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Influence of agrotechnical and chemical measures on weediness in sweet Sorghum crops (*Sorghum Bicolor*) and the output of biogas

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Abstract
Background: The use of agrotechnical and chemical measures for the protection of sweet sorghum crops from weeds improves plant growth conditions, eliminates the competition of weeds, and increases the yield of green and dry mass and the estimated output of biogas.
Materials and Methods: The field data were obtained in 2014–2016 at the research field of Bila Tserkva National Agrarian University, Ukraine. Soil cultivation, application of soil herbicide S-metolachlor (1.8·lha^{-1}), post-emergence herbicide Prosulfuron (0.02 kg·ha^{-1}) were studied. The trial was randomized in a 3-fold repeat.
Results: The effectiveness of the herbicide S-metolachlor application was 56.6–57.7% and the herbicide Prosulfuron – 60.1–60.8%. Using mechanical cultivation destroyed 79.6–80.3% of weeds. Maximum yield of green and dry mass and output of biogas were obtained from the Dovista hybrid in the application of Prosulfuron (69.1 t·ha^{-1}, 16.5 t·ha^{-1}, 6.74 thsd m^3·ha^{-1}).
Conclusions: The use of agrotechnical and chemical measures for the protection of weeds in sweet sorghum crops contributes to a significant improvement in plant growth, eliminates the competition of weeds and significantly reduces their number. The using only mechanical soil cultivation is less effective, which reduces yields of green and dry mass and the estimated output of biogas, compared with chemical measures.

Keywords: biogas, green mass, herbicide, mechanical cultivation, weed

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INTRODUCTION

Solving the problem of weeds in crops is one of the important conditions for obtaining high yields. Using only agrotechnical measures reduces the number of weeds to a certain level. At the same time, complex combination of agronomic measures with the use of herbicides can reduce the level of weeds in crops below economic thresholds for their harmfulness (Zherebko 2004).

At the initial stages of growth and development, it is necessary to use a combined system for protection sorghum from weeds, which includes their mechanical destruction and chemical – with the use of herbicides. If at the beginning of the growing season not to fight weeds, they can completely cover the emergence of sorghum (Silva et al. 2014). Despite the considerable arsenal of agrotechnical measures, it is not possible to completely solve all the problems of weed control. In each case, the agrotechnical measures should complement the chemical methods (Griepentrog and Dedousis 2010).

When planning measures to control the number of weeds in a particular field, it is necessary to take into account a set of the most common species that make up the type of weediness. It takes into account the biological features of weeds, as well as their reaction to certain herbicides (Muenscher 1960). Chemical methods of

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Table 1. Height of sweet sorghum plants depending on weeds control measures, cm (average for 2014–2016 yrs.)

Variety, hybrid	Weeds control measure	Boot stage	Period of panicles ejection	Half-bloom stage	Hard-dough stage
Silosne 42	Weeded control	43.0	109.9	122.7	198.3
	Mechanical cultivation	46.8	129.6	143.1	215.3
	S-metolachlor	46.1	131.0	145.4	218.6
	Prosulfuron	43.6	129.9	145.8	219.9
Dovista	Weeded control	44.2	145.5	159.3	208.8
	Mechanical cultivation	48.1	163.0	178.5	249.7
	S-metolachlor	47.3	165.2	180.6	251.4
	Prosulfuron	44.3	164.4	181.2	252.7

Factor A – variety, hybrid; factor B – stage of growth. LSD – least significant difference, P≤0.05.
LSD (boot stage) for factor A– 0.3; B – 0.4; AB – 0.8.
LSD (period of panicles ejection) for factor A– 1.2; B – 0.8; AB – 2.1.
LSD (half-bloom stage) for factor A– 1.5; B – 1.3; AB – 2.7.
LSD (hard-dough stage) for factor A– 1.6; B – 1.4; AB – 2.3.

weed control in sorghum crops are effectively provided that the seeds are treated with an antidote. Using them in combination with agrotechnical measures ensures the destruction of a significant amount of weeds, increases yields and reduces additional costs for growing sorghum (Delchev 2017).

Anaerobic digestion systems have undergone many modifications in the last two decades, mainly as results of the energy crises. Major developments have been made with regard to anaerobic metabolism, physiological interactions among different microbial species, effect of toxic compounds and biomass accumulation (Pualchamy et al. 2008).

Recently, interest in the sweet sorghum growing as an alternative source for biofuel production (bioethanol, biogas, solid fuel) has grown (Makuh et al. 2013).

The purpose of the research is to determine the productivity of sweet sorghum and the estimated output of biogas, depending on the measures that control the number of weeds.

MATERIALS AND METHODS

The field data were obtained in 2014–2016 at the research field of Bila Tserkva National Agrarian University, located 80 km from Kyiv (49°46'14.8"N 30°04'22.0"E). Soil of the experimental plot is typical leached black soil. Agrochemical characteristics of the soil: the content of humus is 3.5–4.2%, nitrogen – 90–120 mg·kg^{-1}, mobile phosphorus – 130–160 mg·kg^{-1} and exchangeable potassium – 120–130 mg·kg^{-1}.

The research was carried out according to the following scheme: 1. Biological weediness (Weeded control). 2. Mechanical cultivation. 3. Application of soil herbicide S-metolachlor (Dual Gold, 1.8 l·ha^{-1}) before crop sowing. 4. Application of post-emergence herbicide Prosulfuron (Peak 75 WG, 0.02 kg·ha^{-1}) in the phase of 3–6 leaves of the crop. Mechanical cultivation included two inter-rows tilling with KNP–5.6-01 cultivator in the phase of 3–5 leaves at a depth of 6–8 cm and in the phase of 5–7 leaves of sweet sorghum. For growing, we used sweet sorghum: a variety Silosne 42 and a hybrid Dovista. The trial was randomized in a 3-fold repeat.

Mineral fertilizers were applied before sowing of sweet sorghum: N = 80 kg·ha^{-1}, P_2O_5 = 60 kg·ha^{-1}, K_2O = 60 kg·ha^{-1}. In this region, the average precipitation in the period May–October is 382.5 mm; in 2014 it was 395.3, in 2015 – 186.0, in 2016 – 524.8 mm. The average temperature during this period is 16.0 °C, in the research years – 16.2, 17.0 and 17.2 °C.

In this experiment, we determined the number of weeds, the height of sweet sorghum plants, the dry matter content, the yield of green mass of sorghum, the output of biogas. Weediness of crops was determined by a quantitative method before the herbicide application or mechanical cultivation, and 30 days after the herbicide application or mechanical destruction of weeds. Weeds were counted per unit area (1 m^2). The height of sweet sorghum plants was measured before harvesting in the hard-dough stage. The dry matter content was determined by drying the samples at a temperature of 105 °C until its mass is constant. The yield was determined by weighing the green mass in the hard-dough stage of sweet sorghum from each plot, and then converting it into hectare of sown area.

The biogas output was carried out according to the methodical recommendations of the Institute of Bioenergy Crops and Sugar Beet (Ganzhenko 2017).

The statistical processing of the results was performed using Excel and Statistica 6.0.

RESULTS

At the initial stage of sorghum vegetation, there was no significant difference between the experimental variants in plant height; this index was within the range of 43.0–46.8 cm in the variety Silosne 42 and 44.2–48.1 cm in the Dovista hybrid (**Table 1**).

Application of post-emergence herbicide Prosulfuron resulted in suppressing the growth of sweet sorghum plants, which was due to decrease in their height in the boot stage on 5.2–6.7% compared with the variants using the soil herbicide S-metolachlor and mechanical cultivation.

In the period of panicles ejection, the difference in plant height between variants with different weed control measures was leveled, and in the half-bloom stage the preference was given to variants using herbicides. The maximum height of the sorghum plants in the variety Silosne 42 (218.6–219.9 cm) and the Dovista hybrid (249.7–251.4 cm) were noted in the hard-dough stage when applying herbicides.

Table 2. Weed infestation of sweet sorghum crops depending on weeds control measures (average for 2014–2016 yrs)

Variety, hybrid	Weeds control measure	Before applying/ carrying out, pcs./m^2	After applying/ carrying out, pcs./m^2	Effectiveness, %
Silosne 42	Weeded control	109.9	115.0	–
	Mechanical cultivation	112.1	23.0	79.6
	S-metolachlor	109.2	47.5	56.6
	Prosulfuron	107.1	42.8	60.1
Dovista	Weeded control	107.2	113.6	–
	Mechanical cultivation	111.1	22.0	80.3
	S-metolachlor	106.4	45.1	57.7
	Prosulfuron	107.4	42.3	60.8

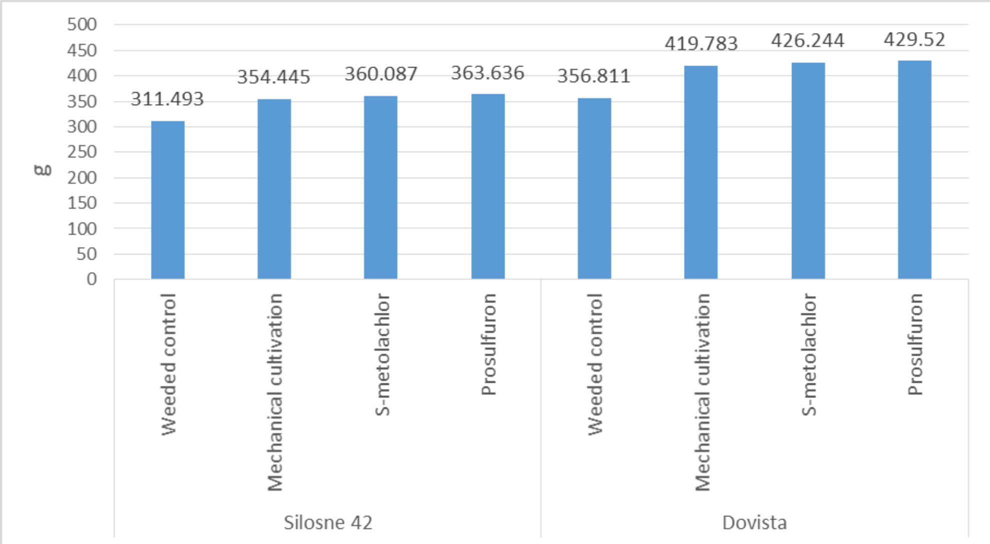

Fig. 1. Weight of one plant of sweet sorghum depending on the weeds control measures in the hard-dough stage, g (average for 2014–2016 yrs)

When using mechanical cultivation, the height of sweet sorghum plants was lower on 2.3–3.8% compared with using chemical measures.

In the sweet sorghum crops, weeds were represented by the following species: *Chenopodium album* L. –17.6%, *Setaria viridis* L. – 5.6%, *Setaria glauca* L. – 10.7%, *Amaranthus retroflexus* L. – 18.3%, *Echinochloa crus-gali* L. – 14.5%, *Convolvulus arvensis* L. – 8.6%, *Capsella bursa pastoris* L. – 6.2%, *Poligonum convolvulus* L. – 6.0%, *Cirsium arvence* L. – 5.1%, *Elytrigia repens* L. – 5.2%, other species – 2.2%.

The application of soil herbicide S-metolachlor (1.8 l·ha^{-1}) resulted in significant inhibition of *C. bursa pastoris*, *P. convolvulus*, *A. retroflexus*. It had less effectiveness against *Ch. album*, *S. viridis*, *S. glauca*, *E. crus-gali*. The effectiveness of the herbicide was 56.6–57.7%. The number of weeds after its application in the variants of the experiment was 45.1–47.5 pcs./m^2 (**Table 2**).

The post-emergence herbicide Prosulfuron (0.02 kg·ha^{-1}) almost completely controlled *Ch. album*, *P. convolvulus*, *A. retroflexus* and others. However, there were problems with the complete elimination of cereal weeds (*S. viridis*, *S. glauca, E. crus-gali*) and low effectiveness against perennial species (*C. arvence*, *E. repens*, *C. arvensis*). The effectiveness of Prosulfuron herbicide was 60.1–60.8%, which is higher on 3.0–3.5% in comparison with the S-metolachlor herbicide.

The low efficiency of the chemical protection system is due to the low effect of the studied herbicides on annual cereals and perennial weeds. In addition, the low effectiveness of the S-metolachlor herbicide is due to the emergence of heat-loving weeds (*Ch. album*, *A. retroflexus*, *P. convolvulus*) after its application and in the period when they were not the most sensitive to the action of this herbicide.

After mechanical cultivation 79.6–80.3% of weeds were destroyed. The greatest effectiveness of this measure was shown against the types of weeds such as *Ch. album*, *S. viridis*, *A. retroflexus*. At the same time, there were problems with the destruction of weeds in the rows of sorghum and perennial species.

On average 20–25 days after the emergence, sweet sorghum plants have ensured the closure of row spacing due to the growth of sufficient vegetative mass, which respectively affected the appearance of weeds and the inhibition of already vegetative ones. At harvesting time of sweet sorghum, in variants with weeds control measures their number decreased to 12.3–38.2 pcs./m^2.

The above ground mass of sweet sorghum is accumulated unevenly during periods of vegetation and depends on varietal features, elements of cultivation technology, and has a great importance in the plants' life. Sweet sorghum plants formed the maximum mass in the hard-dough stage (**Fig. 1**).

Table 3. Yield of green mass of sweet sorghum in hard-dough stage depending on weeds control measures, t·ha^{-1}

Variety, hybrid	Weeds control measure	2014 yr.	2015 yr.	2016 yr.	Average
Silosne 42	Weeded control	47.8	32.0	53.1	44.3
	Mechanical cultivation	59.6	40.0	68.3	55.9
	S-metolachlor	64.8	43.7	72.7	60.4
	Prosulfuron	65.3	44.4	72.2	60.6
Dovista	Weeded control	57.4	38.1	58.6	51.4
	Mechanical cultivation	71.6	46.5	76.1	64.8
	S-metolachlor	75.2	51.6	77.9	68.2
	Prosulfuron	76.1	52.1	79.0	69.1
LSD (P≤0.05)	A (variety, hybrid)	7.8	5.5	8.8	
	B (weeds control measure)	4.9	3.0	5.5	
	AB	12.6	8.6	14.5	

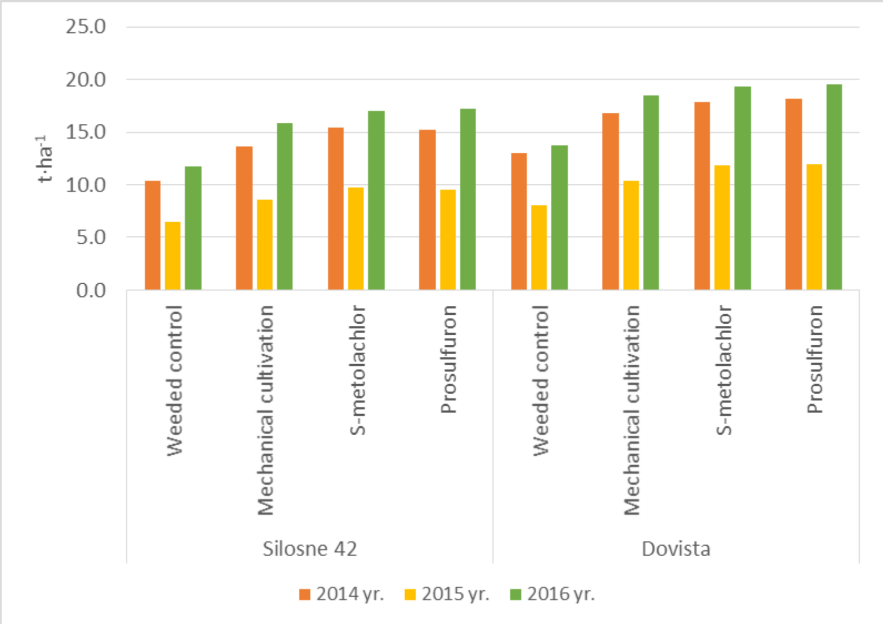

Fig. 2. Yield of dry matter of sweet sorghum in hard-dough stage depending on weeds control measures, t·ha^{-1}

The highest weight of one plant was obtained in the variant using Prosulfuron herbicide – 363.6 and 429.5 g, which exceeded weeded control on 16.7 and 20.4%. In the variant with using the S-metolachlor herbicide, the excess was 15.6 and 19.5%, and with mechanical soil cultivation – 13.8 and 17.6% in the variety Silosne 42 and the hybrid Dovista respectively.

The weight of one plant the Dovista hybrid was 356.8–429.5 g, the Silosne 42 variety – within 311.5–363.6 g, which is less on 14.3–18.2%.

Maximum yields of different varieties and hybrids of sweet sorghum can be obtained provided the plant has the required amount of nutrients, an effective system of protection, taking into account biological characteristics. The varieties and hybrids have different biological characteristics and they react differently in their development to the formation of biomass.

The yield of green mass of sweet sorghum depended on the investigated weeds control measures. In the hard-dough stage, on average for research years, the yield of the green mass of the Silosne 42 variety and the Dovista hybrid at control amounted to 44.3 and 51.4 t·ha^{-1}, with mechanical treatments – 55.9 and 64.8 t·ha^{-1}, on plots using S-metolachlor herbicide – 60.4 and 68.2 t·ha^{-1}, Prosulfuron herbicide – 60.6 and 69.1 t·ha^{-1} (**Table 3**).

In the research years, the yield of green mass of sorghum varied from 47.8 to 79.0 t·ha^{-1} in favorable weather conditions in 2014 and 2016, and 32.0–52.1 t·ha^{-1} in stressful 2015 yr. In 2015 the yield decreased on 28.4–41.5% compared to the years with better climatic conditions.

Application of herbicides turned out to be the most effective method of weeds control measures and forming the productivity of sweet sorghum. In the Silosne 42 variety and the Dovista hybrid, the increase in green mass yield in variants, treated with herbicides, was 32.1–35.5% compared to control. At the same time, there was no significant difference between the variations with the application of herbicides in the years of research.

In our studies, the yield of green mass of sweet sorghum when using mechanical cultivation exceeded the weeded control on 11.6 and 13.4 t·ha^{-1}, but was lower on 3.8–5.1 t·ha^{-1} than the variants with herbicides application.

Similarly, the yield of dry matter also changed: an increase in this index in variants with weeds control measures was noted (**Fig. 2**).

Maximum values of dry matter yield were obtained in the Dovista hybrid after the application of post-

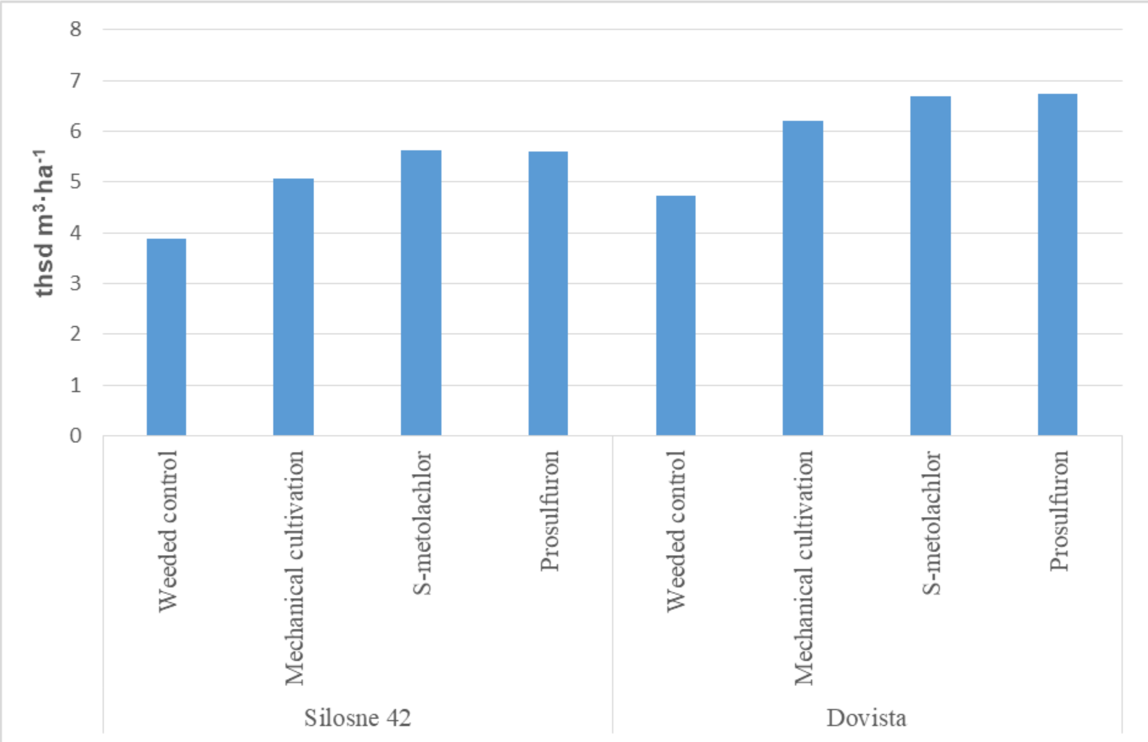

Fig. 3. Estimated output of biogas in sorghum depending on weeds control measures, thsd. $m^3 \cdot ha^{-1}$ (average for 2014–2016 yrs.)

emergence herbicide Prosulfuron – 16.5 $t \cdot ha^{-1}$, which is higher than control on 4.9 $t \cdot ha^{-1}$.

After mechanical soil treatments, the dry matter yield of the Silosne 42 variety was increased on 30.4%, while the Dovista hybrid – on 32.3% compared to the control variant.

Weeds control measures also affected the estimated output of biogas. The lowest biogas output was in the control variant – 3.87 and 4.73 thsd $m^3 \cdot ha^{-1}$, the highest – in variants using herbicides – 5.61–5.62 and 6.68–6.74 thsd $m^3 \cdot ha^{-1}$, respectively in the variety and hybrid (**Fig. 3**).

The chemical protection of sorghum from weeds increased the output of biogas on an average 43.1% compared to control. For mechanical soil treatment, this increase was 42.3%.

The highest estimated output of biogas was in the Dovista hybrid – 4.73–6.74 thsd $m^3 \cdot ha^{-1}$, which is more than in the Silosne 42 variety on 18.3–22.4%.

DISCUSSION

The main problem in sorghum is its high susceptibility to anti-cereals herbicides, and therefore mechanical weeds control should be used, but this increases costs of this crop cultivation. The current strategy of weed control in sorghum crops needs review (Bibard 2004).

The most important characteristic of herbicides is their selective phytotoxicity, which combines, on the one hand, the effectiveness of the destruction of a significant number of weeds species, and, on the other hand, selective action of the herbicide, that is, the absence of a negative impact on crop (Machado et al. 2016). Recently, mainly for environmental reasons, the advantage is given to herbicides that are used in vegetative weeds, despite the fact that in most cases they have a shorter duration of protective action compared with soil preparations (Takano 2016).

According to Galon et al. (2016) it has been shown that flumioxazin (50 $g \cdot ha^{-1}$) has the potential to control broadleaf weeds and has a low level of phytotoxicity symptoms for sweet sorghum. It is not recommended to add tembotrione (100.8 $g \cdot ha^{-1}$), as it caused the death of three plants varieties. Differences in tolerance to atrazine (1.500 $g \cdot ha^{-1}$) among the studied varieties were also observed. In order to provide more information about the susceptibility of the sorghum crop to herbicides, new tests in different soil and climatic conditions, involving new cultivars, herbicides and management strategies, are required, to prospect the selectivity and effectiveness of molecules to the crop.

The highly efficient new technologies in herbicide production may reduce the herbicide doses. Several researchers suggest the possibility of using lower herbicide doses without reducing the yield (Domaradzki and Rola 2003, Zhang et al. 2000).

Increased herbicide efficacy can be achieved by different strategies, for example by using herbicide mixtures and by repeated reduced amounts of herbicides (Deveikyte and Seibutis 2006, Wilson et al. 2005).

After the herbicide application, weed density and weed biomass were significantly reduced compared to the infested control. The best results were achieved after the application of mesotrione tank mixture with S-metolachlor and terbuthylazine. Application of split doses of herbicides was also correlated with the density, biomass, and height of sorghum (Kaczmarek 2017).

The high yield of sorghum biomass is also important in assessing the suitability for biogas production. According to Mahmood (2013), the specific output of methane from some varieties of sweet sorghum was extremely high, but due to reduced yields of their biomass, the output of methane from 1 hectare was smaller. The output of biogas and methane of the some studied varieties, such as Maja, