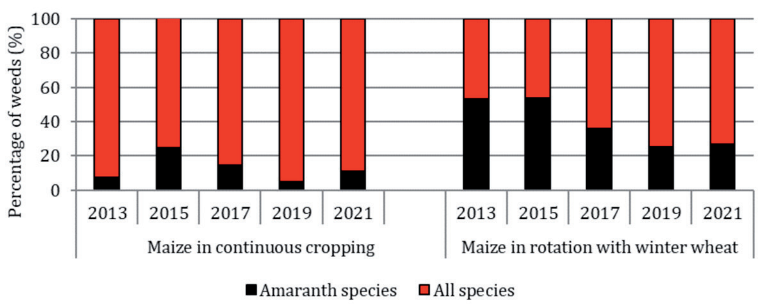
According to obtained results, the applied measures reduced the impact of *Amaranthus* species across all experiments. Although high weed biomass reduction was recorded when maize was grown in a continuous cropping, the general recommendation is to apply crop rotation in order to avoid the dominance of certain perennial weeds (Andújar et al., 2011). However, crop rotation remains a sustainable solution with multiple ecosystem service. Crop rotation is known for millennia for its positive effect on suppressing all weeds, pest and other undesirable microorganisms and has positive effects on soil. In the same experiment, herbicide application as PRE mixture provided the optimal weed control, particularly when continuous maize was considered. Although very small difference in efficacy was obtained between crop rotation and maize monoculture (2%), other weeds, especially perennials, were problematic to control in the continuous cropping (Brankov et al., 2021). Rapid herbicide resistance evolution of foliarly applied herbicides has increased worldwide, the

Table 3. Efficacy of applied herbicides in maize-winter wheat rotation and maize continuous cropping.

	Redroot pigweed				Smooth pigweed			
	Density (Nr m^{-1})		Biomass (g m^{-2})		Density (Nr m^{-1})		Biomass (g m^{-2})	
	C	T	C	T	C	T	C	T
Maize in rotation								
2013	20.0a	0.0b	1441.9a	0.0b	11.0a	0.0b	264.8a	0.0b
2015	81.0a	0.0b	513.4a	0.0b	49.0a	0.0b	497.9a	0.0b
2017	21.0a	0.0b	322.8a	0.0b	25.0a	0.0b	555.3a	0.0b
2019	2.0a	0.0b	75.5a	0.0b	8.0a	0.0b	25.7a	0.0b
2021	7.0a	0.0b	177.4	0.0b	1.0a	0.0b	6.5a	0.0b
Average	26.2a	0.0b	506.2a	0.0b	18.8a	0.0b	270.0a	0.0b
Efficacy, %	100		100		100		100	
Maize in continuous cropping								
2013	49.0a	0.0b	187.1a	0.0b	10.0a	0.0b	14.5a	0.0b
2015	56.0a	0.0b	116.8a	0.0b	73.0a	0.0b	207.3a	0.0b
2017	30.0a	0.0b	316.9a	0.0b	31.0a	0.0b	292.4a	0.0b
2019	8.0a	1.0b	109.3a	13.9b	7.0a	0.0b	109.4a	0.0b
2021	7.0a	1.0b	86.4a	3.7b	10.0a	1.0b	145.8a	3.6b
Average	30.0a	0.4b	163.3a	3.5b	26.2a	0.2b	153.9a	0.7b
Efficacy, %	99.3		97.8		99.2		99.5	

C: Control; T: treatment isoxaflutole+*S*-metolachlor.
Values followed by the same letter in the column within species, do no differ using Tukey's test at α = 0.05.

Figure 1. Distribution of redroot and smooth pigweed in regard to all weeds in control treatments in maize in rotation with wheat and in maize continuous cropping.



application of PRE herbicides seems to be the most potent future strategy for delaying or avoiding of herbicide resistance (Beckie and Reboud, 2009), while the most potent strategy is rotation of active ingredients. Also, using herbicide mixture with a different mode of action, over one formulation, makes it possible to lower the selection pressure on weeds, resulting in lower chance to resistance development. Despite that applied herbicide combination suppressed both targeted species, the integration of crop rotation and PRE herbicides provide an optimal background for successful weed control (Liebman and Dyck, 1993), including weeds from *Amaranthus* genus.

Experiment 2. Impact of row spacing and time of herbicide application

In the experiment with herbicide timing, PRE mixture of *S*-metolachlor and mesotrione resulted in 100% efficacy, although smooth pigweed was not recorded in the field in 2014 (Table 4). Similarly, POST mixture of mesotrione and nicosulfuron provided the same efficacy for both species. The highest density on redroot and smooth pigweed was recorded in 2016, the year with the highest precipitation level. Results from the study indicated high efficacy of applied herbicide mixture on control of redroot and smooth pigweed. Nevertheless, row spacing had no influence on the density and biomass of both species.

