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ORIGINAL ARTICLE

Impact of chemical weed management in sugar beet (*Beta vulgaris*) on productivity, quality and economics

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Abstract

Weeds in sugar beet (*Beta vulgaris* L.) can contribute to a significant reduction in the root yield. The species composition of these plants is an important factor influencing the competition with crops. The aim of the 2-year field experiment with mixtures of: phenmedipham + ethofumesate + metamitron + quinmerac; ethofumesate + metamitron + metamitron + + quinmerac + triflusulfuron-methyl; phenmedipham + ethofumesate + metamitron + + quinmerac + triflusulfuron-methyl + clopyralid + lenacil, and phenmedipham + ethofumesate + metamitron + quinmerac + triflusulfuron-methyl + clopyralid applied in split doses, microdoses and Conviso Smart technology was to determine the weed species community composition and effectiveness of weed control strategies. The most common species occurring in both years were: *Chenopodium album* L., *Fallopia convolvulus* L., and *Geranium pusillum* L. The communities had the highest values of biodiversity indices in 2020 and lower values in 2021. There were no statistically significant differences in the herbicidal effectiveness of the tested herbicidal technologies over both years of research and for individual main weed species – 95–99%. The use of all herbicide variants contributed to achieving significantly higher yields than untreated treatments, and contributed to an increase in profitability of cultivation, but this result depended on the selected strategy. The presented herbicide solutions were characterized by direct income at a similar level.

Keywords: Conviso Smart, herbicides, microdoses, split doses, weeds, yield

Introduction

Sugar beets are plants grown in wide inter-rows and are characterized by slow initial growth. For this reason, they are very susceptible to competition from weeds (Kunz *et al.* 2015). It is worth remembering how important these crops are. In addition to sugar production, they can be used as animal feed and for energy purposes. They are also a valuable element of crop rotations (WIR 2023). The area of sugar beet sown in the European Union in recent years exceeds 1.4 million hectares (Polet 2021). In the world, this value currently amounts to about 4.3 million hectares (FAO 2023). Weeds in sugar beet cultivation can contribute to a significant decrease in yield, both in terms of the quantity and quality of roots (Abou-Zied *et al.* 2017). In addition, they make it difficult to harvest and then process the harvested roots. Improperly conducted control against them contributes to the enrichment of the soil seed bank, which has its consequences in subsequent crops (Cioni and Maines 2010). An important element in the protection of plantations is the correct identification of weeds (Rizk *et al.* 2023). Their species composition depends on many factors, including, among others, the species and varieties of cultivated plants, soil texture, electrical conductivity, soil pH, minerals, the succession of plants, and the sowing date and standard (Gawęda *et al.* 2016; Pätzold *et al.* 2020).

One method of weed control in sugar beet cultivation is the use of plant protection products in split doses. Herbicides can be applied in reduced doses, with an adjuvant added to the composition of the spray solution (Wujek *et al.* 2012). This strategy usually involves three herbicide treatments (Kucharski 2009). Another method of application of herbicides in sugar beet cultivation is their use at micro-rates. In this case, herbicides are applied in even smaller amounts, and an adjuvant must also be added to the composition of the spray solution. Treatments are performed four or five times (Krawczyk *et al.* 2009). In both cases, the developmental phase of weeds is very important. With time, the wax layer covering the plants becomes thicker, which makes it difficult for the applied herbicides to work (Krähmer *et al.* 2021; Placido *et al.* 2022).

Conviso Smart technology has become a new strategy in weed control in sugar beet cultivation. Using traditional breeding methods, plants resistant to ALS (acetolactate synthase) inhibitors were selected. On sugar beet plantations with the aforementioned trait, an herbicide containing foramsulfuron and thiencarbazone methyl can be used (Löbmann *et al.* 2019). In this case, the moment of performing the treatment should be determined by the developmental phase of common lambsquarter. During the treatment, this weed should have a maximum of four leaves (Götze *et al.* 2018).

The aim of this study was to determine the species composition of weeds in the study area along with selected community parameters, the effectiveness of selected herbicidal strategies in sugar beet cultivation and the profitability of each of them.

Materials and Methods

Field trials were conducted in 2020 and 2021 at the Poznan University of Life Sciences Research and Education Center (REC) in Brody (52°43'N, 16°30'), Poland, in Luvisols soil. Sugar beet varieties are shown in Table 1. Sugar beet seeds were sown at the beginning of April and May, 4 cm deep using a mechanical precision seeder, and harvested in September each year. Fifty kg $P_2O_5 \cdot ha^{-1}$ and 75 kg $K_2O \cdot ha^{-1}$ (Agrafoska PK 20-30) were applied prior to plowing in the fall. In spring, nitrogen was applied in two doses – before sowing the plants – 90 kg $N \cdot ha^{-1}$ (ammonium nitrate) and when sugar beet plants covered about 90% of the ground (BBCH 39) – 70 kg $N \cdot ha^{-1}$ (urea). The field study was performed in a randomized complete block design, with four replications. The plots, 2.0 m wide and 10.0 m long (20 m^2), were cultivated conventionally. Each plot consisted of four rows of sugar beets with a spacing of 45 cm.

The herbicides applied in the experiment were CO, P, G, T, S, M, V (Table 2). Herbicides were applied after each new weed emergence (at 2 leaf stage of weeds for 2, 4, 5 and at cotyledons stage of weeds for 6, 7). Spray liquid was applied with a CO_2-pressurized sprayer equipped with Tee Jet XR 110015-VS nozzles calibrated to deliver 230 $l \cdot ha^{-1}$ at 0.22 MPa.

Air temperature during herbicide application in 2020 varied from 11.2 to 18.8°C, relative humidity was usually greater than 45%, and in 2021 these values were 15.8–25.1°C, and 46%, respectively. The vegetation season of the first year of the field study was chillier (16.2 compared to 17.2°C) but wetter than the second one (Table 3). The relative precipitation index RPI is defined as the ratio of total precipitation in a given period to the average multi-year total. The thermal classification of the growing season was developed using the method of Lorenc (Lorenc and Suwalska-Bogucka 1996).

The weed population in untreated control plots was noted by recording the number of plants per square meter in early July each year. The data was used to assess the biodiversity of weed communities in sugar beet by means of the Margalef diversity index (DMg), the Shannon index (H') and Simpson`s index of diversity (D) (Pawlonka *et al.* 2014; Iglesias-Rios and Mazzoni 2014). A comparative analysis of the weed community structure was carried out based on the Sorensen coefficient of similarity index (Ss) (Hammond and Pokorný 2020). To show the differences between years in weed community composition a relative frequency index was used. It indicates which species occur in

Table 1. Soil characteristics, sugar beet variety, planting and harvest dates, and seed rates for field studies carried out in Brody in 2020 and 2021

Year	Soil texture	Soil OM[1] [%]	Soil pH	Sugar beet variety	Planting date	Harvest date	Seed rate number $\cdot ha^{-1}$
2020	LS[2]	1.1	5.9	Panorama, Smart Gladiata	April 7th	September 14th	120,000
2021	LS	1.1	5.8	Panorama, Smart Gladiata	May 6th	September 20th	120,000

[1]organic matter; [2]loamy sand

Table 2. Herbicides applied in the experiment in Research and Education Center in Brody

No.	Abbreviation	Trade name	Rate per ha	Active ingredients, [g · l⁻¹]	Ai [ha]	No. of treatments
1.	Untreated 1	Untreated check (Conviso S. variety)	–	–	–	–
2.	CO	Conviso One	0.5 l	foramsulfuron + thiencarbazone-methyl, 50 + 30	25 + 15	2
3.	Untreated 2	Untreated check (standard variety)	–	–	–	–
4.	P + G	Powertwin 400 SC Goltix Titan 565 SC	l 1.5 l	phenmedipham + ethofumesate, 200 + 200 metamitron + quinmerac, 525 + 40	200 + 200 788 + 60	3
5.	T + G + S	Torero 500 SC Goltix Titan 565 SC Safari 50 WG	1.3 l 0.5 l 10 g	ethofumesate + metamitron, 150+350 metamitron + quinmerac, 525 + 40 triflusulfuron–methyl, 500	195 + 455 262.5 + 20 5	3
6.	P + G + S + M + V	Powertwin 400 SC Goltix Titan 565 SC Safari 50 WG Major 300 SL Venzar 80 WP	0.15 l 0.333 l 10 g 0.1 l 0.2 kg	phenmedipham + ethofumesate, 200 + 200 metamitron + quinmerac, 525 + 40 triflusulfuron-methyl, 500 clopyralid, 300 lenacil, 800	30 + 30 175 + 13 5 30 160	4
7.	P + G + S + M	Powertwin 400 SC Goltix Titan 565 SC Safari 50 WG Major 300 SL	0.3 l 0.5 l 10 g 0.1 l	phenmedipham + ethofumesate, 200 + 200 metamitron + quinmerac, 525 + 40 triflusulfuron-methyl, 500 clopyralid, 300	60 + 60 262.5 + 20 5 30	4

