Effect of Adjuvants and pH Adjuster on the Efficacy of Sulcotrione Herbicide

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Abstract: The effectiveness of herbicides is affected by the pH of the spray liquid. The use of adjuvants can mitigate the negative effect of pH, and it also allows for a reduction in herbicide doses while maintaining high efficiency. Greenhouse studies were performed to evaluate the efficacy of the herbicide sulcotrione (HRAC F2), against barnyardgrass, at full or reduced doses with adjuvants, and a modified pH of the solutions. The contact angle and surface tension of liquid spray drops, as well as the shear viscosity of individual solutions, were also tested. Results indicated that at a low pH of the spray liquid (4), the use of a reduced dose of sulcotrione with adjuvant based on methylated rapeseed oil can increase the effectiveness of barnyardgrass control to the same level as at the full dose of herbicide. The use of adjuvants contributed to the reduction in the contact angle and the surface tension of liquid spray droplets. No significant differences in shear viscosity were observed for individual solutions.

Keywords: sulcotrione; adjuvants; pH adjuster

1. Introduction

At present, increasing attention is being paid to food safety and the responsible use of chemicals that end up in the natural environment [1,2]. Plant protection products are considered as an integral part of modern agriculture. Solutions are being sought to reduce the risk of their residues in food, to minimize the impact on ground and surface water pollution and non-target organisms [3]. Herbicides are the most widely used products to protect crops [4]. Chemical weed control mainly increases production cost, and the intensive use of herbicide is also associated with the selection of herbicide-resistant weed biotypes [5] and this phenomenon is a growing problem [6]. Herbicide resistance is defined as the natural ability of weed biotypes to survive after herbicide application, which should contribute to their killing. [7]. Lowering the dose of herbicide is an integral part of the approach of integrated weed management [8]. However, when inappropriately applied, this may contribute to insufficient weed control, which increases the risk of resistant weed development [9]. It is, therefore, reasonable to look for solutions that improve the effectiveness of herbicides applied in reduced doses, i.e., the use of adjuvants. One type of adjuvant is oil adjuvants. They facilitate the coverage of agrochemicals through the wax layer on the surface of the plant, which contributes to the increase in their effectiveness [10]. Surfactants are another type of activating adjuvants. Their use leads to a decrease in the surface tension of the spray liquid drops, and, as a consequence, better coverage of the treated plants [11].

Sulcotrione is one of the active substances of herbicides. It is used to control monocotyledonous and dicotyledonous weeds in maize cultivation [12]. It is absorbed by the leaves and roots of plants. The solubility of this substance at 25 °C is 165 mg/l [13]. It is a weak acid; its pKa value is 2.87 [14]. This agent belongs to the group of tri-ketones. The mechanism of herbicide action is based on blocking the 4-hydroxyphenyl–pyruvate–dioxygenase enzyme (HPPD) [15]. The enzyme is involved in the transformation of tyrosine into tocopherols and plastoquinones [16]. As a result of the inhibition of this pathway, carotenoid synthesis is disturbed, which leads to chlorophyll degradation [17]. This is manifested by bleaching the leaves of treated plants [18]. Herbicides with this mechanism of action are characterized by high selectivity in relation to the crop; they control a wide spectrum of weed species, and are applied in low doses. They also have low toxicity and high environmental safety [19].

Adjuvants can modify the viscosity of the spray liquid [20]. This parameter affects drop atomization as well as deposit formation [21]. Viscosity (viscosity coefficient) is a measure of the resistance that the substance poses when flowing. Its value can be determined from the following relationship resulting from Newton's law, valid for Newtonian liquids [22]

where: η - viscosity coefficient [Pa · s], τ - shear stress [N / m2], - shear rate [s-1].

To reduce the cost of intensive herbicide application and environment pollution, and enhance biological effectiveness, methods of weed control should be optimized [23]. Many factors influence the effectiveness of herbicides. These include, among others, the species composition of weeds and their development stage, weather conditions, soil type, herbicide formulation, and the addition of adjuvants [24]. The parameters of the water used to prepare the spray liquid are also important, including its pH and hardness [25]. Herbicide water solubility is low when the pH is below the pKa, and the active ingredient is not ionized. When the level of the pH is above the pKa, the herbicide is ionic and more soluble.

The hypothesis assumes that the mixture of adjuvants and pH adjusters influences the effectiveness of sulcotrione. The aim of the study was to assess the impact of the spray liquid pH and the addition of adjuvants belonging to various chemical groups on the effectiveness of sulcotrione in control barnyardgrass (Echinochloa crus-galli (L.) Pal. Beauv.). The viscosity of liquids used to perform the procedure was also tested.

2. Materials and Methods

2.1. Greenhouse Experiment

Barnyardgrass (*Echinochloa crus-galli* (L.) Pal. Beauv.) seeds were planted in the greenhouse in plastic pots (1.0 L, 15 cm diameter) containing a mixture of soil and peat, at 1:1 ratio. Two weeks after emergence, barnyardgrass plants were thinned to eight uniform seedlings per pot. Soil moisture was systematically measured by ML3–ThetaProbe Soil Moisture Sensor, and, by regular replenishment, water losses to the appropriate weight of pots was maintained at 65%–75% of soil water capacity. During the day, greenhouse temperature was maintained at 25 ± 2 °C, and at 20 ± 2 °C during the night. Relative humidity varied from 50 to 80%. Natural sunlight with an intensity of 600 μE m^{-2} s^{-1} was supplemented with lamps.

Sulcotrione at recommended (full) rate 450 g a.i. ha^{-1} (Sulcogan, 300 SC, Adama Agan Ltd, Israel) and reduced rate 225 g ha^{-1}, was used alone and with adjuvants based on methylated rapeseed oil-MSO (Toil, Interagro Ltd., Great Britain) at 950 g a.i. ha^{-1}, polyalkyleneoxide modified heptamethyltrisiloxane–NIS 1 (Silwet L-77, 840 AL, Momentive, USA) at 0.1% v/v concentration, and ethoxylated isodecylalcohol–NIS 2 (Trend, 90 EC, Du Pont, France) at 0.1% v/v concentration. The spraying liquid was lowered to pH 4 by adding citric ($C_6H_8O_7$, Archem, Lany, Poland) or acetic acid (C_2H_4O2, TechlandLab, Tarnobrzeg, Poland) and raised to pH 9 with ammonia solution ($NH_3 \cdot H_2O$, TechlandLab, Tarnobrzeg, Poland) or potassium phosphate (K_2HPO_4, POL-AURA, Dywity, Poland). Greenhouse trial was designed as a randomized complete block with four replications and repeated two times. The herbicide was applied when the plants were in the three-leaf growth stage.

The treatment was performed with a laboratory sprayer with a liquid output of 200 l/ha, equipped with a set of Tee Jet flat-jet nozzles type DGTJ60 11003, at an operating pressure of 0.3 MPa. Sprayers were placed at a height of 50 cm from the plants. Water used for irrigation in Zlotniki Research Station contained (mg/L): 114 Ca^{2+}, 7,4 Mg^{2+}, 0 Na^+, 0 K^+, < 1 Fe^{3+}, 356 $CaCO_3$ and pH 7,3.

Three weeks after treatment, barnyardgrass control was assessed by estimating the reduction in weed fresh mass after sulcotrione treatment compared to untreated control. Thedata was calculated using Henderson–Tilton formula [26]. Visual evaluation of the herbicidal efficacy was based on the comparison of the condition of barnyardgrass plants from objects treated with sulcotrione with plants from the untreated control. Visual weed control was shown using a scale ranging from 0% (untreated) to 100% (full control).

2.2. Laboratory Experiment-Surface Tension and Contact Angle

Physical properties of spray liquid, as surface tension (ST), contact angle (CA) were measured after 8.5 s, and dynamic surface tension (DST) from 0 to 8.5 s, by the KSV Optical tensiometer Theta Lite equipped with a camera taking over 60 photos per second, with a frame interval of 16 ms. The Elmetron pH conductometer CPC-505 equippde with EPS-1 electrode was used to estimate the pH of spray liquids. Laboratory measurements were performed at a constant room temperature of 23 ± 0.1 °C and relative humidity of 60%.

### 2.3. Laboratory Experiment-Viscosity

The temperature and pressure have a significant effect on the viscosity. However, the pressure has a smaller effect than temperature. At the same wall outlet, the shear viscosity of liquid dominated. In this case, we are dealing with the shear viscosity (dynamic viscosity).

The shear viscosity of fluids was measured by Physica MCR 501 rheometer delivered by Anton Parr (Germany). This rheometer can perform rheological tests both in rotational and oscillatory mode. It also ensures absolute control at any time during the rheological tests. The measurements are fully automated, and a further device allows the computer to analyse the results.

In order to measure the fluid, a test sample is provided in the gap between the two measuring elements. The volume of liquid of the rheological test was 3.7 ml. The measuring elements rotate relative to each of them when attributed to the shear rate, and the sample of liquid is subject to shear. The installation has been operated in the system of the concentric cylinders, as is schematically shown in Figure 1. This system is composed of the internal cylinder of radius R1 and the external cylinder of radius R2. The diameter of the internal cylinder was 23.827 mm, and the external cylinder −27.584 mm. The internal cylinder rotates with an angular velocity Ω. This velocity causes a moving liquid film which adheres to the surface of the internal cylinder. The liquid which adheres to the surface of the external cylinder is stationary. The studies were performed at temperature 20 ± 0.1 °C and at the strain rate changed from 10 to 1000 s^{-1}. The measuring device was equipped with a Peltier plate that provided very good temperature control. The rheometer was connected to the computer. Measurements were controlled and analyzed using the software RheoPlus (Anton Parr, Germany).

2.4. Statistical Analysis

Statistical procedures were conducted using Statistica 12 software (StatSoft Inc., Tulsa, OK). Data were subjected to ANOVA and means were separated by honest significant differences (HSD) using Tukey's method when the F-test indicated significant factorial effects at the level of $p > 0.05$. The percent ratings of weed control were arc-sine transformed prior to analysis to correct for unequal variance, but the data in the table are reported as non-transformed [27,28].
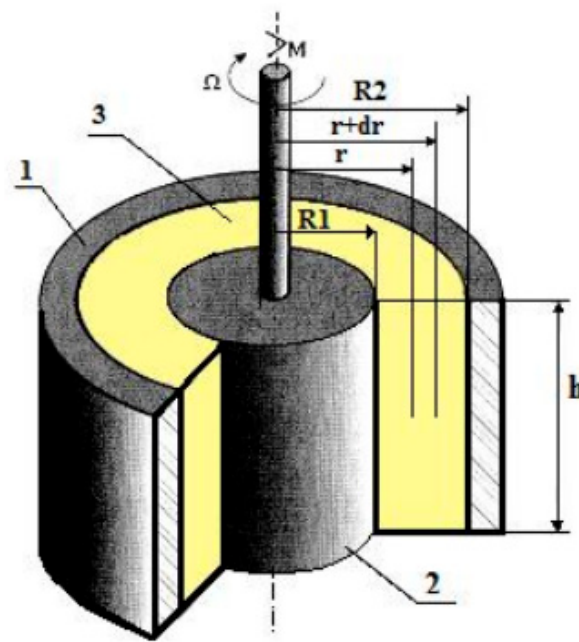
1– outer cylinder, 2–internal cylinder, 3–test liquid

Figure 1. Diagram of coaxial cylinder system:.

3. Results

3.1. Greenhouse Experiment

According to visual assessment, sulcotrione, applied at the full rate in a neutral solution, reduced barnyardgrass biomass by 90%, at a reduced rate of only 74% (Table 1). By adding MSO, NIS 1 and NIS 2 adjuvants to the spray liquid, weed control increased to 81%–86%. Sulcotrione effectivity in acidic solution was 71% (acetic acid) and 83% (citric acid), in basic solution 74%–77%. The adjuvants MSO and NIS 1, when added to acetic acid solution, increased barnyardgrass control to 87%–89%, and NIS 2 to 83%, compared to 71% from acetic acid treatment but, when added to citric solution, it increased control to 95% (MSO), and 90%–91% (NIS 1 and NIS 2), compared to 83% from citric acid treatment. In basic solution, the activity of sulcotrione was lower than in acid solution, and even with adjuvants, it did not go beyond 88%, (MSO) and 77%–81% NIS 1 and NIS 2.

Barnyardgrass control based on fresh weight reduction indicated that sulcotrione in neutral solution, applied at the full rate, controls weed by 90%, at a reduced rate of only 78% (Table 1). The addition of MSO, NIS 1 and NIS 2 adjuvants improved control by 80%–86%. Herbicide in acidic solution reduced 70%–78% of barnyardgrass fresh mass. Adjuvants added to both pH buffers significantly improved barnyardgrass control by 85%-88% (acetic acid) and 91%–93% (citric acid). Sulcotrione control was slightly lower in the basic solution than in the acidic solution. Herbicide with ammonia or potassium phosphate controlled barnyardgrass by 63% or 78%. The addition of adjuvants significantly increased sulcotrione efficacy, with ammonia increasing to 82%–87% and potassium phosphate and MSO to 90%, but, with NIS 1 and NIS 2, only to 79%–80%.

Table 1. Efficacy (%) of sulcotrione depending on adjuvants and pH adjuster.

No.	pH Buffer	Treatment	Adjuvant	Efficacy Based on	
				Visual Assessment[7]	Fresh Weight Reduction
1	Neutral solution[3]	Sulcotrione[1]	-	90 bc	90 ab
2		Sulcotrione[2]	-	74 jk	78 ef
3		Sulcotrione[2]	+ MSO	86 def	86 abcde
4			+ NIS 1	81 gh	80 cde
5			+ NIS 2	84 efg	86 abcde
6	Acidic solution[4]	Sulcotrione + acetic acid	-	71 k	70 fg
7		Sulcotrione + citric acid	-	83 fg	78 ef
8		Sulcotrione[2] + acetic acid	+ MSO	87 cde	88 abc
9			+ NIS 1	89 bcd	88 abc
10			+ NIS 2	83 fg	85 abcde
11		Sulcotrione[2] + Citric acid	+ MSO	95 a	93 a
12			+ NIS 1	91 b	92 a
13			+ NIS 2	90 bc	91 a
14	Basic solution[5]	Sulcotrione + ammonia solution	-	74 jk	63 g
15		Sulcotrione + potassium phosphate	-	77 ij	78 ef
16		Sulcotrione[2] + ammonia solution	+ MSO	86 def	87 abcd
17			+ NIS 1	81 gh	82 bcde
18			+ NIS 2	81 gh	85 abcde
19		Sulcotrione[2] + potassium phosphate	+ MSO	88 bcd	90 ab
20			+ NIS 1	77 ij	80 cde
21			+ NIS 2	79 hi	79 de
	Standard Deviation			2.42	3.00

[1]sulcotrione at 450 g/200 l of spray liquid, [2]sulcotrione at 225 g/200 l of spray liquid, Toil at 1.0 l/200 l of spray liquid, Silwet L–77 840 AL at 0.1%, Trend 90 EC at 0.1%, [3]acidic solution, pH of spray liquid approximately 4, [4]basic solution, pH of spray liquid approximately 9, [5]neutral solution, pH of spray liquid approximately 7, [6]the same letter means not significantly different, [7]0% (untreated) to 100% (full control).

3.2. Laboratory Experiment—Surface Tension and Contact Angle

Results obtained during study indicate that the addition of MSO, NIS 1 or NIS 2 to sulcotrione in neutral solution reduced the surface tension (ST) of spray droplets compared to sulcotrione applied at recommended rate and especially at reduced rate. The ST of sulcotrione spray liquid at a reduced rate applied with adjuvants ranged from 21.2 (NIS 1) by 28.1 (NIS 2) to 29.8 mN/m (MSO), compared to 42.0 from sulcotrione at full rate, and 51.5 from sulcotrione alone at reduced rate (Table 2). In case of acidic solution with sulcotrione and adjuvants, ST ranged from 21.3 to 29.9 and it was similar to results from neutral solution. The ST of acidic solution, with acetic acid and citric acid, was substantially higher 50.5–51.2 mN/m. Those results were at the same level as the ST from basic solution, with ammonia. At a neutral, acidic or basic solution, the ST from sulcotrione with MSO and NIS 2, regardless of buffer, was similar—28.1–29.9 mN/m—but MSO was higher than from NIS 2.

Table 2. The effect of adjuvants on physical properties of spray liquid droplets containing sulcotrione with different pHs.

No.	pH Buffer	Treatment	Adjuvant	Physical Properties			
				Surface Tension (mN/m)		Contact Angle (°)	
1	Neutral solution[3]	Sulcotrione[1]	-	42.0	b	75.3	b
2		Sulcotrione[2]	-	51.5	a	92.1	a
3		Sulcotrione[2]	+ MSO	29.8	c	47.7	c
4			+ NIS 1	21.2	d	24.6	e
5			+ NIS 2	28.1	cd	41.9	cd
6	Acidic solution[4]	Sulcotrione + acetic acid	-	51.2	a	89.5	a
7		Sulcotrione + citric acid	-	50.5	a	88.0	a
8		Sulcotrione[2] + acetic acid	+ MSO	29.9	c	47.2	cd
9			+ NIS 1	21.3	d	25.2	e
10			+ NIS 2	28.4	cd	42.4	cd
11		Sulcotrione[2] + Citric acid	+ MSO	29.5	c	47.3	cd
12			+ NIS 1	21.4	d	24.3	e
13			+ NIS 2	28.5	cd	41.3	d
14	Basic solution[5]	Sulcotrione + ammonia solution	-	51.4	a	89.1	a
15		Sulcotrione + potassium phosphate	-	50.9	a	88.2	a
16		Sulcotrione[2] + ammonia solution	+ MSO	29.7	c	47.5	c
17			+ NIS 1	21.5	d	25.4	e
18			+ NIS 2	28.4	cd	42.4	cd
19		Sulcotrione[2] + potassium phosphate	+ MSO	29.6	c	46.8	cd
20			+ NIS 1	21.7	d	25.9	e
21			+ NIS 2	28.2	cd	42.0	cd
	Standard Deviation			2.94		2.37	

S 1-sulcotrione at 450 g/200 l of spray liquid, S-sulcotrione at 225 g/200 l of spray liquid, CA–citric acid, reaction of spray liquid pH 4, MSO-Toil at 1.0 l/200 l of spray liquid, NIS 1 - Silwet L-77 840 AL and NIS 2-Trend 90 EC at 0.1%, the same letter means not significantly different.

The contact angle (CA) of spray liquid containing sulcotrione at a full and reduced rate in neutral solution shaped up as level 75.3 and 92.1 mN/m (Table 2). The addition of MSO, NIS 1 and NIS 2 reduced the CA of spray liquid to 24.6° (NIS 1) and 41.9–47.7 mN/m (NIS 2 and MSO), similar to adjuvants in the acidic solution with citric acid and acetic acid, and basic solution with ammonia and potassium phosphate. The CA of sulcotrione in an acidic or basic solution created with acetic or citric acid, and ammonia or potassium phosphate, ranged from 88.0 to 89.5°. The lowest CA from sulcotrione + NIS 1, regardless of pH solution, were observed, compared to the significantly higher CA from sulcotrione + NIS 2 or MSO treatments.

The results indicate that both the DST and CA of sulcotrione spray mixture at reduced rate was higher than at full rate. The adjuvants at spray liquid led to further reductions in DST and CA; the most were seen with NIS 1 and NIS 2, and lower rates were seen with MSO (Figures 2 and 3).
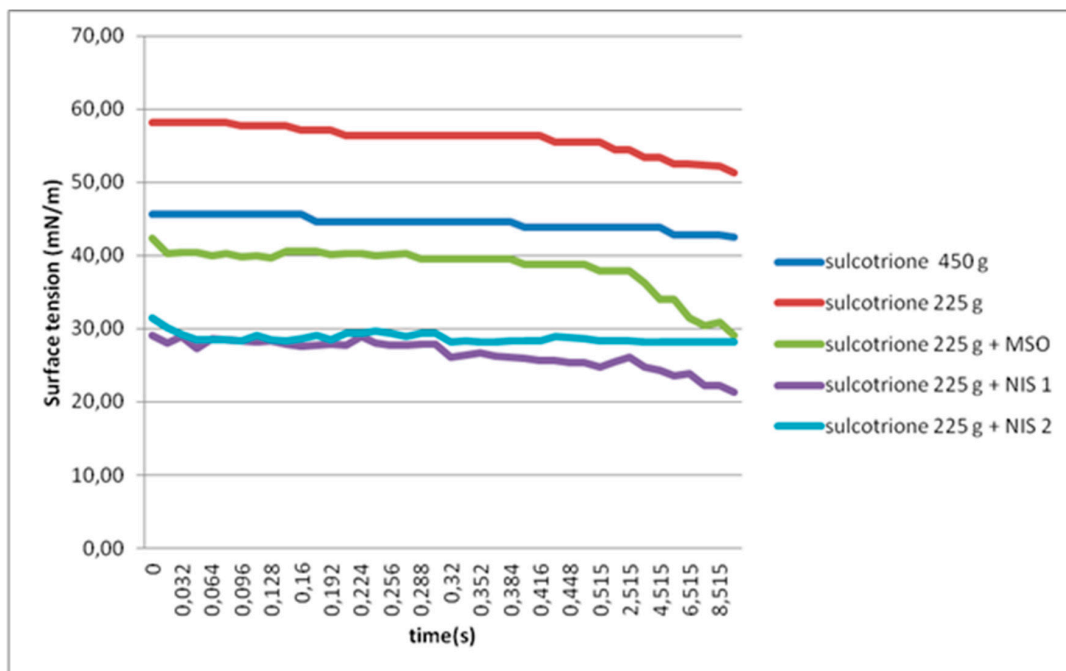
Figure 2. The effect of adjuvants on the dynamic surface tension of spray liquid droplets containing sulcotrione.
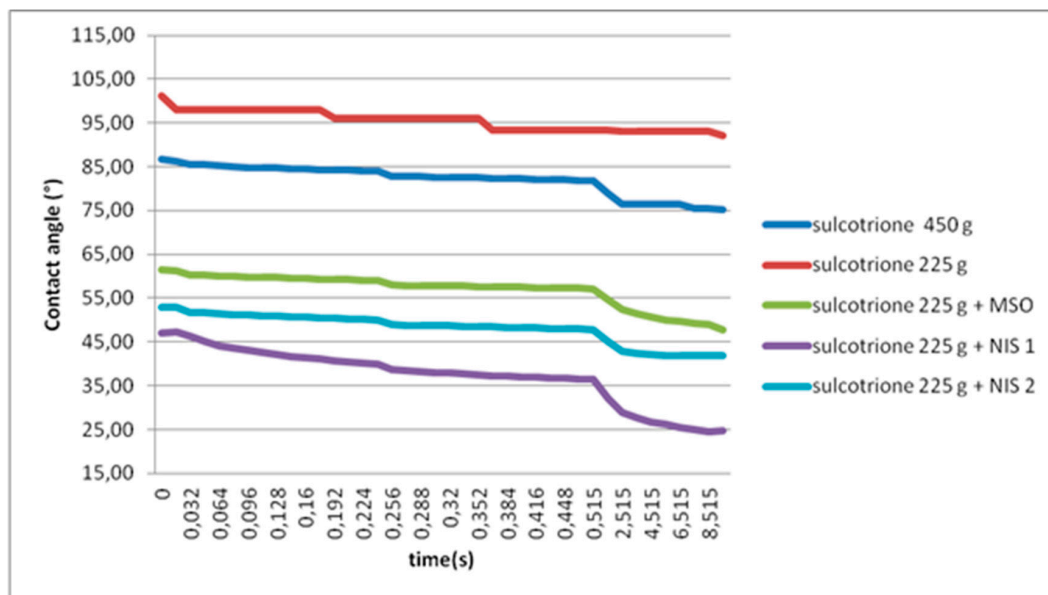

