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DIVERSITY OF SEGETAL FLORA IN ORGANIC SORGHUM (*Sorghum* Moench) CULTIVATION

Summary

The main advantage of sorghum cultivation consists in its resistance to difficult thermal and moisture conditions during vegetation, especially in summer. Sorghum is planted in wide rows, and is characterized by a slow initial growth, which makes it subjected to segetal weed competition in the early stages of its development, especially under organic management system. The aim of the study was to evaluate the diversity of species of segetal flora and the effectiveness of the selected methods of mechanical weed control in organic cultivation of sorghum, under different doses of organic fertilization. A field experiment was conducted in the years 2011-2013, by crossed subblock method, in four replications. Two doses of organic fertilizer were used (20 and 40 t·ha^{-1}) and 3 methods of mechanical crop treatment: A–control treatment (without weed control), B–with a 3-time use of a brush weeder during the season, C–with a 3-times use of a weeding hoe during the season, D–with a 2-time use of a brush weeder during the season and 1-time a hiller. The study shows that the greatest abundance and species richness of segetal flora characterized sorghum crops without applying any treatments whereas the mechanical treatment of intercrops contributed to a significant reduction in weight and number of weeds. The most effective method involved the use of a brush weeder and a hiller, which limited weed infestation on average by 75%. The efficiency of a weeding hoe and a brush weeder used alone was lower and amounted to, respectively, 58 and 51%. In all of the years of the studies, the most aggressive weed species were: Echinochloa crus-galli and Chenopodium album. The dose of organic fertilizer did not significantly affect the number and species composition of segetal flora.
***Key words**: sorghum, weeds, species, mechanical crop treatment, organic agriculture*

RÓŻNORODNOŚĆ FLORY SEGETALNEJ W EKOLOGICZNEJ UPRAWIE SORGO (*Sorghum* Moench)

Streszczenie

Główną zaletą uprawy sorgo jest jego odporność na trudne warunki termiczne i wilgotnościowe w okresie wegetacji, zwłaszcza latem. Sorgo uprawiane jest w szerokich rzędach i charakteryzuje się wolnym początkowym wzrostem, co sprawia, że konkurencja chwastów segetalnych w początkowych fazach rozwojowych jest duża, zwłaszcza w ekologicznym systemie gospodarowania. Celem przeprowadzonych badań była ocena różnorodności gatunkowej flory segetalnej oraz skuteczności wybranych metod mechanicznej regulacji zachwaszczenia w ekologicznej uprawie sorgo przy różnych dawkach nawożenia organicznego. Doświadczenie polowe przeprowadzono w latach 2011-2013, metodą skrzyżowanych podbloków, w czterech powtórzeniach. Zastosowano dwie dawki nawozu organicznego (20 i 40 t·ha^{-1}) oraz 3 sposoby mechanicznej pielęgnacji łanu: A – obiekt kontrolny (bez zwalczania chwastów), B – pielnik szczotkowy 3-krotnie w sezonie, C – opielacz 3-krotnie w sezonie, D – pielnik szczotkowy 2-krotnie oraz jeden raz obsypnik. W badaniach wykazano, że największą liczebnością oraz bogactwem gatunkowym flory segetalnej charakteryzował się łan sorga, w którym nie stosowano żadnych zabiegów pielęgnacyjnych, a mechaniczna pielęgnacja międzyrzędzi przyczyniła się do znacznej redukcji masy i liczby chwastów. Najskuteczniejszą metodą było zastosowanie pielnika szczotkowego i obsypnika, które ograniczały zachwaszczenie średnio o 75%. Skuteczność opielacza i pielnika były mniejsze i wynosiły odpowiednio 58 i 51%. W wszystkich latach prowadzenia doświadczeń najbardziej uciążliwymi gatunkami chwastów były: Echinochloa crus-galli i Chenopodium album. Wysokość dawki nawożenia organicznego nie wpłynęła znacząco na zróżnicowanie liczebności i składu gatunkowego flory segetalnej.
***Słowa kluczowe**: sorgo, chwasty, gatunki, mechaniczna pielęgnacja, gospodarstwo ekologiczne*

1. Introduction

Sorghum is a plant of a large yield-forming potential and high resistance to drought (Corredor et al. 2006, Camargo and Hubbard 1999, Krieg and Lascano 1990). It is due to an extensive root system and high efficiency of water uptake from the soil (Messke and Basson 1995, Singh and Singh 1995). Moreover, the efficient water management of this species results from a low leaf transpiration index, as the leaves are covered with a wax layer to protect them against excessive water evaporation. Sorghum, as a species of photosynthesis type C_4, is characterized by high efficiency of using solar energy and heat, which at current projected climate models, puts it among species of interest as an alternative to maize on weak soils. Sorghum silage is good animal feed due to its high content of sugars soluble in water (Berenji and Dahlberg 2004). The attempts to cultivate sorghum in Poland were undertaken many years ago, but it was taken into account mostly as the second crop to winter rye (Mucha and Brzóska 1983, Krzywiecki and

Szyszkowska 1978, Hryncewicz and Fatyga 1975). Currently, there is a renewed interest in this species not only as a fodder crop (Ceotto et al. 2014, Kozłowski et al. 2006), but also as an energy plant (Monteiro et al. 2012, Kołodziej et al. 2015). A drawback of growing sorghum for feed in Poland may be that most of the currently available cultivars do not reach maturity under the existing climate conditions, so this species can be used mainly for silage.