CO – foramsulfuron + thiencarbazone-methyl; P – phenmedipham + ethofumesate; G – metamitron + quinmerac; T – ethofumesate + metam-itron; S – triflusulfuron-methyl; M – clopyralid; V – lenacil; P + G; T + G + S; P + G + S + M + V; P + G + S + M applied with adjuvant (surfactant) insert at 0.1% v/v

Table 3. Meteorological data at the Research and Education Center in Brody during herbicide application

Year	Treatment date[1]	Treated treatment[2]	Temperature [°C]	Relative humidity [%]	Wind [m · s⁻¹]	Precipitation (WAT) [mm]	Vegetation season	
							precipitation (*RPI*) [mm]	average temperature [°C]
2020	April 27th	6, 7	18.8	30	3.0	6.3	284.1 (N[3])	16.2 (W[4])
	April 30th	2	11.3	77	2.6	14.6		
	May 4th	4, 5	11.2	78	0.9	9.5		
	May 8th	6, 7	15.4	54	2.9	12.6		
	May 15th	4, 5	11.4	34	1.8	0.0		
	May 26th	2, 4, 5, 6, 7	14.7	81	2.9	3.0		
	June 1st	6, 7	17.9	45	2.9	11.8		
2021	May 25th	2, 4, 5, 6, 7	15.8	57	2.7	16.9	204.7 (D[3])	17.2 (AW[4])
	June 7th	4, 5, 6, 7	25.1	46	1.0	13.4		
	June 16th	4, 5, 6, 7	22.9	50	1.1	0.9		
	June 25th	6, 7	20.2	69	1.4	14.0		

WAT – first week after treatment
[1]herbicides applied each time after new weed emergence (at 2 leaf stage of weeds for 2, 4, 5 and at cotyledon stage of weeds for 6, 7); [2]markings according to the numbers in Table 2 (column 1); [3]N – normal, D – dry; [4]W – warm, AW – anomalously warm

comparison to all sampling plots and the presence or absence of a species. Relative frequency (RF) was calculated based on formula:

$$\mathrm{RF} = \frac{\text{number of target species}}{\text{number of all species}} \times 100.$$

Weed control was assessed about 6 weeks after the last herbicide application by estimating the reduction in weed fresh mass from herbicide treatment compared to the untreated control, based on the Henderson-Tilton formula [Reduction % = (1 – n in Co before treatment × n in T after treatment/ n in Co after treatment × n in T before treatment) × 100, where: n – weed population, T – treated, Co – control] (Bailey *et al*. 2013). Visual evaluation of the efficacy of herbicides was performed 21 days after the application of all herbicides. Efficacy was expressed according to a scale (0–100% of weed control compared to the untreated check). Sugar beet root yield was determined by harvesting two central rows from each plot and expressed in $T \cdot ha^{-1}$. Sucrose, alpha-amino-nitrogen, sodium and potassium content were determined in the laboratory of Nordzucker Poland Ltd. in Opalenica, Poland (ICUMSA 2022). In order to supplement the results obtained, the following root quality parameters were calculated according to the formula:

$$CL (\%) = 0.12 \times (K + Na) + 0.14 \times (N\text{-}\alpha\text{-amin}) + 1.08;$$
$$TSO (\%) = CS - CL;$$
$$YTSC (t \cdot ha^{-1}) = YRY \times (Pol - CL) \times 100^{-1},$$

where: CL – loss of sugar productivity, TSO – technological sugar output (%), CS – sucrose content in roots (%), YTSC – technological sugar yield, YRY – root yield ($t \cdot ha^{-1}$) (Artyszak *et al*. 2014; Jakubowska *et al*. 2020).

