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Influence of nozzle type and adjuvant selection on nicosulfuron efficacy on some common weeds in maize (*Zea mays* L.)

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SUMMARY

The field experiment was conducted during 2021 and 2022 at the Maize Research Institute Zemun Polje, Zemun Polje in Serbia. The goal of this study was to evaluate the influence of adjuvants and nozzle types on the efficacy of two herbicides based on the same active ingredient - nicosulfuron. The study was arranged as a split-block design in four replication with 12 treatments plus weed-free, as well as weedy season long treatments. Weeds were sampled 21 day after treatment (DAT) and both fresh and dry biomas were measured (only dry biomass is shown). Visual estimation of efficacy was assessed 7, 14 and 21 DAT. Among all treatments no differences between herbicides were observed. In addition, treatments with AMS showed a lower level of efficacy compared to treatments with non-ionic surfactant (NIS) adjuvant where the efficacy was higher and where it led to faster weed decay. Based on dry biomass reduction, all factors had a statistically very significant impact on the results, both individually and in mutual interaction.
***Keywords*:** nicosulfuron, efficacy, adjuvants, nozzle, weeds.

INTRODUCTION

As the most dominant group of pests in annual spring row crops, weeds may cause up to 34% of yield reduction in maize (Oerke, 2006). For example, in a seven year study in the US and Canada, weed presence in maize caused an average yield loss of 52% or 142 million tons of maize, valued over 28 billion dollars annually (Soltani et al., 2016).

Weed management over the past decades has changed due to multiple factors, whereby some of the most important factors which are leading this trend are climate change, introduction of invasive weed species and weed resistance. Also, following the EU Regulation 1107/2009 a lot of herbicides have been banned. Bearing all this in mind, with the lack of new herbicide modes of action, weed management has become more challenging. Consequently, a different approach in weed control needs to be used for better weed management and especially for a more sustainable use of herbicides. This approach is based on using different weed control options, also known as the concept of Integrated Weed Management (IWM). Compared to other weed management options, herbicides remain the best way to control weeds. Nevertheless, many factors must within the optimum range in order for herbicides to achieve their maximum efficacy. Numerous factors can lead to reduced herbicide efficacy, e.g. malfunction of the spraying equipment (Nath et al., 2024), spraying weeds out of the optimum stage, based on the label (Varanasi et al., 2016; Moraes et al., 2021), weather conditions before, during and after herbicide application (Stewart et al., 2012; Jugulam et al., 2019; Park et al., 2021) as well as the weed leaf structure and herbicide characteristics (Chachalis et al., 2001; Sanyal et al., 2006; Hatterman-Valenti et al., 2011; Barnes et al., 2020). The specificity of weed leaf structure in combination with herbicide characteristics can not only lead to reduced herbicide efficacy, but also to herbicide resistance due to the reduced amount of herbicide that has been uptaken and translocated to the site of action (Vrbničanin, 2020).

ALS-inhibiting herbicides are the most commonly used group of herbicides in Serbia (Brankov et al., 2023b), with nicosulfuron being one of the most commonly used active ingredients from this group. Nicosulfuron was first introduced on the market in 1990 in the USA and two years later in Europe – France (Foy and Witt, 1990; Lewis et al., 2016). Together with primisulfuron, these were the first selective postemergence herbicides to effectively control annual and perennial grasses, as well as some broadleaf weeds (Foy and Witt, 1990). According to the list of registered pesticides of the Republic of Serbia (Anonymus, 2023), nicosulfuron-based herbicides in Serbia are formulated as water dispersible granules (WG) with 750 g a.i. kg^{-1}, suspension concentrate (SC) with 40 or 240 g a.i. L^{-1} and oil dispersion (OD) with 40 or 60 g a.i. L^{-1}. When formulated as WDG and SC herbicides, the recommendation is to add a surfactant into the tank-mix for better efficacy (Nalewaja et al., 1995). The biggest challenge in maize production in Serbia is the control of *Sorghum halepense* (L.) Pers., especially its rhizome form which is more competitive than the seed form (Ghosheh et al., 1996).

Of all available adjuvant types, surfactants are one of the most commonly used. Of all surfactants, non-ionic surfactant (NIS) is most widely used in agriculture. When applied with herbicides it should provide a better spreading and wetting area of droplets on plant leaves by reducing surface tension, as well as a better penetration through the leaf surface (Castro et al., 2014; Brankov et al., 2023b; Brankov et al., 2024a). On the other hand, ammonium sulfate (AMS) belongs to the group of water conditioners, but the ammonium ion can also associate with the herbicide active ingredient and may increase herbicide absorption into the leaf (Brankov et al., 2023b).

Different nozzles produce different sizes of droplets and deliver them in different shapes. Both types of nozzles used in this study are flat fan nozzles. TTI nozzles compared to XR nozzles produce bigger droplets, less prone to drift (Brankov et al., 2023b). TTI nozzles have an exit orifice of 15° offset from vertical position, compared to XR nozzles without the exit orifice offset. The influence of different nozzle types on herbicide efficacy may vary depending on the weather conditions, herbicide type (systemic or non-systemic) and nozzle droplet size. Etheridge et al. (2001) point out that a better efficacy of non-systemic herbicides has been observed when using nozzles with finer droplets. The droplet size produced by different nozzle types can have a different impact depending on the weed species. Brankov et al. (2023c) report that nozzles producing coarser droplets do not affect systemic herbicide efficacy, whereby Brankov et al. (2023a) suggest using nozzles producing coarser droplets in windy conditions, while nozzles producing smaller droplets could be used in no wind conditions, because those nozzles provide a better coverage. Specific research should be conducted for certain weed species and herbicides in order to make appropriate recommendations.

The goal of this study was to see the impact of nozzle and adjuvant selection in weed control, as well as to investigate the difference in efficacy of two nicosulfuron herbicides.

MATERIAL AND METHODS

Experimental site. The field study was conducted at the Maize Research Institute Zemun Polje, Zemun Polje in Serbia. Maize hybrid ZP707 was planted on 21st of April in 2021 and 13th of April in 2022 at a planting density of 64935 plants per hectare. The preceding crop in both years was winter wheat (*Triticum aestivum* L.). The study was established as a split-block design with four replication and individual plot size of 24.5 m^{-2} (4.9 x 5 m), whereby each plot had 7 maize rows. The yield and yield components were measured from the central row and the row left to it. Weather data was collected from a meteorological station near the experimental field and are given in table 1.

All treatments were applied with a CO_2 backpack sprayer with a four-nozzle boom with 50 cm nozzle spacing (Bellspray, Inc. Opelousas, LA, United States) when maize plants had developed 5-6 leaves (BBCH15-16). In 2021 the application occurred on May 14th and harvest on September 17th, while in 2022 the application occurred on May 12th and maize harvest on September 8th (Table 2). Weather conditions at herbicide application in both years were uniform and are presented with spraying parameters in Table 2.

Table 1. Weather conditions (precipitation and average air temperature) in 2021 and 2022
Tabela 1. Meteorološki podaci (padavine i prosečna temperatura vazduha) 2021. i 2022. godine

				2021		
	April	**May**	**June**	**July**	**August**	**September**
Temperature (°C)	11.4	17.4	22.0	26.7	24.3	21.9
Precipitation (mm^{-2})	45.9	73.0	19.5	105.5	38.0	16.5
				2022		
	April	**May**	**June**	**July**	**August**	**September**
Temperature (°C)	12.3	20.3	24.8	25.8	23.5	18.0
Precipitation (mm^{-2})	80.1	32.2	43.3	66.5	66.7	32.3

Table 2. Spraying parameters, weather conditions, planting and harvesting information in the study
Tabela 2. Parametri tretiranja, vremenski uslovi, datum setve i berbe u ogledu

	2021	**2022**
Maize planting	21 April	13 April
Treatment application	14 May	12 May
Air temperature (°C)	21	22
Wind (m s^{-1})	2-3	4
Pressure (kPa)	**276 ±10%**	
Speed (km h^{-1})	4.56	
Flow rate (L min^{-1})	0.75	
Spray volume (L ha^{-1})	200	
Droplet size range	XR – fine TTI – very-coarse	
Maize harvest	17 September	8 September

Before planting, in both years the field was prepared with a field cultivator. No other herbicides, as well as no pre-emergence herbicides were used. The study included 12 treatments as a combination of one of two herbicides with the same active ingredient: H_1) Motivell extra 6 OD® and H_2) Talisman OD®, two adjuvants: A_1) AMS and A_2) NIS plus treatments without adjuvant and two nozzle types: N_1) TeeJet® XR12002 and N_2) TeeJet® TTI12002, as well as weed-free (WF) and weedy season-long (C). Two nicosulfuron-based herbicides were chosen to compare the level of efficacy between original and generic (Table 3, 4).

Table 3. Herbicides used in the field experiment in 2021 and 2022
Tabela 3. Herbicidi primenjenji u ogledu u 2021. i 2022. godini

Trade name	**g a.i. L^{-1}**	**g a.i. ha^{-1}**	**Manufacturer**
Motivell extra 6 OD®	60	45	Certis Belchim, Londerzeel, Belgium
Talisman OD®	40	50	Galenika Fitofarmacija, Zemun, Srbija

Two adjuvants from different groups were chosen to test their impact on herbicide performance (Table 4). Also, treatments without adjuvants were included in the study.

Table 4. Adjuvants used in the field experiment in 2021 and 2022
Tabela 4. Ađuvanti primenjeni u ogledu 2021. i 2022. godine

Adjuvant	Trade name	Rate % v/v	Manufacturer
None	/	/	/
AMS	AmoSulfan WG*	5.00	Elixir Group DOO, Šabac, Serbia
Non-ionic Surfactant	Dash® EC**	0.50	BASF SE, Ludwigshafen RP, Germany

*ammonium sulphate, 20% N + 24% S
**mixture of methyl-palmitate and methyl-oleate 348.8 g L^{-1}, phosphate ester of ethoxylated fatty alcohol 209.2 g L^{-1} and olein acid 46.5 g L^{-1}

Two different types of nozzles were chosen, one standard flat fan nozzle which produces fine droplets and the other Venturi type of nozzle which produces very-coarse droplets (Table 5).

Table 5. Nozzles and specifications used in the field experiment in 2021 and 2022
Tabela 5. Rasprskivači i njihove karakteristike primenjeni u ogledu 2021. i 2022. godine

Trade name	VDM* range μm**	Drift potential	Manufacturer
Extended Range TeeJet®	106-235	High	TeeJet® Technologies, Glendale Heights, IL, USA
Turbo TeeJet® induction	503-665	Low	

*VMD, Volume Median Diameter;
**according to the American Society of Agricultural Engineers (ASABE) S572.1 and to *TeeJet®* Technical Information brochure.

After applying the first six treatments the nozzles were changed and the spraying system was triple rinsed as well as between each treatment. All treatments used in the study are given in table 6.

Table 6. Treatments used in the study
Tabela 6. Tretmani primenjeni u ogledu

Treatment	Nozzle type	Herbicide brand	Adjuvant
H1	XR	Motivell extra 6 OD®	N/A*
H1A1			AMS
H1A2			Dash®
H2		Talisman OD®	N/A
H2A1			AMS
H2A2			Dash®
H1	TTI	Motivell extra 6 OD®	N/A
H1A1			AMS
H1A2			Dash®
H2		Talisman OD®	N/A
H2A1			AMS
H2A2			Dash®
Weedy	/	/	/
Weed-free	/	/	/

*N/A – no adjuvant.

Visual evaluation of efficacy was rated 7, 14 and 21 day after treatment (DAT) on a scale from 0 – 100 %, where 100 represents total weed control. Also, 21 DAT a weed sample from 1 m^{-2} was taken from each plot to determine the weed composition, weed density and to measure fresh and dry biomass.

The data was analyzed by ANOVA and Tukey test, with IBM SPSS Statistics, Version 26.0.

RESULTS AND DISCUSSION

Weed density and weed composition. Some of the most dominant weed species in the study were: *Amaranthus hybridus* L., *Amaranthus retroflexus* L., *Chenopodium hybridum* L., *Datura stramonium* L. and *Sorghum halepense* (L.) Pers. (Table 7).