Sowiński and Szydełko-Rabska (2013) have shown that under the conditions of the South-Western Poland, a very early cultivar of sorghum 251, reached full grain maturity, whereas grain quality depended on weather conditions, especially temperature during seedling emergence and plant maturing. We can therefore expect, that a greater interest in the cultivation of this species in the conditions of central Europe mobilize breeders to biological development and creation of new varieties adapted to growing in our climatic conditions.

Similarly to maize, sorghum is planted in wide rows, and is characterized by a slow initial growth, which makes it subjected to segetal weed competition in the early stages of its development, especially under organic management system. According to Rola and Rola (1987), the losses of maize yields due to weed infestation may reach 70%, while under massive occurrence of weeds, even more. Studies carried out by Staniak et al. (2012) have shown that mechanical treatment of sorghum significantly reduced the number and weight of weeds. The effectiveness of using a brush hoe or a hoe ranged from 60% to as much as 89%. According to Skrzypczak et al. (2008), however, mechanical treatment of inter-rows of sorghum crops was effective only at the level of 72% in relation to the number of weeds and 57% in relation to their weight. Species that compete the most with the cultivated plants were: *Echinochloa crus-galli* and *Chenopodium album*. The aim of the study was to evaluate the diversity of species of segetal flora and the effectiveness of the selected methods of mechanical weed control in organic cultivation of sorghum, under different doses of organic fertilization.

2. Material and methods

A field experiment was conducted in the years 2011-2013, at the Agricultural Experimental Center in Grabów (the Mazowieckie voivodeship) belonging to IUNG-PIB by crossed subblock method, in four replications. Two doses of organic fertilizer were used: 20 and 40 t·ha-1 (composted manure) and 3 methods of mechanical crop treatment: A – control treatment (without weed control), B – with a 3-time use of a brush weeder during the season (at the stage of 1-2 leaves, 4-6 leaves, at the plant height of 25-30 cm), C – with a 3-time use of a weeding hoe during the season (at the stage of 1-2 leaves, 4-6 leaves, at the plant height of 25-30 cm), D – with a 2-time use of a brush weeder during the season (at the stages of 1-2 and 4-6 leaves) and a hiller (at the plant height of 25-30 cm). The experiment was set up on lessive soil formed on light loam, very good rye complex of class IIIa. The concentration of available forms of nutrients in the soil amounted to (in mg per 100 g of the soil): P – 11.5, K – 12.6, Mg – 4.1. Soil pH determined in 1n KCl was 6.0. The sowing of sorghum was performed on: 18 May 2011, 18 May 2012 and 14 June 2013, while the harvest dates were: 24 October 2011, 12 October 2012 and 7 October 2013.

The analysis of segetal flora in sorghum crops was performed twice in the growing season: term 1 - a week after the last mechanical treatment, term 2 - before harvesting. The studies included the assessment of species composition, abundance of individual species, and the determination of fresh and air-dry matter of weeds. They were performed on the area of 1 m^2 by frame method, in 4 replications. The significance of the impact of the tested factors on weed weight was evaluated using variance analysis, with confidence half-intervals set by Tukey's test at the significance level of $\alpha = 0.05$.

3. Results

Weather conditions have a large impact on the yields of sorghum and its accompanying flora. In 2011, the total rainfall during the growing season of plants was higher than the average from the long-term period, whereas rainfall distribution was uneven. Very high rainfall was recorded in July (3.5-fold higher than the average from the long-term period), while shortages occurred in June (73% of the norm) and August (47%). The second year of the studies (2012) was also unfavorable in terms of quantity and distribution of rainfall. Significant moisture deficits were recorded in May (64% of the norm) and June (75%). They were accompanied by high air temperatures which adversely affected crop yields. In 2013, there were favorable weather conditions with heavy rainfalls in the spring, whereas summer saw long rainless periods, which limited the growth and development of plants (July – 25%, August – 15% of the norm).