Results were analyzed with Statistica 13 software (StatSoft Ltd., Kraków, Poland). Analysis of variance (ANOVA) to determine significant differences between treatments was used. Means were separated by protected Tukey`s HSD test at $p = 0.05$. The untreated check was not included in the weed control analysis. Interactions year by year were not significant, so 2020 and 2021 data are presented separately.

Results

The most common species occurring in both years (Table 4) were common lambsquarter (*Chenopodium album* L.), black bindweed (*Fallopia convolvulus* L.), and small-flowered crane`s-bill (*Geranium pusillum* L.). During the field study, the following occurred but with lower intensity or they were not found in both years: field pansy (*Viola arvensis* Murr.), common fumitory (*Fumaria officinalis* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medicus), purple dead-nettle (*Lamium amplexicaule* L.), cleavers (*Galium aparine* L.), and knotgrass (*Polygonum aviculare* L.).

The communities had the highest values of biodiversity indices in 2020 (H' = 0.74, DMg = 4.39, and

Table 4. Indicates of weed community biodiversity

Scientific name	RF [%] (individual species of weeds)		D_{Mg}		H'		D		Ss
			(total weed population)						
	2020	2021	2020	2021	2020	2021	2020	2021	2020–2021
Chenopodium album	52.7	83.1	4.39	4.05	0.74	0.45	0.72	0.48	0.52
Geranium pusillum	5.4	7.1							
Brassica napus	0.3	–							
Papaver ssp.	12.5	0.2							
Polygonum aviculare	4.1	0.7							
Fallopia convolvulus	15.9	5.9							
Galium aparine	4.7	–							
Viola arvensis	0.7	0.7							
Lamium amplexicaule	0.7	–							
Cirsium arvense	1.7	–							
Erodium cicutarium	1.3	–							
Veronica hederifolia	–	0.9							
Fumaria officinalis	–	0.2							
Capsella bursa-pastoris	–	0.7							
Setaria ssp.	–	0.2							
Lycopsis arvensis	–	0.3							

RF – relative frequency; DMg – Margalef diversity index; H' – Shannon index; D – Simpson`s index of diversity; Ss – Sorensen coefficient of similarity index

D = 0.72) and lower values in 2021 (H' = 0.45, DMg = 4.05, and D = 0.48). Weed community composition was not identical in the years of the study and the proportion of a given species varied in both years, and the Ss indicated a moderate similarity between communities in both years. Relative frequency (RF), which most often occurred in species like *Ch. album,* varied from 52.7 to 83.1% in 2020 and 2021 *G. pusillum* 5.4–7.1%, *F. convolvulus* 15.9–5.9% (Table 4).

During both years of the study significant differences in the herbicide effectiveness of the herbicide treatments tested were not observed. Also, there were no significant differences between individual major weed species – 95–99% (Table 5). However, the results showed a lower POLCO control in 2020, when a 3-fold mixture of P + G + I was applied with the adjuvant (Table 5). In contrast, the 2 years of the study, 2020 and 2021, showed lower POLCO control efficacy after a 4-fold active ingredient (a.i.) mixture of T + G + + S + I (89%). The Conviso One system, which was based on two active substances (foramsulfuron + + thiencarbazone-methyl) and was applied twice in both years of the study, greatly controlled the dominant weed species in the experimental field community.

Sugar beet root yield, biological sugar yield, and technological sugar yield were not significantly different. Only in 2020 did the variation in root sugar content affect significant variation in converting the biological and technological yield of sugar per unit urea with the treatments T + G + S + I and P + G + S + + M + I (Table 6).

Figure 1 shows what amount of a.i. were applied per hectare of land considering the multiplicity of individual applications of herbicide treatments (from two to four times). The total amount of a.i. varied between 80 and 3744 g a.i. · ha^{-1}. It is noteworthy that in the micro-rates system (P + G + S + M + V + I; P + G + S + +M + I), due to a significant reduction in herbicide rates, even despite their 4-fold application, the total amount of a.i. reaching the environment (1772 and 1762 g a.i. · ha^{-1}) was much lower than with the other treatments (from 2813 to 3744 g a.i. · ha^{-1}). In terms of a.i. usage, by far the most favorable solution was the application of herbicides in the CO system (80 g a.i. · ha^{-1}).