Table 7. Weed spectrum, plant height and weed density in the study at the moment of herbicide application
Tabela 7. Spektar korova, visina i brojnost korova u ogledu pre primene tretmana

Weed species	Average density in the study (m^{-2})		Weed height in the study (cm)	
	2021	2022	2021	2022
Amaranthus hybridus	9	6	1 – 4	1 – 6
Amaranthus retroflexus	5	4	1 – 4	2 – 5
Chenopodium hybridum	8	8	2 – 10	3 – 12
Datura stramonium	10	5	2 – 5	4 – 8
Sorghum halepense	7	18*	3 – 10	8 – 18

**S. halepense* was present in rhizome form in 2022

Weed density and weed height varied between years. In 2021 the weed height was lower, because the weeds emerged later compared to 2022 and 12 weed species were present compared to 2022 when the number of weed species was nine (data not shown).

***Amaranthus hybridus* and *Amaranthus retroflexus*.** The efficacy on both *A. retroflexus* and *A. hybridus* across all treatments in both years was 100%, as well as the dry biomass reduction. This result presents an important information and means that the Amaranth weed population present in the study was highly sensitive to ALS inhibitors. As recorded earlier by Malidža et al. (2015b), *A. retroflexus* has developed resistance to ALS inhibitors in parts of Serbia near the location where the study was conducted. ALS herbicides are classified as a high risk group of herbicides for resistance development, which has been claimed in some cases where *A. hybridus* developed resistance to ALS inhibitors after two years of use (Tranel and Wright, 2002).

Chenopodium hybridum. The efficacy on *C. hybridum* varied across years, but did not vary between nozzle types. In 2021 all treatments, except those where AMS was added (H1A1 and H2A1), showed excellent weed control (Figure 1). In 2022 weeds were taller and the efficacy was lower (Figure 2), but biomass reduction was similar (Table 8, 9). In 2021 the efficacy of both herbicides applied with both types of nozzles was excellent when applied alone or with NIS – H1, H2, H1A2 and H2A2, but decreased when AMS was added (H1A1 and H2A1). In 2022, only when NIS was added (H1A2 and H2A2) the efficacy was excellent.

In 2021, treatments without adjuvants and treatments which included NIS (H1, H2, H1A2 and H2A2) provided 100.00% visual efficacy 14 DAT, compared to 2022, where only treatments which included NIS (H1A2 and H2A2) as an adjuvant provided 100.00% of control 21 DAT, but

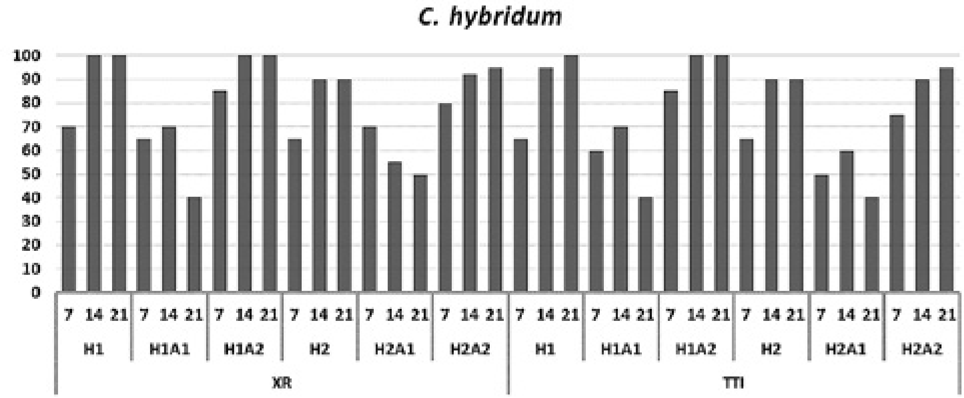

Figure 1. Visual efficacy on *C. hybridum* 7, 14 and 21 DAT in 2021
Grafik 1. Vizuelna efikasnost na *C. hybridum* 7, 14 i 21 DNT u 2021. godini

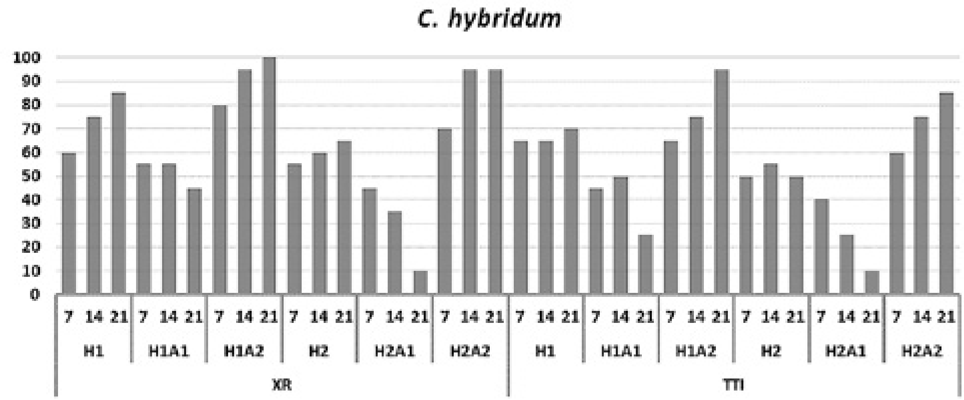

Figure 2. Visual efficacy on *C. hybridum* 7, 14 and 21 DAT in 2022
Grafik 2. Vizuelna efikasnost na *C. hybridum* 7, 14 i 21 DNT u 2022. godini

not 14 DAT on plants 5 cm tall or less (1-2 pairs of leaves). In 2022, Motivell extra 6 OD® (H1) showed better control of *C. hybridum* compared to Talisman OD® (H2) in all combinations. Treatments applied with TTI nozzles provided the same level of efficacy in 2021 compared to 2022 where XR nozzles provided better or same level of efficacy as TTI nozzles did (Figure 2).

Therefore, *C. hybridum* can be controlled with nicosulfuron products, but the level of efficacy depends on several factors such as adjuvant and nozzle selection, plant height and weather conditions (Kapusta et al., 1994).

