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NON-HERBICIDE SOLUTIONS AS A POSSIBLE ALTERNATIVE IN WEED CONTROL

Zlatko Milićević[1*], Anja Milosavljević[1], Danijela Šikuljak[2], Ana Anđelković[2], Nenad Trkulja[2], Snežana Janković[3], Miloš Rajković[4]

[1]Research and Development Center, Sunoko, Inđija, Serbia,
[2]Institute for Plant Protection and Environment, Belgrade, Serbia,
[3]Institute for Science Application in Agriculture,Belgrade, Serbia,
[4]Institute for Medical Plant Research „Dr. Josif Pančić", Belgrade, Serbia,
***Corresponding author: zlatko.milicevic@sunoko.rs**

Abstract: We investigated the effectiveness of non-herbicidal agents to control weeds in sugar beets. Experiments were performed under field and laboratory conditions. We monitored the level of effect of 50, 70 and 100% solutions of vinegar, and alcohol, also 50, 70 and 100^{0}C hot water, and an open flame. The sensitivity/efficiency under laboratory conditions was tested by analyzing the changes in the chlorophyll content of weeds (*Abutilon teophrasti, Chenopodium album*) and sugar beet plants. The obtained results indicate that any method of weed control in sugar beet is acceptable, especially when aiming to reduce the use of herbicides. Application of flame (with shields) was shown to be the safest alternative weed control measure. Weeds and sugar beet plants are sensitive to treatments with alcohol, vinegar, flame and hot water as measured by chlorophyll content.

Keywords: Non-herbicides, Sugar beet, Weed, Chlorophyll

INTRODUCTION

Sugar beet is grown in Serbia on 60.000-75.000 ha. The highest production is achieved by producers in the territory of Srem (51 t/ha), and the lowest in Banat region (33 t/ha) (www.plodnazemlja.com). However, similar to the rest of Europe, there is a decline in sugar beet production (<14%) and in planted areas (7%) each year (www.cefs.org). In addition to financial constraints, this trend is driven by climate change, reduced use of pesticides and synthetic fertilizers, and the declining availability of effective pesticide options (development of resistance, list of prohibited active substances, etc.).

Recently, Serbia has experienced prolonged drought in addition to record-high average daily temperatures (July and August) affected dry leaf and root weight, total dry weight, net assimilation rate, specific leaf area etc. (Albayrak and Çamas, 2007).

High temperatures and poor distribution of precipitation affect the metabolic processes in sugar beet, while the presence of weeds suppresses plant growth and development, particularly root growth and the biosynthesis of soluble sugars (Seadh et al., 2013). Therefore, selected and timely applied methods of weed control, especially in the first eight weeks after sowing, significantly affect the sugar beet (Zoschke and Quadranti, 2002; May and Wilson, 2006).

Producers have long relied on the application of herbicides as the safest way to eliminate weeds and achieve high yields. Today, minimal or zero tolerance for the use of pesticides, concern for the environment and the goal to produce health-safe food limits the use of herbicides in sugar production (EPA, 2025). Considering these challenges, it is necessary to react quickly by applying new technologies, innovative solutions and adopt agricultural practices in order to minimize the negative effects.

In addition to the above, the introduction of alternative weed control measures: inter-row cultivation, harrowing, mulching, hoeing, growing mixed crops, crop rotation, application of flames, application of hot water, innovative technologies, bioherbicides, etc. provides one of the sure ways to control weeds.

The aim of this work was to examine different alternative methods of weed removal in sugar beet crops.

MATERIAL AND METHODS

In the production unit of the company "Carnex doo" in Bačko Dobro Polje in the South Bačka District, Serbia, Southeast Europe, the cultivar "Eduarda" KWS of sugar beet was established for the field part of the experiment. The experiments were conducted under laboratory and field conditions in 2024. Laboratory tests were performed at the Institute for Plant Protection and Environment (Belgrade, Serbia). The tested treatments under field conditions are shown in Table 1. The list of treatments applied under laboratory conditions is shown in Table 2.