With such a significant use of active substances per unit area, price calculations including the costs of weed control with the presented herbicides showed a direct income, calculated on the basis of the purchase price of sugar beet roots and the costs of herbicide protection, at a similar level (103.4–106.7% as the value of the reference combination 4 – 100%, Table 7). The lowest values in both years were obtained from untreated checks (net return 5.7–9.1). The value of root yield enhancement varied between years, especially in untreated checks and T + G + S + I treatment, less so than the other ones.

Table 5. Efficacy of herbicide mixtures applied in sugar beets in Research and Education Center Brody in Brody in the years 2020 and 2021

No.	Treatment	Weed species			
		CHEAL	POLCO	GERPU	Total*
		Efficacy [%]			
		2020			
2.	CO	99 a	100 a	98 a	98 a
4.	P + G + I	100 a	88 a	100 a	96 a
5.	T + G + S + I	99 a	89 a	98 a	97 a
6.	P + G + S + M + V + I	95 a	97 a	100 a	95 a
7.	P + G + S + M + I	99 a	100 a	100 a	98 a
		2021			
2.	CO	99 a	100 a	99 a	98 a
4.	P + G + I	100 a	100 a	100 a	99 a
5.	T + G + S + I	100 a	89 a	100 a	97 a
6.	P + G + S + M + V + I	98 a	98 a	100 a	96 a
7.	P + G + S + M + I	98 a	97 a	99 a	97 a

CO – foramsulfuron + thiencarbazone-methyl; P – phenmedipham + ethofumesate; G – metamitron + quinmerac; T – ethofumesate + metamitron; S – triflusulfuron-methyl; M – clopyralid; V – lenacil; I – surfactant; CHEAL – *Chenopodium album*; POLCO – *Fallopia convolvulus*; GERPU – *Geranium pusillum*. Means followed by the same letter do not significantly differ ($p = 0.05$, Tukey's HSD).

Herbicides applied each time after new weed emergence (at 2 leaf stage of weeds for 2, 4, 5 and at cotyledon stage of weeds for 6, 7); markings according to the numbers in Table 2 (column 1)

*includes all weed species found during study

Table 6. Impact of herbicide on sugar beet roots and sugar yield

No.	Treatment	Weed species			
		roots yield	content of sucrose	biological sugar yield	technological sugar yield
		[t · ha⁻¹]	[%]	[t · ha⁻¹]	[t · ha⁻¹]
		2020			
1.	Untreated 1	1.8 b	17.7 abc	0.3 c	0.2 c
2.	CO	68.8 a	17.6 abc	12.1 ab	11.4 ab
3.	Untreated 2	3.1 b	18.0 ab	0.6 c	0.5 c
4.	P + G + I	71.7 a	17.1 c	12.2 ab	11.5 ab
5.	T + G + S + I	69.6 a	17.1 c	11.9 b	10.9 b
6.	P + G + S + M + V + I	75.4 a	17.4 bc	13.1 ab	12.1 ab
7.	P + G + S + M + I	76.9 a	18.4 a	14.1 a	13.3 a
					2021
1.	Untreated 2	5.2 b	17.1 d	0.89 b	0.83 b
2.	CO	65.9 a	18.2 ab	12.0 a	11.3 a
3.	Untreated 2	8.1 b	18.5 a	1.5 b	1.4 b
4.	P + G + I	68.0 a	17.9 bc	12.2 a	11.5 a
5.	T + G + S + I	74.8 a	17.4 cd	13.0 a	12.0 a
6.	P + G + S + M + V + I	67.5 a	17.2 d	11.6 a	10.9 a
7.	P + G + S + M + I	68.6 a	17.5 cd	12.0 a	11.3 a

CO – foramsulfuron + thiencarbazone-methyl; P – phenmedipham + ethofumesate; G – metamitron + quinmerac; T – ethofumesate + metamitron; S – triflusulfuron-methyl; M – clopyralid; V – lenacil; I – surfactant. Herbicides applied each time after new weed emergence (at 2 leaf stage of weeds for 2, 4, 5 and at cotyledon stage of weeds for 6, 7); markings according to the numbers in table 2 (column 1).
Means followed by the same letter do not significantly differ ($p = 0.05$, Tukey's HSD)