Figure 3. The effect of adjuvants on the dynamic contact angle of spray liquid droplets containing sulcotrione.

3.3. Laboratory Experiment-Viscosity

Figure 4 shows how the shear viscosity varies with the strain rate of the shear viscosity. For all test solutions, the shear viscosity value maintains an almost constant level in relation to the changing rate of deformation. The fact that shear viscosity is a value independent of shear rate indicates that the tested liquids belong to the group of Newtonian fluids.

No significant differences were found between the tested objects for the viscosity of the tested liquids and controls (tap water). The results from acidic and basic solution treatments did not differ between each other, and that is why they are not shown. The sulcotrione concentration did not affect

the viscosity of the liquid. The addition of adjuvants to the liquid containing sulcotrione resulted in an increase in shear viscosity. The shear viscosities of the tested liquids for a strain rate of 1000 s-1 are presented in Figure 5.
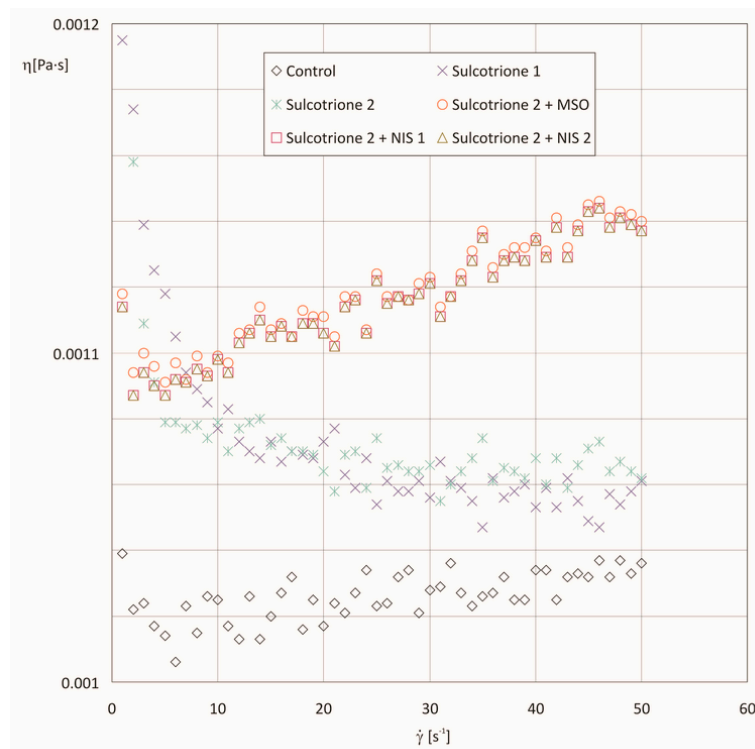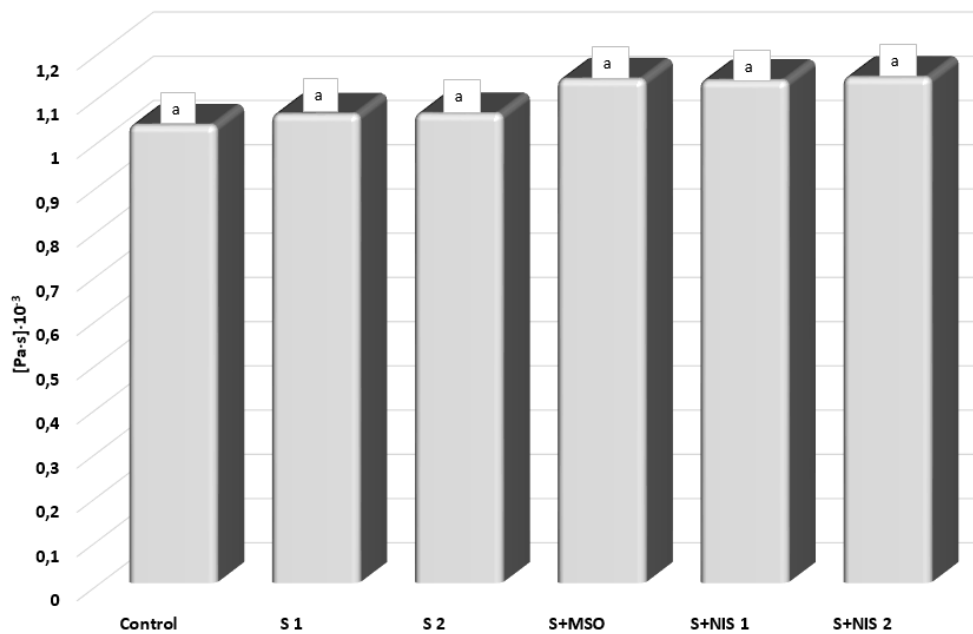

Figure 4. Dependence of shear viscosity on strain rate (control—tap water; S 1-sulcotrione at 450 g/200 l of spray liquid, S 2-sulcotrione at 225 g/200 l of spray liquid, MSO-Toil at 1.0 l/200 l of spray liquid, NIS 1-Silwet L-77 840 AL and NIS 2-Trend 90 EC at 0.1%).

S 1-sulcotrione at 450 g/200 l of spray liquid, S2, S-sulcotrione at 225 g/200 l of spray liquid, MSO-Toil at 1.0 l/200 l of spray liquid, NIS 1-Silwet L-77 840 AL and NIS 2-Trend 90 EC at 0.1%, the same letter means not significantly different.

Figure 5. Shear viscosity value of tested liquids for the rate of deformation equal to 1000 $s^{-1.}$

4. Discussion

When analyzing the visual evaluation of the herbicidal efficacy, a favourable effect of low pH spray liquid of sulcotrione was found, but only if citric acid was the pH adjuster. This relationship was not confirmed by the results obtained from the reduction in fresh weed weight. The high pH adjusters did not improve the sulcotrione efficacy. The properties of the water used to prepare the spray liquid are of great importance in achieving the adequate effectiveness of the applied plant protection products. The pH of the spray liquid affects the solubility of herbicides and their hydrolysis [29]. Water hardness is determined by the number of ions contained in it. The high value of this parameter contributes to the reduction in herbicide effectiveness [30]. The highest level of herbicide effectiveness at a reduced dose was observed in the combination where the spray liquid pH was modified using citric acid with the addition of adjuvant MSO. Citric acid, in addition to reducing the pH of the spray liquid, also has an impact on the sequestration of ions contained in hard water [31]. The addition of adjuvants to liquids with a low pH resulted in an increase in effectiveness to a level similar to the full dose of sulcotrione, or an even better effect was observed in the presence of citric acid and MSO in the tank-mix. The effectiveness of sulcotrione after the addition of K3PO4 depended on the type of adjuvant included in the spray liquid. Green and Hale [32] also noted that the effectiveness of the active substance depended on the pH of the spray liquid and, at the same time, the type of adjuvant included in the spray liquid. Sulcotrione activity depended on the pH of spray liquid and the addition of adjuvants. The best efficacy of sulcotrione was observed when the low pH of the liquid was obtained with the addition of citric acid as a pH adjuster and MSO adjuvant.