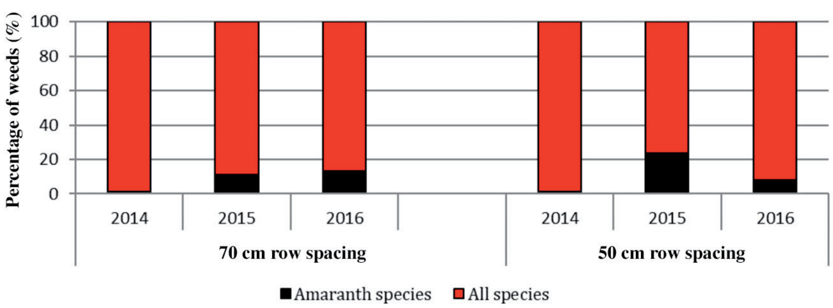
The share of *Amaranthus* species in total weed biomass is presented in the Figure 2. In the first year, the percentage of both species was very low, it was 1% of total weed population, while the highest biomass was recorded in 2015, with one quarter of all weeds (23.8%).

Table 4. Efficacy of applied herbicides in the experiment with different row spacing.

	Redroot pigweed						Smooth pigweed					
	Density (Nr m^{-1})			Biomass (g m^{-2})			Density (Nr m^{-1})			Biomass (g m^{-2})		
	C	PRE	POST	C	PRE	POST	C	PRE	POST	C	PRE	POST
Row spacing 70 cm												
2014	1.0a	0.0b	0.0b	7.5b	0.0b	0.0b	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
2015	2.0a	0.0b	0.0b	7.0b	0.0b	0.0b	4.0a	0.0b	0.0b	42.6a	0.0b	0.0b
2016	11.0a	0.0b	0.0b	173.1b	0.0b	0.0b	17.0a	0.0b	0.0b	120.7a	0.0b	0.0b
Average	4.7a	0.0b	0.0b	62.5a	0.0b	0.0b	7.0a	0.0b	0.0b	54.4a	0.0b	0.0b
Efficacy, %		100	100		100	100		100	100		100	100
Row spacing 50 cm												
2014	2.0a	0.0b	0.0b	4.7a	0.0b	0.0b	2.0a	0.0b	0.0b	2.6a	0.0b	0.0b
2015	3.0a	0.0b	0.0b	19.4a	0.0b	0.0b	7.0a	0.0b	0.0b	103.6a	0.0b	0.0b
2016	8.0a	0.0b	0.0b	156.3a	0.0b	0.0b	2.0a	0.0b	0.0b	22.9a	0.0b	0.0b
Average	4.3a	0.0b	0.0b	60.1a	0.0b	0.0b	3.8a	0.0b	0.0b	129.1a	0.0b	0.0b
Efficacy, %		100	100		100	100		100	100		100	100

C: Control; PRE: *S*-metolachlor+mesotrione; POST: nicosulfuron+mesotrione.
Values followed by the same letter in the column within species, do not differ using Tukey's test at $\alpha = 0.05$.

Figure 2. Distribution of redroot and smooth pigweed in regard to all weeds in control treatments in the second experiment.



Despite row spacing, when herbicide mixtures were applied, either PRE or POST, maximum weed control was achieved. PRE herbicide mixture had a prolonged effect on weeds, but there is a minimum amount of precipitation that is needed for herbicide activation (Hartzler, 2021). For all 3 yr, enough precipitation level was obtained, which led to the high weed biomass reduction. Furthermore, the POST mixture emphasized the same efficacy as the PRE treatment, indicating the possibility of mitigating population of both redroot and smooth pigweed in fields. As previously mentioned, the crucial advantage of herbicide mixture with different modes of action, provide a good background for successful weed control (Beckie and Reboud, 2009). Similarly to our results, Bayat et al. (2021) evaluated the impact of PRE and POST herbicides on purple nut sedge (*Cyperus rotundus* L.) in tomato indicating that applied herbicides programs were effective for the targeted weed suppression. Irrespective to high connection between maize biomass increase and total weed biomass reduction (including both *Amaranthus* species), in treatments with 70 cm inter-row distance, generally, row spacing did not express the influence on density or biomass reduction for targeted species.

Experiment 3. Impact of adjuvants and nozzles

Based on the obtained results, 100% weed control was achieved when nicosulfuron was applied. Although, the density of both tested species was low (≤ 3) in the experiment, selected nozzles did not compromise the efficacy (Table 5). The efficacy progress is presented in Table 6. According to obtained data, 7 and 14 d after treatments, higher efficacy was observed with sprayings followed by XR nozzle compared to TTI, while at 21st day no differences in efficacy were observed (100%).