Table 1. Experimental design (field)

Treatment	***I***	***II***	***III***
Crop	BBCH 14	BBCH 14-16	BBCH 16-18
Weed	Ponici + 2 lista	Korovi 2-4 lista + p	Korovi 4-6 listova + p
Date	13.4.2024.	28.4.2024.	13.5.2024.
K1	-	-	-
K2=T6	Powertwin 1 l/ha + Hemomitron 1 l/ha + Safari 30 g/ha + Trend 100 ml/ha	Powertwin 1,5 l/ha + hemomitron 1,5 l/ha + safari 30 g/ha +Trend 100 ml/ha	Powertwin 1,5 l/ha + Hemomitron 1,5 l/ha + Safari 30 g/ha + Loret 0,2 l/ha + Trend 100 ml/ha
T7	Cultivator	Alcohol 1:3, 65 l/ha	Alcohol 1:3, 130 l/ha
T8	Cultivator	Vinegar, 200 l/ha	Vinegar, 200 l/ha
T9	Cultivator	Hot water, 200 l/ha	Hot water, 200 l/ha
T10	Cultivator	Open flame	Open flame

Table 2. Experimental design (laboratory)

	Alcohol	***Vinegard***	***Hot water***	***Flame***
Weeds and sugar beet	50%	50%	50^0C	propane-butane gas
	70%	70%	70^0C	
	100%	100%	100^0C	

Application of the flame in the field was carried out at an angle of 45 degrees (with a shield), at a height of 15 cm. Solutions of alcohol, water and vinegar applied with „Solo“ sprayer (20 L).

Laboratory experiments

The efficacy was tested on weed species under laboratory conditions on the most abundant weed species collected in the field: *Abutilon teophrasti* and *Chenopodium album*. Application of non-chemical agents was done using a hand sprayer in concentrations of 50, 70 and 100% (alcohol, vinegar), 50, 70 and 100^{0}C hot water and a flame.

Sugar beet and weed plants were grown from seed under controlled conditions (12:12h day:night, T=22/16^{0}C day and night, watering as needed).

Weed plants were treated when they developed 2 leaves. Efficacy was evaluated 14 days after the treatment. The treatment of sugar beet plants was done at 7, 14, 21, 28 and 35 days after the emergence and the sensitivity assessment was done 14 days after application.

In all species, the efficacy of the applied treatments was assessed by measuring the content of chlorophyll *a, b* and total chlorophyll.

Chlorophyll extraction

Extraction of chlorophyll was done by liquid nitrogen from plant leaves (0.5 g). Methanol (5 mL) was added to each sample, centrifuged at 1500 rpm for 10 min before measurement and analyzed on a spectrophotometer (UV 2100, Shimadzu). The absorption of chlorophyll a was read at λ = 653 nm, chlorophyll b at λ = 666 nm and carotenoids at λ = 470 nm. The content of chlorophyll (total, *a, b*) was calculated according to the formulas given by Wellburn (1994).

Statistics: The number of weeds and the evaluation of the effectiveness of the applied methods under field conditions were performed 14 days after the treatment and shown as a percentage compared to the control (K-number of weeds in the variant/K x 100). Analysis of the obtained data for the extracted chlorophyll was performed by analysis of variance ANOVA (LSD test) and t-test in the Statistica 7 package.

RESULTS AND DISCUSSION

Field experiment

Based on the analysis of the results in Table 3, it can be concluded that the application of hot water showed the lowest level of efficacy on the present weed species (4.25-12.07%), while the application of herbicides showed the highest level of efficacy (76.78-94.12%). In the control of species *Abutilon teophrasti* and *Ambrosia artemisiifolia*, the application of herbicides showed satisfactory efficacy, while the application of alcohol, hot water and vinegar showed poor efficacy. The use of flames has proven to be an alternative method that, under conditions without the use of herbicides, can help the crop in competition with weeds. Control of *Chenopodium album* species was only good after the application of herbicides, while in the control of *Chenopodium hybridum* the application of flames achieved the level of efficacy over 50%. Control of *Datura stramonium* was good after herbicide application and satisfactory after the flame application. Control of *Solanum nigrum* was good after herbicide application and satisfactory after the flame application (Table 3).

Table 3. Effeciency (%) of non-herbicides tested in the field 14 days after treatment

	Herbicides	***Alcohol***	***Vinegar***	***Hot water***	***Flame***
			Efficacy (%)		
Abutilon teophrasti	78.89	26.76	17.78	8.89	35.55
Ambrosia artemisiifolia	76.78	25.89	21.43	7.14	53.57
Chenopodium album	91.49	17.02	13.83	4.25	36.17
Chenopodium hybridum	91.38	36.21	24.14	12.07	51.72
Datura stramonium	94.12	47.06	32.35	11.76	76.47
Solanum nigrum	93.02	30.23	17.44	11.63	76.74

Laboratory experiment

It can be stated that the efficacy under laboratory conditions is similar to the efficacy determined under the field conditions. Analysis of the effect of the tested non-herbicide solutions under laboratory conditions showed that the effectiveness compared to the control is very weak, except for the use of open flame (Table 4). Visual damage was observed only under laboratory conditions on the plants after the application of 70-100% vinegar and an open flame.

Table 4. Efficacy (%) of non-herbicides 14 days after treatment on weeds and sugar beet in the laboratory

	Chenopodium album	***Abutilon teophrasti***	**Sugar beet**
		Efficacy (%)	
Alcohol 50%	17%	0%	selective
Alcohol 70%	75.22	30%	
Alcohol 100%	100%	35%	
Vinegard 50%	12.25%	0%	
Vinegard 70%	15%	7.5%	
Vinegard 100%	15.65%	10%	
Hot water 50^0C	0%	0%	
Hot water 70^0C	8.25%	0%	
Hot water 100^0C	10%	5%	
Open flame	100%	80%	80-90%

Contrary to the efficacy in the field and laboratory, the analysis of chlorophyll (*a, b* and total) content showed the sensitivity of both weeds and sugar beet to non-herbicide solutions (Tables 5, 6, 7). *Chenopodium album* plants were especially sensitive to 100% alcohol and 50,70 and 100% vinegar (total damage).

Table 5. Chlorophyll *a* content in weed plants

	Chenopodium album	***Abutilon teophrasti***
C - Alcohol 50%	0.000**	0.000**
C - Alcohol 70%	0.000**	0.000**
C - Alcohol 100%	0	0.000**
C - Vinegard 50%	0	0.000**
C - Vinegard 70%	0	0.000**
C - Vinegard 100%	0	0.000**
C - H.Water 50^{0}C	0.000**	0.000**
C - H.Water 70^{0}C	0.000**	0.000**
C - H.Water 100^{0}C	0.000**	0.000**
C - Open flame	0	0.000**
SD	0.97	1.573
mean	1.03	2.706

C-control, sd-standard deviation, p<0,05*, p<0,01**, efficacy 14 days after treatment

Table 6. Chlorophyll *b* content in weed plants

	Chenopodium album	***Abutilon teophrasti***
C - Alcohol 50%	0.000**	0.000**
C - Alcohol 70%	0.000**	0.000**
C - Alcohol 100%	0	0.000**
C - Vinegard 50%	0	0.000**
C - Vinegard 70%	0	0.000**
C - Vinegard 100%	0	0.000**
C - H.Water 50^{0}C	0.004**	0.000**
C - H.Water 70^{0}C	0.000**	0.000**
C - H.Water 100^{0}C	0.000**	0.000**
C - Open flame	0	0.000**
SD	0.376	0.607
mean	0.390	0.850

C-control, sd-standard deviation, p<0,05*, p<0,01**, efficacy 14 days after treatment

Table 7. Total chlorophyll content in weed plants

	Chenopodium album	***Abutilon teophrasti***
C - Alcohol 50%	0.000**	0.000**
C - Alcohol 70%	0.000**	0.000**
C - Alcohol 100%	0	0.000**
C - Vinegard 50%	0	0.000**
C - Vinegard 70%	0	0.000**
C - Vinegard 100%	0	0.000**
C - H.Water 50^{0}C	0.000**	0.000**
C - H.Water 70^{0}C	0.000**	0.000**
C - H.Water 100^{0}C	0.000**	0.000**
C - Open flame	0	0.000**
SD	1.335	2.113
mean	1.42	3.557

C-control, sd-standard deviation, p<0,05*, p<0,01**, efficacy 14 days after treatment

Analysis of the chlorophyll content in sugar beet plants after the application of non-herbicidal solutions showed that they are sensitive to the application of alcohol, vinegar, hot water, and flame. High sensitivity (based on the content of chlorophyll *a* and *b*) under laboratory conditions is observed after the flame application (youngest plants), 100 % vinegar (plants old 14 and 28 days), 100% alcohol (plants old 35 days) (Table 8). Statistical analysis of the sensitivity of sugar beet plants treated at different stages of development is shown in Table 8.

Table 8. Total chlorophyll content in sugar beet plants

Plant age	**7 days old**	**14 days old**	**21 days old**	**28 days old**	**35 days old**
			IV efficacy		
C - Alcohol 50%	ns	0.000**	0.000**	0.000**	0.000**
C - Alcohol 70%	0.000**	0.000**	0.000**	0.000**	0.000**
C - Alcohol 100%	0.000**	0.000**	0.000**	0.000**	0
C - Vinegard 50%	0.000**	0.000**	0.000**	0.000**	0.000**
C - Vinegard 70%	0.000**	0.000**	0.000**	0.000**	0.000**
C - Vinegard 100%	0.000**	0	0.000**	0	0.000**
C - H.Water 50^{0}C	0.000**	0.000**	0.000**	0.000**	0.000**
C - H.Water 70^{0}C	0.000**	0.000**	0.000**	0.000**	0.000**
C - H.Water 100^{0}C	0.000**	0	0.000**	0.000**	0.000**
C - Open flame	0	0.000**	0.000**	0.000**	0.000**
SD	4.823	5.689	3.909	6.675	5.659
mean	9.613	9.854	13.613	10.551	11.455

C-control, sd-standard deviation, p<0,05*, p<0,01**, efficacy 14 days after treatment, ns-nonsignificant differences

Sugar beet as a crop is extremely demanding in terms of growing conditions. With their presence weeds affect the yield and as regular companions of cultivated plants they cause numerous negative effects: they take up living space, consume light, nutrients and water for cultivated plants (da Silva et al., 2022). New/old alternative non-herbicide weed control measures are gaining importance: mulches, flames, steam and foam, infrared rays, electric current (Jabran and Chauhan, 2018), as well as cultivation of more resistant and competitive genotypes, improvement of cultivation technology, etc. (Monteiro and Santos, 2022). The non-herbicidal treatments tested exhibited low levels of weed control under field conditions, except for the flame application. Conversely, no visual symptoms of damage were observed on sugar beet and weed plants except after the flame application. Contrary to this, damage to weed plants was observed under laboratory conditions after the application of flame and the highest concentrations of alcohol and vinegar.

However, the application under laboratory conditions showed that there are both visual and physiological symptoms of damage. In particular, the effectiveness was expected after the application of a 100% solution of vinegar and alcohol and 100^{0}C water. Visual damage symptoms were observed after the application of 70 and 100% (4-7% vinegar in 100% solution) on the leaves of *Abutilon teophrasti* and complete decay of *Chenopodium album* seedlings.

However, analysis of the chlorophyll content showed a higher level of sensitivity (Tables 5, 6 and 7) and even a complete decay of seedlings of: *Chenopodium album* after application of 100% alcohol and 50, 70 and 100% vinegar and *Abutilon teophrasti* after the flame application. Similar results were obtained by Radhakrishnan et al. (2003). The use of vinegar for weed control has been studied several times (Evans et al., 2009, 2011; Johnson et al., 2003; Webber III et al., 2012) and it has been shown that it can be used as a contact herbicide. Also, it was concluded that vinegar is most effective in suppressing seedlings and preventing weed seeds' germination (Owen, 2002). Webber III et al. (2018) successfully controlled *Chenopodium album, Abutilon teophrasti, Amaranthus hybridus* and *Cirsium arvense* under controlled conditions using 5, 10.5, 15.3 and 20.2% vinegar solutions. Low levels of effectiveness of vinegar under field conditions (Table 2) can be related to the climatic conditions in the open field, the use of vinegar without adjuvants and the low concentration of acetic acid in the solution (4-7%).

The effectiveness of applied hot water and flame as a possible herbicide was expected because high temperatures damage cells by expansion of intercellular water after cell rupture (few seconds at 100^0C water; Peerzada and Chauhan, 2018). Also, De Cauwer et al. (2015) found that at the most early-stage broadleaf weeds are sensitive to hot water. Hwang et al. (2012) successfully controlled *Setaria viridis* using 2% ethanol (75 and 100 l/ha). The weak effectiveness of the applied alcohol in the experiments performed can be related to the fact that some alcohols (e.g. methanol) can have a stimulating effect on the growth of plants, especially C3 (wheat, *Lolium sp*., *Poa pratensis*, etc.) (McGiffen and Manthey, 1996) or to the fact that ethanol has an inhibitory effect (slows down the growth of plants) (Miller, 2006). During the experiment, the application of flame confirmed the possibility of its use as a method for weed control, which was also documented by numerous researchers (Taylor et al., 2012; Zhang et al., 2012; Rajković, 2018).

The limiting factor of flame application is the high sensitivity of sugar beet plants, especially after application without a shield. On the other hand, none of the tested non-herbicidal agents have shown a safety level acceptable for use in sugar beet crops. Analyzing the content of chlorophyll, especially of total chlorophyll, showed that there is a decrease in the content in the treated plants compared to the control. On the other hand, the analysis of sugar beet yield and digestion in treatments where non-herbicidal agent was applied (field conditions) showed that there were no statistically significant differences compared to the control.

Although a certain level of weed control was achieved, non-herbicidal treatments remain less effective than conventional herbicide applications (Hoffman and Regnier, 2006). Also, as a function of time, one herbicide treatment has a longer effect compared to several applications of e.g. acetic acid (20 and 30% acetic acid solution, applied 3 to 5 times) (Domenghini, 2020).

Nowadays, in line with the "*Green Agenda for the Western Balkans*" strategy, which aims to address climate-change challenges and support the green transition, it is necessary to intensify the use of alternative weed-control measures in order to meet the requirement of zero pesticide residues in food. Long-term pesticide use has led to environmental pollution, food residues, resistance development, and other challenges (Melander and McCollough, 2021), highlighting the need for alternative weed-control strategies.

CONCLUSION

The obtained results indicate that any method of weed control in sugar beet crops is acceptable, especially when aiming to reduce the use of herbicides. Application of flame (with shields) proved to be the safest alternative weed control measure. The application of alcohol, hot water and vinegar, as non-herbicidal agents, did not affect the growth and development of weed plants in the open field vs. laboratory conditions. Based on the measurement of chlorophyll content, the tested weed species showed sensitivity to vinegar, alcohol and hot water. The species Chenopodium album showed greater sensitivity to the application of flame. The highest sensitivity was shown in the treatment with vinegar and 100% alcohol.

Application of non-chemical weed control measures can increase sugar beet yield and reduce herbicide use by up to 50% because even 1 weed individual/m2 can reduce sugar beet root yields by up to 11% (Longden, 1989).

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