In the experiment, the addition of adjuvants to the composition of the spraying liquid contributed to the decrease in surface tension and the angle of adhesion of the spraying liquid droplets. To the highest extent, the value of these parameters decreased in the case of mixtures containing surfactants—NIS1 and NIS2, respectively. Activator adjuvants improved the effectiveness of sulcotrione under the neutral conditions of the spray liquid, compared to its reduced dose without adjuvants, which was confirmed by the results of the visual assessment. The lowest static and dynamic surface tension and contact angle of spray liquid droplets (NIS 1) did not contribute to the greatest herbicidal effectiveness of sulcotrione. The smaller adhesion angle and drop tension leads to better coverage of the sprayed plants. Other studies have shown that the use of an organosilicone surfactant can contribute to a significant increase in the coverage of barnyardgrass leaves by liquid drops [33]. However, it should be remembered that an increase in leaf wetting may lead to an increase in the evaporation rate of spray liquid drops [34]. Adjuvants are substances that do not have a direct herbicidal effect, but they can modify the properties of the spraying liquid, which can lead to an increase in the effectiveness of herbicides [35]. They can affect the droplet size of the spraying liquid, their surface tension and spreading on the sprayed surface, wetting plants, taking and translocating applied plant protection products [36]. An important point in terms of the effectiveness of herbicides is the possibility of the penetration of active ingredients through the cuticular layer [37]. A factor that additionally hinders the deposition of spray liquid drops on the surface of weeds belonging to the grass family is their vertical arrangement of narrow leaves [38]. The presence of oil adjuvants in the composition of the spray liquid contributes to the dissolution of the cuticular wax layer [39]. Studies show that the physical properties of liquid can be changed even by the addition of small amounts of other substances, especially surfactants [40]. The value of surface tension for water at room temperature is equal 73 mN/m [41]. In the experiment, adjuvants decrease dynamic surface tension and the dynamic contact angle of spray liquid droplets—these parameters are most affected by NIS 1, NIS 2, and the least by MSO. An important factor affecting the effectiveness of the application of herbicides is to reduce the rebounding of droplets in the spray liquid. This depends on the dynamic surface tension [42]. The low level of dynamic surface tension causes uniformly low surface tension to occur at the interface of air, liquid and solid. The receding behavior of drops is limited. The drops spread evenly on the hydrophobic surface on which they fall [43]. The pH adjusters tested in the experiment did not reduce either surface tension or droplet contact angle.

No statistically significant differences in shear viscosity were found for the tested solutions. The viscosity of the spray liquid drops affects their atomization and drift [44]. The shear viscosity of individual solutions remained almost constant in relation to the changing deformation rate. This indicates that the tested liquids can be included in the group of Newtonian fluids. Spraying liquids are often classified as non-Newtonian liquids. This may be due to the presence of solid particles in solutions [45]. In the experiment, the tested herbicide was used in the SC formulation. This is a liquid suspension concentrate where the active substance is in finely divided form. It has good solubility in water [46]. Additionally, herbicides belonging to 4-HPPD inhibitors are applied in low doses [47]. The presence of solid particles may, therefore, not affect the shear viscosity of the solutions tested in this case.

5. Conclusions

The effectiveness of herbicides depends on many factors. In the conducted experiment, it was shown that the addition of adjuvants to the composition of the spraying liquid contributed to the reduction in surface tension and contact angle of the droplets of the spraying liquid and an increase in the level of control of barnyardgrass. In the experiment, it was proved that the use of reduced dose of sulcotrione in a low pH (citric acid) and MSO adjuvant allows to increase the effectiveness of control barnyardgrass at the same level as the full dose of herbicide. The application of sulcotrione in a low pH condition does not always cause an improvement in effectiveness and depends on the type of compound used (citric acid is better than acetic acid). The use of adjuvants, substances that modify the pH of the spray liquid and reduce water hardness can achieve a high effectiveness of the plant protection product applied in a reduced dose. This approach to the application of herbicides is important because of the need to limit the amount of chemicals that end up in the environment.

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