The application techniques that improve herbicide efficacy were examined in the third experiment. Adding adjuvants in herbicide solution enables better translocation in weeds, thus providing higher efficacy. Nozzles did not have an influence on the efficacy, which means that nozzles that produce coarser droplets (TTI) could be used for these herbicide applications. In our research, differences in efficacy were noticed only 7 and 14 d after treatments, and the reason may be found in droplet distribution, since selected nozzles produce different scale of droplets (Ferreira et al., 2020). If nozzle selection does not influence efficacy (Butts et al., 2018; Moraes et al., 2021), nozzle selection can be done with a TTI nozzle and herbicides can be applied in less favorable conditions (windy conditions), reducing herbicide off-target movement (Vieira et al., 2018b). According to our findings, nicosulfuron applied without adjuvant had the same level of efficacy (100%), which can be explained by the high susceptibility of redroot and smooth pigweed to nicosulfuron in both years. However, there is a constant risk of the application of ALS herbicides because of herbicide resistance, and crop and herbicide rotation, as well as herbicide mixtures should be used in order to overcome or delay this issue. Recent studies suggest adding adjuvants in order to achieve the best possible effects on weed control (Xu et al., 2010; Jing et al., 2015; Palma-Bautista et al., 2020).

Table 5. Nicosulfuron efficacy as influenced by adjuvants and nozzles.

	XR						TTI					
	Density (Nr m^{-1})			Biomass (g m^{-2})			Density (Nr m^{-1})			Biomass (g m^{-2})		
	C	A1	A2	C	A1	A2	C	A1	A2	C	A1	A2
Redroot pigweed												
2020	2.0a	0.0b	0.0b	19.7a	0.0b	0.0b	2.0a	0.0b	0.0b	19.7a	0.0b	0.0b
2021	1.0a	0.0b	0.0b	22.6a	0.0b	0.0b	1.0a	0.0b	0.0b	22.9a	0.0b	0.0b
Average	1.5a	0.0b	0.0b	21.2a	0.0b	0.0b	1.5a	0.0b	0.0b	21.3a	0.0b	0.0b
Efficacy, %		100	100		100	100		100	100		100	100
Smooth pigweed												
2020	3.0a	0.0b	0.0b	107.4a	0.0b	0.0b	3.0a	0.0b	0.0b	97.4a	0.0b	0.0b
2021	2.0a	0.0b	0.0b	43.1a	0.0b	0.0b	3.0a	0.0b	0.0b	33.1a	0.0b	0.0b
Average	2.5a	0.0b	0.0b	75.2a	0.0b	0.0b	3.0a	0.0b	0.0b	65.2a	0.0b	0.0b
Efficacy, %		100	100		100	100		100	100		100	100

XR: Extended range nozzles; TTI: turbo TeeJet induction; C: control; A1: non-ionic surfactant (NIS) adjuvant; A2: ammonium sulphate (AMS) adjuvant.
Values followed by the same letter in the column within species, do not differ using Tukey's test at $\alpha = 0.05$.

Table 6. Efficacy progress of nicosulfuron as influenced by XR and TTI nozzles 7, 14, and 21 d after treatments.

	7				14				21			
	XR		TTI		XR		TTI		XR		TTI	
	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2
Redroot pigweed												
2020	30	25	10	10	75	82	35	30	100	100	100	100
2021	25	30	15	5	80	85	30	25	100	100	100	100
Efficacy %, average	27.5a	27.5a	12.5b	7.5b	77.5a	83.5a	32.5b	27.5b	100a	100a	100a	100a
Smooth pigweed												
2020	25	30	10	15	72	85	35	30	100	100	100	100
2021	30	30	10	10	75	85	30	30	100	100	100	100
Efficacy %, average	27.5a	30a	10b	12.5b	73.5a	85a	32.5b	30b	100a	100a	100a	100a

XR: Extended range nozzles; TTI: turbo TeeJet induction; A1: non-ionic surfactant (NIS) adjuvant; A2: ammonium sulphate (AMS) adjuvant. Values followed by the same letter in the row within a date 7, 14, 21 d, do not differ using Tukey's test at $\alpha = 0.05$.

CONCLUSIONS

Obtained results indicated the possibilities for both redroot and smooth pigweed control in different maize production systems. In this research, crop rotation as a factor did not have significant influence on the *Amaranthus* control, irrespective that maize cropping in rotation was characterized with slightly greater biomass of redroot pigweed, as well as its enhanced control with PRE herbicide mixture. Accordingly, to the herbicide timing, when POST herbicides were applied as a mixture, satisfactory weed control was achieved. Similarly, our findings suggest herbicide application with nozzles that produce coarser droplets, without compromising the efficacy, while off-target movement is mitigated. What is more, adjuvants are recommendable strategy to increase herbicide efficacy.

It was shown that *Amaranthus* species are still not dominant weed in the semi-arid climate of the north Serbia and that applied strategies, such as crop rotation, different timing of herbicide application, as well as herbicide application by different nozzles and adjuvants still could be successfully used for their control in maize crop. Nevertheless, due to the climate change and increased presence of drier seasons, the abundance of species from *Amaranthus* genus, could be expected to increase in the future, so continual monitoring is required, particularly when herbicide resistant genotypes are considered. The upcoming research regarding the weed control in maize will consider the use of alternative methods for weed control, such as cover crops and mechanical weed control, which will prolong and delay upcoming resistance in fields.

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