Table 1**.** Course of weather conditions during the vegetation periods
Tabela 1. Przebieg warunków pogodowych podczas sezonów wegetacyjnych

Specification	Year	Month							Sum (III-VIII)
		III	IV	V	VI	VII	VIII	IX	
Rainfalls (mm)	2011	17.6	35.9	74.5	52.4	298.8	35.6	3.6	518.4
	2012	20.9	37.8	36.5	54.3	81.6	64.2	64.2	359.5
	2013	41.1	29.9	112.0	116.3	20.8	11.6	63.9	395.6
Rainfalls mean from multi-years (mm)*		**30.0**	**39.0**	**57.0**	**71.0**	**84.0**	**75.0**	**50.0**	**406.0** Average (III-VIII)
Temperature (°C)	2011	2.9	10.3	13.9	18.5	18.4	18.8	14.7	13.9
	2012	2.4	9.6	15.3	17.7	20.9	18.8	14.5	14.2
	2013	-2.1	8.3	15.3	18.6	19.7	19.2	11.8	13.0
Temperature mean from multi-years (°C)*		**1.6**	**7.7**	**13.4**	**16.7**	**18.3**	**17.3**	**13.2**	**12.6**

* Average from years 1871-2000

Source: own work / *Źródło*: praca własna

The largest number and species diversity of segetal weeds occurred in the treatments where sorghum was not subjected to mechanical cultivation. In 2011, in the first term of the determinations, there were on average 44.8 plant items per 1 m^2, while in the second term – 33.8 plant items per 1 m^2, in 2012 – 34.0 i 50.7, while in 2013 – 53.8 and 40.0, respectively (Tables 2-7). In the mechanically cultivated treatments, the number of undesirable species was much lower, whereas the least weeds were found in the treatments using a brush weeder and a hiller. In 2011, it was on average 2.8 items per 1 m^2 in the first, and 11.8 in second term of the determinations, in 2012 – 6.0 and 10.0, while in 2013 – 5.0 and 15.2, respectively. The dose of organic fertilizers did not significantly affect the abundance and diversity of segetal weed species in sorghum crops.

Table 2. Weed species composition and number of weeds (plants·m^{-2}) depending on cultivation method and dose of fertilization in 2011 (one week after last cultivation treatment)

Tabela 2. Skład gatunkowy i liczebność chwastów (szt.·m^{-2}) w zależności od sposobu pielęgnacji i dawki nawozu w roku 2011 (tydzień po ostatnim zabiegu mechanicznym)

Weed species	A*	B	C	D	A	B	C	D	Average
	dose of manure 20 t·ha^{-1}				dose of manure 40 t·ha^{-1}				
Monocotyledonous									
Echinochloa crus-galli	26.0	11.0	4.5	1.5	37.0	12.0	6.5	3.5	**12.8**
Elymus repens	-	-	-	-	2.5	-	0.5	-	**0.4**
Sum of Monocotyledonous	**26.0**	**11.0**	**4.5**	**1.5**	**39.5**	**12.0**	**7.0**	**3.5**	**13.2**
Dicotyledonous									
Anthemie arvensis	-	-	-	-	0.5	-	-	-	**0.1**
Brassica napus	0.5	3.0	-	-	-	-	-	-	**0.4**
Capsella bursa-pastoris	-	-	-	-	1.5	1.0	-	-	**0.3**
Chenopodium album	4.0	1.0	-	-	9.5	1.5	0.5	-	**2.1**
Cirsium arvense	0.5	5.5	-	-	-	-	-	-	**0.8**
Erigeron canadensis	-	-	-	-	1.0	-	-	-	**0.1**
Geranium dissectum	1.5	-	-	-	1.0	-	-	-	**0.3**
Lapsena communis	-	-	-	-	-	0.5	-	-	**0.1**
Trifolium arvense	0.5	-	-	-	-	-	-	-	**0.1**
Tripleurospermum maritimum	0.5	-	-	-	-	-	-	-	**0.1**
Polygonum aviculare	0.5	-	-	-	0.5	-	-	-	**0.1**
Polygonum persicaria	-	-	-	-	-	-	-	0.5	**0.1**
Sum of Dicotyledonous	**8.0**	**9.5**	**0.0**	**0.0**	**14.0**	**3.0**	**0.5**	**0.5**	**4.6**
Eguisetum arvense	0.5	-	5.0	-	1.5	-	2.5	-	**2.4**
Total	**34.5**	**20.5**	**9.5**	**1.5**	**55.0**	**15.0**	**10.0**	**4.0**	**20.2**

A – control object, B – brush weeder, C – weeding hoe, D – brush weeder+hiller *Source*: own work / *Źródło*: praca własna

Table 3. Weed species composition and number of weeds (plants·m^{-2}) depending on cultivation method and dose of fertilization in 2011 (before harvest)

Tabela 3. Skład gatunkowy i liczebność chwastów (szt.·m^{-2}) w zależności od sposobu pielęgnacji i dawki nawozu w roku 2011 (przed zbiorem)

Weed species	A*	B	C	D	A	B	C	D	Average
	dose of manure 20 t·ha^{-1}				dose of manure 40 t·ha^{-1}				
Monocotyledonous									
Echinochloa crus-galli	24.0	5.5	2.5	2.0	21.5	5.5	4.0	0.5	**8.2**
Elymus repens	-	-	-	-	0.5	-	-	0.5	**0.1**
Poa annua	0.5	0.5	-	-	-	-	-	-	**0.1**
Setaria pumila	-	-	-	0.5	0.5	0.5	-	-	**0.2**
Sum of Monocotyledonous	**24.5**	**6.0**	**2.5**	**2.5**	**22.5**	**6.0**	**4.0**	**1.0**	**8.5**
Dicotyledonous									
Brassica napus	0.5	-	-	2.0	0.5	-	-	-	**0.4**
Capsella bursa-pastoris	-	-	-	-	-	1.0	0.5	1.0	**0.3**
Chenopodium album	4.5	0.5	-	1.0	6.0	2.0	0.5	0.5	**1.9**
Cirsium arvense	-	1.0	1.5	1.0	-	-	0.5	-	**0.5**
Filaginella uliginosa	-	-	-	0.5	-	-	-	-	**0.1**
Galinsoga parviflora	-	0.5	-	-	-	-	-	-	**0.1**
Geranium dissectum	0.5	0.5	0.5	1.0	0.5	-	-	-	**0.4**
Plantago major	0.5	-	-	-	2.0	-	-	-	**0.3**
Solanum nigrum	0.5	-	-	1.0	0.5	0.5	0.5	0.5	**0.4**
Sonchus asper	-	-	-	-	-	-	-	0.5	**0.1**
Stellaria media	-	2.0	-	1.5	-	0.5	0.5	0.5	**0.6**
Tripleurospermum maritimum	-	-	-	-	-	-	-	0.5	**0.1**
Veronica persica	-	-	-	-	-	-	-	0.5	**0.1**
Viola arvensis	-	-	-	0.5	0.5	-	-	-	**0.1**
Sum of Dicotyledonous	**7.0**	**5.0**	**2.0**	**8.5**	**10.0**	**4.0**	**2.5**	**4.0**	**5.4**
Eguisetum arvense	1.0	0.5	10.5	7.0	3.0	3.0	13.5	0.5	**4.9**
Total	**31.5**	**10.5**	**15.0**	**18.0**	**35.5**	**13.0**	**20.0**	**5.5**	**18.8**

* See tab. 2 *Source*: own work / *Źródło*: praca własna

Table 4. Weed species composition and number of weeds (plants·m^{-2}) depending on cultivation method and dose of fertilization in 2012 (one week after last cultivation treatment)
Tabela 4. Skład gatunkowy i liczebność chwastów (szt.·m^{-2}) w zależności od sposobu pielęgnacji i dawki nawozu w roku 2012 (tydzień po ostatnim zabiegu mechanicznym)

Weed species	A*	B	C	D	A	B	C	D	Average
	dose of manure 20 t·ha^{-1}				dose of manure 40 t·ha^{-1}				
Monocotyledonous									
Echinochloa crus-galli	5.8	1.5	0.8	1.0	5.5	0.8	1.0	1.3	**2.2**
Sum of Monocotyledonous	**5.8**	**1.5**	**0.8**	**1.0**	**5.5**	**0.8**	**1.0**	**1.3**	**2.2**
Dicotyledonous									
Amaranthus retroflexus	-	0.3	0.5	0.3	0.3	-	-	-	**0.2**
Anthemie arvensis	-	-	-	0.3	-	-	-	-	**0.0**
Capsella bursa-pastoris	0.8	-	0.8	0.5	-	-	1	-	**0.3**
Chenopodium album	27.3	8.5	12.5	4.0	21.5	2.8	10.5	3.0	**11.3**
Convolvulus arvensis	-	0.3	0.3	-	0.3	-	-	-	**0.1**
Galium aparine	-	-	-	-	-	-	0.3	0.3	**0.1**
Geranium dissectum	-	-	0.3	0.3	0.3	-	-	-	**0.1**
Gnaphalium uliginosum	-	-	0.3	-	-	-	-	-	**0.0**
Plantago major	1.0	-	0.3	-	0.5	-	-	0.3	**0.3**
Polygonum aviculare	-	0.3	0.3	-	0.5	-	-	-	**0.1**
Polygonum hydropiper	-	-	0.3	-	-	-	-	-	**0.0**
Polygonum persicaria	-	-	-	0.3	-	0.3	0.3	-	**0.1**
Stellaria media	0.5	0.3	-	-	-	-	-	-	**0.1**
Trifolium arvense	2.0	-	-	-	0.8	-	0.5	-	**0.4**
Viola arvensis	0.3	-	0.3	-	0.3	-	-	-	**0.1**
Sum of Dicotyledonous	**31.9**	**9.7**	**15.9**	**5.7**	**24.5**	**3.1**	**12.6**	**3.6**	**13.4**
Eguisetum arvense	0.3	-	-	-	-	-	-	0.5	**0.1**
Total	**38.0**	**11.2**	**16.7**	**6.7**	**30.0**	**3.9**	**13.6**	**5.4**	**15.7**

* See tab. 2 *Source*: own work / *Źródło*: praca własna

Table 5. Weed species composition and number of weeds (plants·m^{-2}) depending on cultivation method and dose of fertilization in 2012 (before harvest)
Tabela 5. Skład gatunkowy i liczebność chwastów (szt.·m^{-2}) w zależności od sposobu pielęgnacji i dawki nawozu w roku 2012 (przed zbiorem)

Weed species	A*	B	C	D	A	B	C	D	Average
	dose of manure 20 t·ha^{-1}				dose of manure 40 t·ha^{-1}				
Monocotyledonous									
Echinochloa crus-galli	4.3	4.5	2.3	0.8	2.8	2.3	3.3	0.3	**2.6**
Sum of Monocotyledonous	**4.3**	**4.5**	**2.3**	**0.8**	**2.8**	**2.3**	**3.3**	**0.3**	**2.6**
Dicotyledonous									
Amaranthus retroflexus	1.3	1.0	0.8	0.5	0.8	-	0.8	-	**0.7**
Capsella bursa-pastoris	-	-	0.3	-	-	-	-	-	**0.0**
Cirsium arvense	0.5	-	-	-	-	-	-	-	**0.1**
Chenopodium album	35.8	13.0	9.0	8.5	54.0	7.5	13.5	6.3	**18.5**
Convolvulus arvensis	-	-	-	-	-	-	0.5	-	**0.1**
Gnaphalium uliginosum	-	-	-	-	-	-	-	0.3	**0.0**
Lamium amplexicaule	-	0.5	0.3	0.3	-	-	0.5	0.3	**0.2**
Plantago major	0.8	-	0.5	-	-	-	0.3	-	**0.2**
Polygonum aviculare	-	-	-	-	-	-	0.3	-	**0.0**
Polygonum persicaria	-	-	-	-	-	0.5	-	-	**0.1**
Solanum nigrum	-	0.3	-	-	-	-	0.3	-	**0.1**
Stellaria media	-	-	-	-	-	-	-	-	**0.0**
Taraxacum officinale	-	-	0.3	-	-	-	-	-	**0.0**
Trifolium arvense	0.8	-	0.5	-	-	-	0.8	-	**0.3**
Sum of Dicotyledonous	**39.2**	**14.8**	**11.7**	**9.3**	**54.8**	**8.0**	**17.0**	**6.9**	**20.2**
Eguisetum arvense	0.3	-	-	-	-	-	-	2.8	**0.4**
Total	**43.8**	**19.3**	**14.0**	**10.1**	**57.6**	**10.3**	**20.3**	**10.0**	**23.2**

* See tab. 2 *Source*: own work / *Źródło*: praca własna

Table 6. Weed species composition and number of weeds (plants·m^{-2}) depending on cultivation method and dose of fertilization in 2013 (one week after last cultivation treatment)

Tabela 6. Skład gatunkowy i liczebność chwastów (szt.·m^{-2}) w zależności od sposobu pielęgnacji i dawki nawozu w roku 2013 (tydzień po ostatnim zabiegu mechanicznym)

Weed species	A*	B	C	D	A	B	C	D	Average
	dose of manure 20 t·ha^{-1}				dose of manure 40 t·ha^{-1}				
Monocotyledonous									
Echinochloa crus-galli	10.0	5.0	6.5	4.0	16.0	3.0	3.0	4.5	**6.5**
Elymus repens	0.5	-	-	-	-	-	1.0	-	**0.2**
Poa annua	1.0	-	1.0	-	-	-	-	-	**0.2**
Sum of Monocotyledonous	**11.5**	**5.0**	**7.5**	**4.0**	**16.0**	**3.0**	**4.0**	**4.5**	**6.9**
Dicotyledonous									
Anthemie arvensis	1.0	-	-	-	0.5	-	-	-	**0.2**
Artemisia vulgaris	-	-	0.5	-	-	-	-	-	**0.1**
Capsella bursa-pastoris	18.5	3.0	2.5	0.5	11.5	-	1.5	-	**4.7**
Chenopodium album	13.0	0.5	2.0	-	13.0	-	1.5	-	**3.8**
Chenopodium polyspermum	-	-	0.5	-	-	-	-	-	**0.1**
Cirsium arvense	1.0	1.0	-	-	1.0	1.5	-	-	**0.6**
Fallopia convolvulus	-	-	-	-	-	-	0.5	-	**0.1**
Galium aparine	-	-	-	-	-	-	0.5	-	**0.1**
Geranium dissectum	-	-	-	-	0.5	-	-	-	**0.1**
Gnaphalium uliginosum	1.0	-	0.5	-	-	-	-	-	**0.2**
Lamium purpureum	2.0	-	-	-	-	-	-	-	**0.2**
Plantago lanceolata	-	-	-	-	1.5	-	-	-	**0.2**
Plantago major	5.5	-	0.5	-	1.5	-	-	-	**0.9**
Polygonum persicaria	-	-	0.5	-	1.0	1.0	-	-	**0.3**
Solanum nigrum	-	-	0.5	-	-	-	-	-	**0.1**
Stellaria media	2.5	-	-	-	1.5	-	-	0.5	**0.6**
Taraxacum officinale	0.5	-	-	-	-	-	-	-	**0.1**
Veronica persica	2.0	-	-	-	1.0	0.5	-	-	**0.4**
Sum of Dicotyledonous	**47.0**	**4.5**	**7.5**	**0.5**	**33.0**	**3.0**	**4.0**	**0.5**	**12.5**
Eguisetum arvense	-	-	-	0.5	-	-	-	-	**0.1**
Total	**58.5**	**9.5**	**15.0**	**5.0**	**49.0**	**6.0**	**8.0**	**5.0**	**19.5**

* See tab. 2 *Source*: own work / *Źródło*: praca własna

Table 7. Weed species composition and number of weeds (plants·m^{-2}) depending on cultivation method and dose of fertilization in 2013 (before harvest)

Tabela 7. Skład gatunkowy i liczebność chwastów (szt.·m^{-2}) w zależności od sposobu pielęgnacji i dawki nawozu w roku 2013 (przed zbiorem)

Weed species	A*	B	C	D	A	B	C	D	Average
	dose of manure 20 t·ha^{-1}				dose of manure 40 t·ha^{-1}				
Monocotyledonous									
Echinochloa crus-galli	7.5	4.0	6.5	3.0	6.0	3.5	6.0	5.0	**5.2**
Poa annua	1.5	-	-	-	-	0.5	0.5	-	**0.3**
Setaria pumila	-	-	0.5	-	-	-	-	-	**0.1**
Sum of Monocotyledonous	**9.0**	**4.0**	**7.0**	**3.0**	**6.0**	**4.0**	**6.5**	**5.0**	**5.6**
Dicotyledonous									
Amaranthus retroflexus	0.5	-	-	-	-	-	0.5	-	**0.1**
Capsella bursa-pastoris	11.5	1.5	3.0	-	10.0	3.0	1.5	-	**3.8**
Chenopodium album	16.5	-	2.0	1.5	12.0	8.5	1.5	2.0	**5.5**
Cirsium arvense	1.0	5.0	-	-	0.5	-	-	-	**0.8**
Conyza canadensis	0.5	-	0.0	-	-	-	-	0.5	**0.1**
Galinsoga parviflora	-	-	-	-	-	-	-	0.5	**0.1**
Galium aparine	-	-	0.5	0.5	-	-	0.5	-	**0.2**
Geranium dissectum	-	-	0.5	1.5	0.5	0.5	3.0	2.5	**1.1**
Gnaphalium uliginosum	1.0	-	-	-	-	-	-	-	**0.1**
Plantago major	7.0	0.6	1.0	-	0.5	-	-	-	**1.1**
Polygonum persicaria	-	-	-	-	-	-	0.5	-	**0.1**
Stellaria media	1.0	-	2.5	3.0	1.5	1.5	0.5	2.5	**1.6**
Trifolium arvense	-	-	-	1.0	-	-	-	-	**0.1**
Tripleurospermum maritimum	-	-	-	0.5	-	-	-	-	**0.1**
Veronica persica	1.0	1.0	0.5	0.5	-	0.5	-	-	**0.4**
Viola arvensis	-	-	-	-	-	-	-	0.5	**0.1**
Sum of Dicotyledonous	**40.0**	**8.1**	**10.0**	**8.5**	**25.0**	**14.0**	**8.0**	**8.5**	**15.3**
Eguisetum arvense	-	-	-	5.5	-	-	-	-	**0.7**
Total	**49.0**	**12.1**	**17.0**	**17.0**	**31.0**	**18.0**	**14.5**	**13.5**	**21.5**

* See tab. 2 *Source*: own work / *Źródło*: praca własna

Table 8. Number of weed species depending on cultivation method and dose of organic fertilization
Tabela 8. Liczba gatunków chwastów zależności od sposobu pielęgnacji i dawki nawożenia organicznego

Year	Term	A**	B	C	D	A	B	C	D
		dose of manure 20 t·ha^{-1}				dose of manure 40 t·ha^{-1}			
2011	1*	9	4	2	1	9	4	4	2
	2	8	8	4	11	10	7	7	10
2012	1	8	6	11	7	9	3	5	5
	2	7	5	8	4	3	3	9	5
2013	1	13	4	10	3	11	4	6	2
	2	11	5	10	9	7	7	9	7
Average		**9,3**	**5,3**	**7,5**	**5,8**	**8,2**	**4,7**	**6,7**	**5,2**

*1 – one week after last cultivation treatment, 2 – before harvest
* See tab. 2

Source: own work / *Źródło*: praca własna

Species composition of weeds was similar in all the years of the research. Sorghum crops included 32 species weeds in total, including 5 monocotyledonous ones. The highest number of species was recorded in the treatments without mechanical cultivation (averagely 8.8), while in other treatments (mechanically cultivated), the number of species was lower and similar (averagely 5.9) (Table 8). In all the years of the research, the dominant species of segetal weeds, both in the first and second term of the determinations were: *Echinochloa crus-galli* and *Chenopodium album*. In 2011, a relatively high abundance of *Eguisetum arvense*, while in 2013 – of *Capsella bursa-pastoris* was recorded. Among the perennial species, there were occasional occurrences of: *Elymus repens*, *Cirsium arvense* i *Eguisetum arvense*.

In all the years of the research, the highest weed infestation in sorghum crops were recorded in the treatments without weed control, while the mechanical cultivation contributed to a considerable reduction in the weight of undesirable species (Tables 2-4). Using a brush hoe (twice during the season) or a hiller was the most effective method of mechanical care. With the cultivation treatments executed in this manner, dry weight of weeds was reduced in 2011 by 95% in the first term (a week after the last procedure) and by 93% in the second term of the determinations (before the harvest). In 2012, it was, respectively, 70 and 43%, while in 2013 - 70 and 81% in comparison with the treatments without mechanical care (differences statistically significant). In 2011, a weeding hoe proved to be a highly efficient. After a 3-time use of this tool, dry weight of weeds decreased by 92% in the first term and by about 80% in the second term of the determinations, compared with the weed infestation in the control object. A brush weeder was found to be less effective, reducing dry weight of weeds by, respectively, 64 and 72%. In 2012 and 2013, the effectiveness of a weeding hoe and a brush hoe in removing weeds was smaller and amounted to, accordingly: in 2012 – 40 and 62% in the first and 39 and 28% in the second term; in 2013 – 42 and 30% in the first and 58 and 49% in the second term of the determinations. The three years of the studies have shown that a 2-time use of a brush weeder in the growing period, combined with a hiller was the most effective method for mechanical treatment of sorghum crops, eliminating 75% of the weed weight in the stand. The effectiveness of a weeding hoe and a brush hoe, used three times during the growing season was lower, and amounted to, respectively, 58 and 51%. The dose of organic fertilizers did not significantly affect the size of the fresh and dry weight of weeds. Only in the first and third year of studies, a higher occurrence of undesirable species was recorded in the treatments fertilized with higher doses of manure (40 kg/ha).

Table 9. Fresh and dry matter of weeds depending on cultivation method and dose of fertilization in 2011
Tabela 9. Świeża i sucha masa chwastów w zależności od sposobu pielęgnacji i dawki nawożenia w 2011 roku

Cultivation method	Dose of manure [t·ha^{-1}]	Fresh matter [g·m^{-2}]	Dry matter [g·m^{-2}]	Fresh matter [g·m^{-2}]	Dry matter [g·m^{-2}]
		one week after last cultivation method		before harvest	
A – control object	20	981.6	146.3	712.5	218.6
	40	1362.7	169.6	740.3	235.6
B – brush weeder	20	501.6	65.5	217.0	56.7
	40	337.7	47.0	225.2	69.3
C – weeding hoe	20	60.9	8.9	114.3	30.6
	40	119.8	17.5	177.6	59.2
D – brush weeder+hiller	20	23.0	3.4	86.7	23.7
	40	71.7	12.2	93.3	26.3
Mean for cultivation method					
A – control object		1172.2 a*	158.0 a	726.4 a	227.1 a
B – brush weeder		419.6 b	56.3 b	221.1 b	63.0 b
C – weeding hoe		90.4 c	13.2 b	145.9 b	45.0 b
D – brush weeder+hiller		47.4 c	7.8 b	50.2 b	15.2 b
Mean for manure dose					
20		391.8 a	56.0 a	284.9 a	78.2. a
40		473.0 a	61.6 a	289.2 a	96.9 a

* values marked with the same letter did not differ significantly ($\alpha = 0.05$)

Source: own work / *Źródło*: praca własna

Table 10. Fresh and dry matter of weeds depending on cultivation method and dose of fertilization in 2012
Tabela 10. Świeża i sucha masa chwastów w zależności od sposobu pielęgnacji i dawki nawożenia w 2012 roku

Cultivation method	Dose of manure [t·ha^{-1}]	Fresh matter [g·m^{-2}]	Dry matter [g·m^{-2}]	Fresh matter [g·m^{-2}]	Dry matter [g·m^{-2}]
		one week after last cultivation method		before harvest	
A – control object	20	1924.8	378.2	2127.0	1055.2
	40	1986.5	563.8	2074.0	1178.5
B – brush weeder	20	1261.5	253.5	2192.8	901.2
	40	730.0	108.2	1471.2	717.2
C – weeding hoe	20	1301.2	261.2	1246.5	602.0
	40	1600.2	301.8	1672.5	757.0
D – brush weeder+hiller	20	635.8	106.8	1519.0	702.2
	40	734.8	170.8	1245.8	563.5
Mean for cultivation method					
A – control object		1955.6 a*	471.0 a	2100.5 a	1116.9 a
B – brush weeder		995.8 bc	180.9 b	1832.0 ab	809.2 ab
C – opielacz weeding hoe		1450.8 ab	281.5 ab	1459.5 ab	679.5 b
D – brush weeder+hiller		685.2 c	138.8 b	1382.4 b	632.9 b
Mean for manure dose					
20		1280.8 a	249.9 a	1771.3 a	815.2 a
40		1262.9 a	286.1 a	1615.9 a	804.1 a

* see tab. 8 *Source*: own work / *Źródło*: praca własna

Table 10. Fresh and dry matter of weeds depending on cultivation method and dose of fertilization in 2013
Tabela 10. Świeża i sucha masa chwastów w zależności od sposobu pielęgnacji i dawki nawożenia w 2013 roku

Cultivation method	Dose of manure [t·ha^{-1}]	Fresh matter [g·m^{-2}]	Dry matter [g·m^{-2}]	Fresh matter [g·m^{-2}]	Dry matter [g·m^{-2}]
		one week after last cultivation method		before harvest	
A – control object	20	215.8	39.2	340.6	121.9
	40	330.8	54.0	330.6	109.0
B – brush weeder	20	126.9	27.3	169.7	55.8
	40	162.1	37.6	175.4	63.1
C – weeding hoe	20	171.8	31.0	98.8	36.0
	40	114.8	22.9	163.2	61.6
D – brush weeder+hiller	20	59.6	14.5	30.6	10.2
	40	47.2	13.7	114.1	33.8
Mean for cultivation method					
A – control object		273.3 a*	46.6 a	335.6 a	115.5 a
B – brush weeder		144.5 ab	32.4 ab	172.5 ab	59.4 ab
C – opielacz weeding hoe		143.3 ab	27.0 ab	131.0 b	48.8 b
D – brush weeder+hiller		53.4 b	14.1 b	72.4 b	22.0 b
Mean for manure dose					
20		143.5 a	28.0 a	159.9 a	55.9 a
40		163.7 a	32.1 a	195.8 a	66.9 a

* see tab. 8 *Source*: own work / *Źródło*: praca własna

4. Discussion

Late sowing, cultivation in wide rows, and the slow sprouting of sorghum create very good conditions for the development of weeds, so under environmental farming system without using pesticides, the cultivation of such species is a big challenge. The occurrence of weeds in a field causes significant yield losses. According to Hruszka (2003b), every 10 items of weeds per 1 m^2 reduce the efficiency of maize by nearly 0.57 t of green matter. Within the three years of our research, in the plots without using any treatment methods, 43 items of weeds per 1 m^2 were recorded, which resulted in a significant competitiveness of segetal flora in relation to the cultivated plants. Among sorghum crops, we distinguished 32 weed species in total, whereas the most aggresive were: *Echinochloa crus-galli*, *Chenopodium album*, *Eguisetum arvense and Capsella bursa-pastoris*. The first two species belong to the group of common weeds, which are difficult to control and frequently occur among plants cultivated in wide rows. Earlier studies demonstrated that among the organic maize crops, the most predominant species were: *Echinochloa crus-galli*, *Stellaria media*, *Chenopodium album*, *Capsella bursa-pastoris* and *Polygonum convolvulus* (Staniak et al. 2011). Rola (1986) found that a high incidence of *Echinochloa crus-galli* in the crop may cause a decrease in maize yields down to 69%.

Agronomic-mechanical method is the most common method of weed control in organic farming system. On large areas, the treatments are carried out mechanically. Sowing plants in wide rows allows carrying them out several times during a season, as long as they do not damage crops (Dubas 2000). In the three-year period of research, a brush weeder, used twice during the season, accompanied

by a hiller, used once, were the most effective tools for mechanical treatment of sorghum crops. They reduced on average 75% of the weed weight in the crop stands. The effectiveness of a weeding hoe, and a brush weeder used alone was lower, and amounted to, respectively, 58 and 51%. Skrzypczak et al. (2008) showed a 55% effectiveness of mechanical treatment of interrows in sorghum and maize crops, Hruszka (2003a) – 50% in forage maize, and Waligóra et al. (2009) – about 60% in sugar maize.

In organic farming, mechanical weed control is very well known and widely used by farmers. These methods however, do not guarantee full effectiveness in the fight against weeds, as the treatments must be performed in such a way as to not damage the crops and their root system. Therefore, the weeds, which grow in the close vicinity of the crops are not destroyed. We should underline, however, in contrast to chemical methods, often causing large phytotoxicity, mechanical treatments do not negatively affect the crops (Heydel et al. 1999).

Weather conditions, especially humidity have a large impact on the efficiency of mechanical weed control methods. In the summer months of the years with water deficits, Staniak et al. (2011) recorded a higher effectiveness of mechanical methods than in the years with optimal precipitation. The dose of organic fertilizer did not significantly affect the fresh and dry weight of weeds. There was, however, a tendency to increase the weight of segetal species in the treatments fertilized with higher manure doses, as confirmed by previous observations of the above-mentioned authors.

5. Conclusions

1. The greatest abundance and species richness of segetal flora characterized sorghum crops without applying any treatments.
2. Mechanical treatment of intercrops contributed to a significant reduction in weight and number of weeds. The most effective method was to use a brush weeder and a hiller, which limited weed infestation on average by 75%. The efficiency of a weeding hoe and a brush weeder used alone was lower and amounted to, respectively, 58 and 51%.
3. In all of the years of the studies, we recorded the occurrence of weed species characteristic for crops grown in wide rows, whereas the most aggressive were: *Echinochloa crus-galli* and *Chenopodium album*.
4. The dose of organic fertilizer did not significantly affect the number and species composition of segetal flora.

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