Table 8. Dry biomass reduction of *C. hybridum* in 2021
Tabela 8. Procenat redukcije suve mase vrste *C. hybridum* u 2021. godini

Nozzle	Treatment					
	H1	H1A1	H1A2	H2	H2A1	H2A2
XR	99.94 bc	97.00 b	100.00 c	98.38 bc	76.31 a	96.13 b
TTI	98.88 bc	98.88 b	100.00 c	100.00 bc	79.00 a	100.00 b

a, b, c - statistically significant differences between treatment based on Tukey's test ($p<0.05$)

Table 9. Dry biomass reduction of *C. hybridum* in 2022
Tabela 9. Procenat redukcije suve mase vrste *C. hybridum* u 2022. godini

Nozzle	Treatment					
	H1	H1A1	H1A2	H2	H2A1	H2A2
XR	91.10 b	78.03 a	98.61 d	98.33 d	88.46 a	90.68 c
TTI	79.36 b	87.54 a	95.41 d	92.91 d	75.86 a	92.49 c

a, b, c, d - statistically significant differences between treatment based on Tukey's test ($p<0.05$)

In both years the observed factors had a statistically very significant impact on dry biomass reduction both individually and in interaction. The best results in 2021 were recorded in H1A2 treatments (100.00%), as well as in H2 treatments (92.91 and 98.33%) (Table 8). Nozzle impact was not statistically significant, compared to that of adjuvants, where AMS (H1A1 and H2A1) caused the lowest biomass reduction in 2021 (76.31 and 79.00%) (Table 8) as well as in 2022 (75.86 and 88.46%) (Table 9).

Datura stramonium. The visual efficacy varied among treatments and depending on the weed height. The field observation and visual estimation of efficacy showed that the efficacy in controlling *D. stramonium* within one treatment depends primarily on plant height (Figure 3, 4).

When evaluating the visual efficacy of *D. stramonium* control, plants smaller than 4 cm (2-leaf stage) were much easier to control and 14 DAT 100.00% of efficacy was observed (Pictures 1).

In 2021, all treatments caused a very high percent of dry biomass reduction (Table 10). In 2022 the differences between treatments were much higher, whereby the highest biomass reduction was observed in both H1A2 treatments (95.96-97.87%) and the lowest in AMS treatments (H1A1 and H2A1) (62.77-74.47%) (Table 11). By comparing nozzle types, the obtained parameter values were identical across treatments, so no differences between nozzels were observed. For *D. stramonium* control with nicosulfuron products, weed height is an important factor for successful control based on our research. Like with *C. hybridum,* plants smaller than 5 cm are easier to control, especially when applied in combination with NIS (H1A2 and H2A2).

Table 10. Dry biomass reduction of *D. stramonium* in 2021

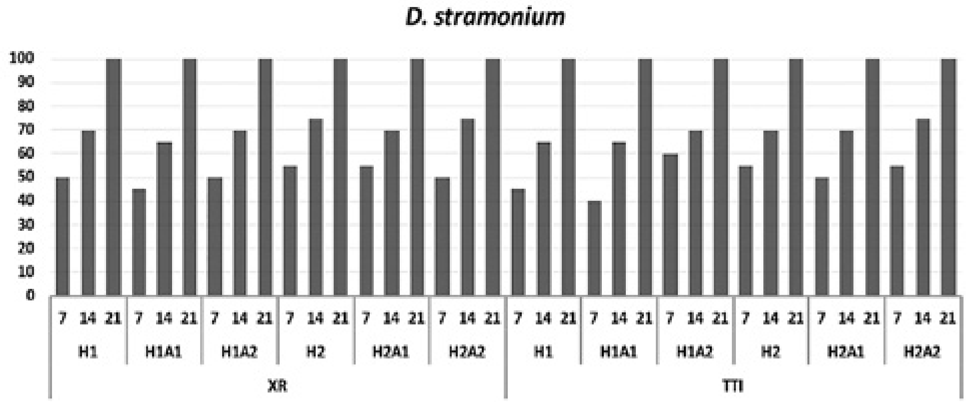

Figure 3. Visual efficacy of controlling *D. stramonium* in 2021
Grafik 3. Vizuelna efikasnost u suzbijanju *D. stramonium* u 2021. godini

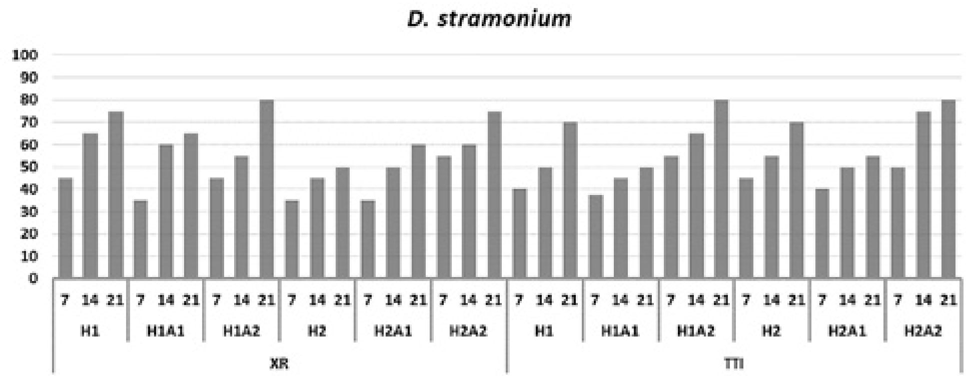

Figure 4. Visual efficacy of controlling *D. stramonium* in 2022
Grafik 4. Vizuelna efikasnost u suzbijanju *D. stramonium* u 2022. godini

Pictures 1. Efficacy of TTI/H1 in 3 cm (a) and 6 cm (b) tall *D. stramonium* plants in 2022
Slika 1. Efikasnost tretmana TTI/H1 *D. stramonium* visine 3 cm (a) i 6 cm b) u 2022. godini

Tabela 10. Procenat redukcije suve mase vrste *D. stramonium* u 2021. godini

Nozzle	Treatment					
	H1	H1A1	H1A2	H2	H2A1	H2A2
XR	100.00 b	100.00 a	100.00 b	100.00 b	100.00 b	100.00 b
TTI	100.00 b	95.88 a	100.00 b	100.00 b	100.00 b	100.00 b

a, b - statistically significant differences between treatment based on Tukey's test ($p<0.05$)

Table 11. Dry biomass reduction of *D. stramonium* in 2022
Tabela 11. Procenat redukcije suve mase vrste *D. stramonium* u 2022. godini

Nozzle	Treatment					
	H1	H1A1	H1A2	H2	H2A1	H2A2
XR	92.23 c	77.66 b	95.96 e	91.17 d	62.77 a	92.02 c
TTI	76.60 c	73.40 b	97.87 e	92.55 d	74.47 a	76.60 c

a, b, c, d, e - statistically significant differences between treatment based on Tukey's test ($p<0.05$)

Sorghum halepense. *S. halepense* represents one of the most troublesome weeds in field and vegetable crops in Serbia. Due to its ability to form rhizomes it is much more challenging to control because the rhizome form cannot be controlled with residual herbicides, therefore a foliar herbicide needs to be applied. In fact, not only applied, the foliar herbicides must be translocated through the rhizome system to all growing points (Bromilow and Chamberlain, 1991). All individual plants that emerged from seeds will form rhizomes the same year, if not controlled and continue to develop over the following years by extending the rhizome system (González-Andújar et al., 2011). In our study, in 2021 only the seed form of *S. halepense* was present, compared to 2022 where the rhizome form was present. In 2021 all treatments with XR nozzles provided biomass reduction greater than 90.00%, compared to TTI nozzles where the biomass reduction varied between all six treatments (Table 12). The highest biomass reduction in 2021, when applied with TTI nozzles, was recorded in treatments with NIS (H1A2 and H2A2). In 2022, where the rhizome form was present, the percent of biomass reduction

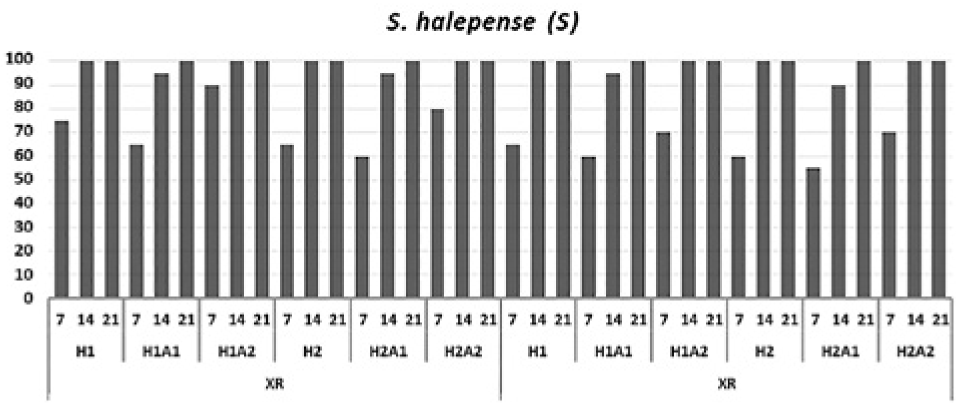

Figure 5. Visual efficacy of control of *S. halepense* from seed 7, 14 and 21 DAT in 2021
Grafik 5. Vizuelna efikasnost na semenskom *S. halepense* 7, 14 i 21 DNT u 2021. godini

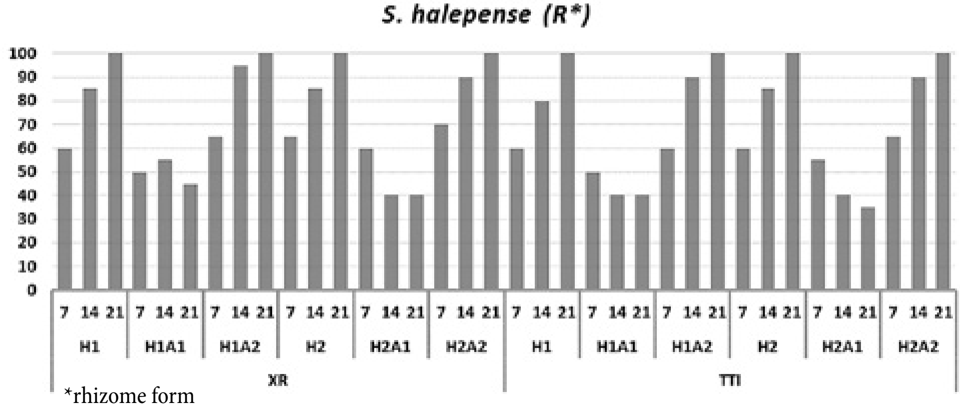

Figure 6. Visual efficacy of cotrnol of *S. halepense* from rhizome 7, 14 and 21 DAT in 2022
Grafik 6. Vizuelna efikasnost na rizomskom *S. halepense* 7, 14 i 21 DNT u 2022. godini

was much lower and in some treatments it was 0.00%. All treatments when applied with TTI nozzles showed less biomass reduction than when applied with XR nozzles. According to the visual estimation of efficacy, in both years all treatments provided excellent efficacy of control of *S. halepense* developed from seed (Figure 5, 6).

Comparing the efficacy of treatments on the rhizome form of *S. halepense*, 21 DAT all treatments where AMS was added (H1A1 and H2A1) did not show efficacy higher than 40.00% (Pictures 2). Treatments without adjuvants or with NIS (H1A2 and H2A2) provided better efficacy. There was no difference in visually estimated efficacy between XR and TTI nozzles, as well as between treatments with eather Motivell extra 6 OD® (H1) or Talisman OD® (H2). The biomass reduction of the rhizome form was much lower compared to the seed form.

Pictures 2. XR/H2A1 treatment efficacy on rhizome form *S. halepense* 14 DAT (a) and 21 DAT (b)
Slika 2. Efikasnost tretmana XR/H2A1 na rizomski *S. halepense* 14 DNT (a) i 21 DNT (b)

Table 12. Dry biomass reduction of *S. halepense* in 2021
Tabela 12. Procenat redukcije suve mase vrste *S. halepense* u 2021. godini

Nozzle	Treatment					
	H1	H1A1	H1A2	H2	H2A1	H2A2
XR	99.66 d	100.00 c	98.14 e	93.22 b	98.98 a	100.00 d
TTI	84.75 d	77.97 c	91.86 e	79.66 b	61.69 a	84.41 d

a, b, c, d, e - statistically significant differences between treatment based on Tukey's test ($p<0.05$)

Table 13. Dry biomass reduction of *S. halepense* in 2022
Tabela 13. Procenat redukcije suve mase vrste *S. halepense* u 2022. godini

Nozzle	Treatment					
	H1	H1A1	H1A2	H2	H2A1	H2A2
XR	86.01 b	71.42 a	92.12 e	76.10 c	72.07 b	78.21 d
TTI	32.66 b	0.00 a	65.87 e	40.86 c	6.27 b	72.14 d

a, b, c, d, e - statistically significant differences between treatment based on Tukey's test ($p<0.05$)

Differences in biomass reduction of *S. halepense* varied based on the seed or rhizome form. In both years application with XR nozzles provided a better biomass reduction than with TTI nozzles (Table 12, 13), whereas the differences between treatments were much higher in 2022. Both nozzle types and treatments (herbicide plus adjuvant) had a statistically very significant impact on biomass reduction. Especially important is the information that when AMS added, the percentage of dry biomass reduction in 2022 varied from 0 to 6.27% (H1A1 and H2A1) (Table 13). Based on dry weight, better results were achieved without the adjuvant than with AMS. Also, when adding AMS as an adjuvant and applying the treatments with TTI nozzles, biomass reduction was lower than with XR nozzles.

To enhance herbicide efficacy, the herbicide must be uptaken in a proper amount so it can be translocated through epidermal cells, mesophyll, plasmodesms and symplast all through the phloem and further throughout the whole plant (Currier and Dybing, 1959). To increase herbicide efficacy the amount of herbicide which penetrates into the cell and reaches the site of action needs to be increased, which can be achieved by adding adjuvants (Burghardt et al, 2006). This goal was achieved by adding NIS into the tank mix. NIS did not affect the pH of water, which is very important for sulfonylurea herbicides. With AMS the efficacy decreased because of the better solubility and slower degradation of nicosulfuron in alkine water (Brown, 1990; Green and Cahill, 2003), compared to acid water. AMS as an adjuvant has been used for water acidification. After a decrease in visual efficacy and biomass reduction, we used the pH meter (Inolab wtw series pH/ION 735) to measure the pH of pure water as well as after adding 5% of AMS. Before adding AMS the pH was 6.829 whereas after adding AMS the pH was 3.755. Green and Cahill (2005) point out that sulfonylureas are acidic in nature and that their pKa value ranges from 3.3 to 5.2, with nicosulfuron having a pKa value of 4.3. Solubility in water is low if the pH value of the solution is below the pKa value of the compound, when dispersions are formed. Conversely, when the pH is above the pKa value, solubility is better.

The same authors state that the solubility limit of nicosulfuron at pH 5 is 360 mg L^{-1}, pH 6.9 is 12200 mg L^{-1}, and at pH 8.8 it is 29200 mg L^{-1} (higher value of mg L^{-1} ensures greater solubility thus achieving better efficiency).

Based on the results, our recommendation is to use nozzles which produce coarser droplets than finer droplets, because of lower herbicide drift risk. We also recommend to use a NIS even if nicosulfuron products are formulated as oil dispersion to accomplish a better level of efficacy on weeds which have an upright position of leaves, waxes or trichomes on leaves, as well as in years where weather can affect herbicide efficacy. According to Vieira et al, (2019) exposing weeds to sublethal doses for a certain period of time, increases resistance development. This implies that off-target movement, as well as decreased ammounts of active ingredient translocated to the site of action can cause faster development of resistance.

With the increasing number of ALS inhibiting herbicides, applied both as PRE and as POST herbicides, the use of ALS inhibitors for Amaranth weed species control ought to be directed for crops where not much other choices are available such as ALS tolerant sunflower (*Helianthus annuus* L.) or ALS tolerant canola (*Brassica napus* L.). Therefore, in maize, instead of ALS inhibitors, farmers ought to use herbicides with alternative modes of action, such as HPPD's or synthetic auxin herbicides. As reported by Malidža et al. (2014; 2015a,b; 2017) *S. halepense* has already developed resistance to ALS inhibitors, and Malidža and Rajković (2018) confirmed multiple resistance of *S. halepense* to both ALS and ACC-inhibitors. One of the reasons which led to this situation could be inadequate application of nicosulfuron. The most common way of inadequate application of nicosulfuron especially when using WDG- or SC-formulated products is using an acidic mineral fertilizer instead of using surfactants as adjuvants, which can decrease herbicide efficacy, but also applying nicosulfuron out of the label as well as applying it during bad weather conditions.

CONCLUSION

Adjuvant and nozzle selection can play a crucial role in weed control. By using NIS (A2) as an adjuvant, the percentage of weed control is the same or better, but never less compared to treatments with AMS (A1). With nicosulfuron, as well as with other sulfonylurea herbicides, we recommend not to apply AMS, as well as other water conditioners which decrease the pH of water, like UREA. Herbicide as a tested factor did not show a significant difference in biomass reduction, but according to visual efficacy Motivell extra 6 OD® (H1) applied at 45 g a.i. ha^{-1} showed better stability across both years and all six treatments compared to Talisman OD® (H2) applied at 50 g a.i. ha^{-1}. For OD formulated herbicides, no adjuvants needed to be added into the tank mix but in our research both visual efficacy and dry biomass reduction were higher when NIS was applied with herbicides. Overall, in 2021 weed control was better than in 2022. When comparing the overall efficacy between XR and TTI nozzles no differences were observed, which leads to a conclusion that TTI nozzles can be recommended for herbicide application due to the lower risk of herbicide drift. However, based on both visual efficacy and dry biomass reduction, NIS should be added when applying nicosulfuron, especially if weather conditions are unfavorable and if rhizome form of *S. halepense* is present. Further research needs to be done for weeds on which nicosulfuron is not that effective by adding other tank-mix herbicies, whereby adjuvant and nozzle choice must be based on the obtained results even considering separate application of nicosulfuron as a grass control herbicide mainly from typically broadleaf herbicides.

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LITERATURE

Barnes, E. R., Knezevic, S. Z., Lawrence, N. C., Irmak, S., Rodriguez, O., Jhala. A. J.: Control of velvetleaf (*Abutilon theophrasti*) at two heights with POST herbicides in Nebraska popcorn. Weed Technology, 34 (4), 560-567, 2020.

Brankov, M., Alves, G. S, Vieira, C. B., Zaric, M., Kruger R. G.: Particle drift potential of mesotrione and rimsul furon plus thifensulfuron-methyl tank mixture in a low-speed wind tunnel. Plant Protectection Science, 59 (3), 284-291, 2023a. https://doi.org/10.17221 /39/2023-PPS

Brankov, M., Simić, M., Piskackova, T., Zarić, M., Rajković, M., Pavlović, N., Dragičević. V.: A post-emergence herbicide program for weedy sunflower (*Helianthus annuus* L.) control in maize. Phytoparasitica, 52 (1), 1-9, 2024a. https://doi.org/10.1007/s12600-024-01126-w

Brankov, M., Simić, M., Samuelson, S. L., Nikolić, D., Čamdžija, Z., Mandić, V., Dragičević, V.: Nicosulfuron Weed Control in Maize as Influenced by Adjuvants: Original vs. Generic Herbicide. Journal of Crop Health, 76 (4), 1117-1124, 2024b. https://doi.org/10.1007/s10343-024-01014-7

Brankov, M., Simić, M., Ulber, L., Tolimir, M., Chachalis, D., Dragičević, V.: Effects of nozzle type and adjuvant selection on common lambsquarters (*Chenopodium album*) and johnsongrass (*Sorghum halepense*) control using nicosulfuron in maize. Weed Technology, 37 (2), 156-164, 2023b. https://doi.org/10.1017/wet.2023.16

Brankov, M., Vieira, B. C., Alves, G. S., Zaric, M., Vukoja, B., Houston, T., Kruger, G. R.: Adjuvant and nozzle effects on weed control using mesotrione and rimsulfuron plus thifensulfuron-methyl. Crop Protection, 167(4), 2023c. https://doi.org/10.1016 /j.cropro.2023. 106209

Bromilow, R. H., Chamberlain, K.: Pathways and Mechanisms of Transport of Herbicides in Plants. In: Kirkwood, R. C. (Ed.) Target Sites for Herbicide Action. Topics in Applied Chemistry. Springer, Boston, MA. 1991, https://doi.org/10.1007/978-1-4899-2433-9_9.

Brown, M. H.: Mode of action, crop selectivity, and soil relations of the sulfonylurea herbicides. Pest Science, 29 (3), 263-281, 1990.

Burghardt, M., Friedmann, A., Schreiber, L., Riederer, M.: Modelling the effects of alcohol ethoxylates on diffusion of pesticides in the cuticular wax of *Chenopodium album* leaves. Pest Management Science, 62 (2), 137-147, 2006.

Castro, M. J. L., Ojeda, C., Cirelli, A. F.: Advances in surfactants for agrochemicals. Environmental Chemistry Letters, 12 (1), 85-95, 2014.

Chachalis, D., Reddy, K., Elmore, C., Steele, M.: Herbicide efficacy, leaf structure, and spray droplet contact angle among Ipomoea species and smallflower morningglory. Weed Science, 49 (5), 628-634, 2001.

Currier, H., Dybing, C.: Foliar Penetration of Herbicides: Review and Present Status. Weeds, 7 (2), 195-213, 1959.

Etheridge, R. E., Hart, W. E., Hayes, R. M., Mueller, T. C.: Effect of Venturi-type nozzles and application volume on postemergence herbicide efficacy. Weed Technology, 15 (1), 75-80, 2001.

Foy, C. L., Witt, H. L.: Johnsongrass control with DPX-V9360 and CGA-136872 in Corn (*Zea mays* L.) in Virginia. Weed Technology, 4 (3), 615-619, 1990.

Ghosheh, H. Z., Holshouser, D. L., Chandler, J. M.: The Critical Period of Johnsongrass (*Sorghum halepense*) control in field corn (*Zea mays*). Weed Science, 44 (4), 944-947, 1996. https://doi.org/10.1017/S0043174500094960

González-Andújar, J. L., Fernández-Quintanilla, C., Izquierdo, J.: „Population dynamics of perennial weeds." Weed Science, 59 (1), 69-74, 2011. https://doi.org/10.1614/WS-D-10-00141.1.

Green, M. J., Cahill, R. W.: Enhancing the biological activity of nicosulfuron with pH Adjusters. Weed Technology, 17 (2), 338-345, 2003.

Green, M. J., Cahill, R. W.: Increasing and decreasing pH to enchace the biological activity of nicosulfuron. Weed Technology, 19 (2), 468-475, 2005.

Hatterman-Valenti, H., Pitty, A., Owen, M.: Environmental Effects on Velvetleaf (*Abutilon theophrasti*) epicuticular wax deposition and herbicide absorption. Weed Science, 59 (1), 14-21, 2011.

Jugulam, M., Varanasi, K. A., Varanasi, K. V., Prasad, V. P. V.: Climate change influence on herbicide efficacy and weed management. Food Security and Climate Change, 1, 433-448, 2019.

Kapusta, G., Krausz, R. F., Khan, M., Matthews, J. L.: Effect of nicosulfuron rate, adjuvant and weed size on annual weed control in corn (*Zea mays* L.). Weed Technology, 8 (4), 696-702, 1994. https://doi.org/10.1017/S0890037X00028542

Lewis, K. A., Tzilivakis, J., Warner, D., Green, A.: An international database for pesticide risk assessments and management. Human and Ecological Risk Assessment: An International Journal, 22 (4), 1050-1064, 2016.

List of registered pesticides of the Republic of Serbia, 2023. https://uzb.minpolj.gov.rs/wp-content/uploads/2023/12/Lista_registrovanih_sredstava_za_zastitu_bilja_30nov2023.pdf

Malidža, G., Rajković, M.: Johnsongrass (*Sorghum halepense*) resistance to ACCase inhibiting herbicides in Serbia. Book of Abstracts, 18th EWRS Symposium, Ljubljana, Slovenia, 2018.

Malidža, G., Rajković, M.: Rezistentnost divljeg sirka (*Sorghum halepense* (L) Pers.) na herbicide inhibitore ACC-aze u Srbiji. XIV Savetovanje o zaštiti bilja, Zlatibor, Zbornik rezimea radova, 92-93, 2017.

Malidža, G., Rajković, M., Vrbničanin, S., Božić, D.: Cross-resistance of *Sorghum halepense* to ALS inhibitors in Serbia and implications for resistance management. VII Congress on Plant Protection "Integrated Plant Protection Knowledge-Based Step Towards Sustainable Agriculture, Forestry and Landscape Architecture", Zlatibor, Serbia. Book of Abstracts, 143-144, 2014.

Malidža, G., Rajković, M., Vrbničanin, S., Božić, D.: Identification and distribution of ALS resistant *Sorghum halepense* populations in Serbia. In the Proceedings of 17th EWRS Symposium "Weed Management in Changing Environments", Montpellier, France, 2015a.

Malidža, G., Rajković, M., Vrbničanin, S., Božić, D., Jurišić, J.: Suzbijanje divljeg sirka i običnog štira rezistentnih na ALS inhibitore. Zbornik rezimea radova XIII savetovanja o zaštiti bilja, Zlatibor, 70-71, 2015b.

Moraes, G. J., Butts, R. T., Anunciato, M. V., Luck, D. J., Hoffmann, C. W., Antuniassi, R. U., Kruger, R. G.: Nozzle Selection and Adjuvant Impact on the Efficacy of Glyphosate and PPO-Inhibiting Herbicide Tank-Mixtures. Agronomy, 11 (4), 754, 2021.

Nalewaja, J. D., Praczyk, T., Matysiak, R.: Surfactants and Oil Adjuvants with Nicosulfuron. Weed Technology, 9 (4), 689-695, 1995. https://doi.org/10.1017/S089 0037X00024064

Nath, C. P., Singh, R. G., Choudhary, V. K., Datta, D., Nandan, R., Singh, S. S.: Challenges and Alternatives of Herbicide-Based Weed Management. Agronomy, 14 (1), 126, 2024. https://doi.org/10.3390/ agronomy1401012

Oerke, E. C.: Crop losses to pests. The Journal of Agricultural Science, 144 (1), 31-43, 2006.

Park, H. H., Lee, D. J., Kuk, I. Y.: Effects of various environmental conditions on the growth of *Amaranthus patulus* Bertol. and changes of herbicide efficacy caused by increasing temperatures. Agronomy, 11 (9), 1773, 2021.
Sanyal, D., Bhowmik, C. P., Reddy, N. K.: Influence of leaf surface micromorphology, wax content, and surfactant on primisulfuron droplet spread on barnyardgrass (*Echinochloa crus-galli*) and green foxtail (*Setaria viridis*). Weed Science, 54, 627-633, 2006.
Soltani, N., Anita Dille, J. A., Burke, I. C., Everman, W. J., van Gessel, M. J., Davis, V. M., Sikkema, P. H.: Potential Maize Yield Losses from Weeds in North America. Weed Technology, 30 (4), 979-984, 2016.
Stewart, L. C., Soltani, N., Nurse, E. R., Hamill, S. A., Sikkema, H. P.: Precipitation PRE- and POST-emergence herbicide efficacy in maize. American Journal of Plant Science, 3 (9), 1193-1204, 2012.
Tranel, P. J., Wright, T. R.: „Resistance of weeds to ALS-inhibiting herbicides: what have we learned?". Weed Science, 50 (6), 700-712, 2002. https://doi.org/10.1614/0043-1745(2002) 050[0700:RROWTA]2.0.CO;2
Varanasi, A., Prasad, V. P. V., Jugulam, M.: Impact of climate change factors on weed and herbicide efficacy. Advances in Agronomy, 135, 107-146, 2016.
Vieira, B. C., Luck, J. D., Amundsen, K. L., Gaines, T. A., Werle, R., Kruger, G. R.: Response of *Amaranthus* spp. following exposure to sublethal herbicide rates via spray particle drift. PLoS ONE, 14 (7), 1-19, 2019. e0220014.
Vrbničanin, S.: Rezistentnost korova na herbicide. Acta herbologica, 29 (2), 79-96, 2020.

Uticaj tipa rasprskivača i ađuvanta na efikasnost nikosulfurona u suzbijanju pojedinih korova u usevu kukuruza (*Zea mays* L.)

REZIME

Poljski ogled je sproveden tokom 2021. i 2022. godine u Institutu za kukuruz Zemun Polje u Srbiji. Cilj ovog istraživanja bio je da se ispita uticaj različitih ađuvanata i tipova rasprskivača na efikasnost dva herbicida na bazi iste aktivne supstance – nikosulfurona. Ogled je postavljen kao split-blok dizajn u četiri ponavljanja sa 12 tretmana plus tretmani bez korova, kao i zakorovljene parcele. Nakon 21 dana od tretiranja (DNT) uzorkovani su korovi i izmerene su sveža i suva masa korova. Vizuelna ocena efikasnosti je urađena 7, 14 i 21 DNT. Nije uočena razlika u redukciji suve mase između herbicida. Pored toga, tretmani gde je primenjivan AMS (H1A1 i H2A1) su ispoljili smanjenu efikasnost u poređenju sa tretmanima sa nejonskim surfaktantom – NIS (H1A2 i H2A2), gde je efikasnost bila veća što je dovelo do bržeg propadanja korova. Svi ispitivani parametri, kao i njihova interakcija, su imali statistički značajan uticaj na redukciju suve mase, kod svih ispitivanih korovskih vrsta.

Ključne reči: nikosulfuron, efikasnost, ađuvanti, rasprskivači, korovi.