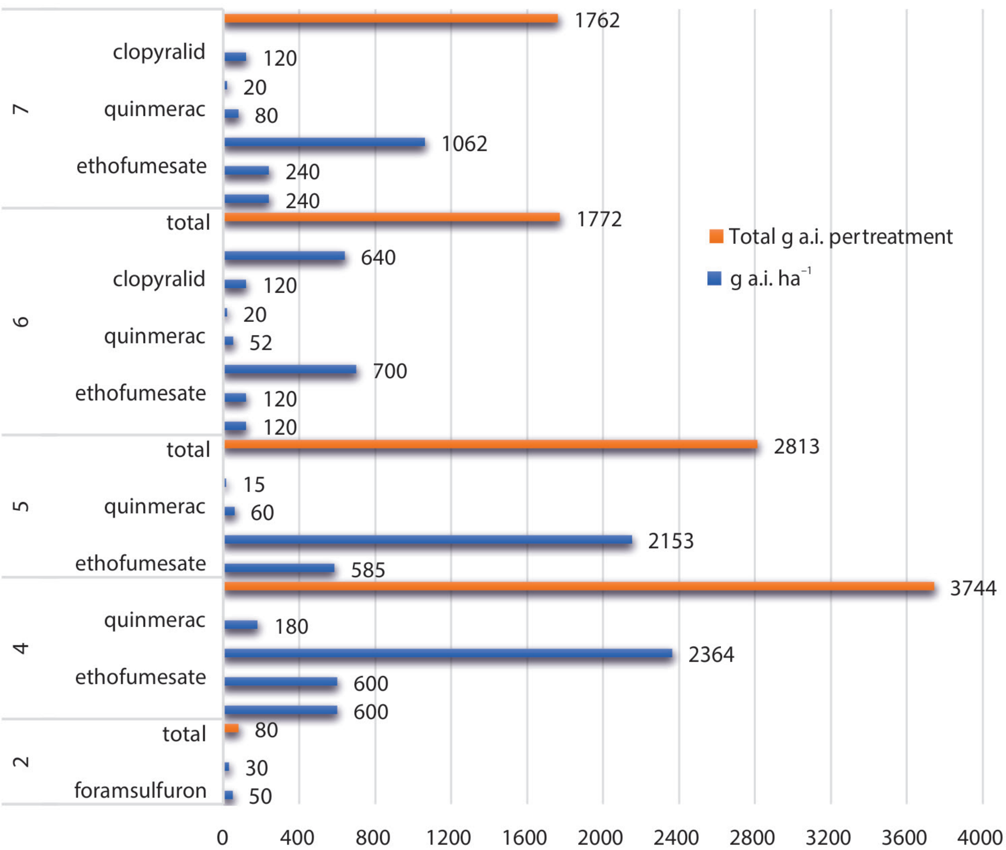

Fig. 1. Impact of weed control strategy on usage of active ingredients of herbicides (the amount of a.i. after all applications); orange – total g a.i. per treatment, blue – g a.i. · ha⁻¹; markings according to the numbers in Table 2 (column 1).

Table 7. Effect of herbicides on weed management indicates in sugar beets, Research and Education Center Brody in Brody (2020–2021)

No.	Treatment	Value of root yield enhancement index** (€ · ha^{-1})		Cost of weed control index** (€ · ha^{-1})	Net return index*		
		2020	2021	2020–2021	2020	2021	average
1.	Untreated 1	2.5 (50.4)	7.6 (166.7)	0 (0)	2.8 (50.4)	8.6 (166.7)	5.7 (108.4)
2.	CO	95.9 (1924.4)	96.9 (2112.1)	40.1 (92.4)	103.1 (1832.0)	103.6 (2019.7)	103.4 (1925.9)
3.	Untreated 2	4.3 (86.8)	12.9 (259.6)	0 (0)	4.9 (86.8)	13.3 (259.6)	9.1 (173.2)
4.	**P + G + I**	**100 (2007.6)**	**100 (2179.4)**	**100 (230.6)**	**100 (1777.0)**	**100 (1948.8)**	**100 (1862.9)**
5.	T + G + S + I	97.1 (1948.8)	110.0 (2397.3)	85.4 (196.9)	98.6 (1751.9)	112.9 (2200.4)	105.8 (1976.2)
6.	P + G + S + M + V + I	105.2 (2111.2)	99.3 (2163.4)	90.8 (209.4)	107.0 (1901.8)	100.3 (1954.0)	103.7 (1927.9)
7.	P + G + S + M + I	107.3 (2153.2)	100.9 (2198.6)	82.7 (190.6)	110.4 (1962.6)	103.0 (2008.0)	106.7 (1985.3)

CO – foramsulfuron + thiencarbazone-methyl; P – phenmedipham + ethofumesate; G – metamitron + quinmerac; T – ethofumesate +metamitron; S – triflusulfuron-methyl; M – clopyralid; V – lenacil; I – surfactant. Herbicides applied each time after new weed emergence (at 2 leaf stage of weeds for 2, 4, 5 and at cotyledon stage of weeds for 6, 7); markings according to the numbers in Table 2

*calculations were done based on average prices of sugar beet roots, herbicides, and cost of their application

**other treatments in relation to P + G + I (as a standard)

Means followed by same letter do not significantly differ ($p = 0.05$, Tukey's HSD)

Discussion

The vegetation of sugar beet and its accompanying weeds took place under varying weather conditions. Based on precipitation totals from April to September, 2020 was classified as normal and 2021 as dry. In terms of thermal conditions, the examined periods in the years were classified as warm and anomalously warm, respectively. Weather conditions during and after pesticide application have the most significant impact on foliar herbicide efficacy (Robinson and Gross 2010). However, effectiveness of herbicides is also strongly modified by biological properties of the target weeds. Weather conditions in both years rather favored the herbicide efficacy, especially the temperature in 2021.

An analysis of variability in weed communities in our own study, carried out using ecological indicators, indicated differences between the years in the studied plant community. The results obtained indicated that in terms of species richness the weed communities were similar in both years, with *C. album* dominating and the influence of the other species varying. The values of the indicators used to describe the communities indicated greater biodiversity in the first year of the study and moderate similarity between the communities in both years. The composition of weed communities is the main factor determining weed control strategies and the choice of active substances appropriate to the weed infestation (Kraehmer *et al.* 2014).

The use of split doses of herbicides allows for effective weed control and reduces their amount in the soil (Kaya 2012). An even greater reduction in the amount of chemicals is possible thanks to the application of herbicides in the micro-dosing system. However, it is important to apply herbicides at the right time. As the weeds grow, the ratio of the dose of the applied preparations to the surface of the sprayed plants also decreases (Sarabi *et al.* 2011). Therefore, weeds controlled with a micro-dose system should be in the cotyledon stage. Plants, as they develop, are covered with an increasingly thick layer of wax which hinders the penetration of herbicides into the cells of sprayed plants. Ivaschenko and Ivaschenko (2019) showed this relationship for *C. album*. This species was dominant during the study. The level of its control largely determined the general degree of weed infestation.

In this experiment, the application of an herbicide based on ALS enzyme inhibitors contributed to a high level of weed control with the lowest amounts of active substances released into the environment. However, it should be remembered that ALS enzyme inhibitors are a group of substances for which a major problem of weed resistance is observed. When deciding to include these substances in the protection strategy of another plant, herbicides with different mechanisms of action should be selected for other crops. The rotation of herbicides with different mechanisms of action is one of the basic principles of the anti-resistance strategy (Kumar *et al*. 2018).

Conclusions

Weed species composition recorded during this research was characteristic of sugar beets. All herbicidal strategies used in the experiment gave satisfactory results. To date, the most commonly used strategy is split doses. The presented alternatives will allow farmers to compare this method to others that are gaining popularity. Regardless of some differences between years, slightly better activity of Conviso Smart treatments was observed, while at the same time low consumption of active substances, which ultimately can contribute to better environmental protection. The use of appropriately selected herbicides in a micro-rates system (significantly reduced rates of agents with the addition of adjuvant) also helps to reduce the number of chemicals used, and thus the number of substances reaching the environment.

Abbreviations

DMg – Margalef diversity index
H' – the Shannon index
D – Simpson`s index of diversity
Ss – Sorensen coefficient of similarity index
RF – Relative frequency
OM – organic matter
LS – loamy sand
CO – foramsulfuron + thiencarbazone-methyl
P – phenmedipham + ethofumesate
G – metamitron + quinmerac
T – ethofumesate + metamitron
S – triflusulfuron-methyl
M – clopyralid
V – lenacil
I – surfactant
N – normal
D – dry
W – warm
AW – anomalously warm
CL – loss of sugar productivity
TSO – technological sugar output (%)
CS – sucrose content in roots (%)
YTSC – technological sugar yield
YRY – root yield ($t \cdot ha^{-1}$)

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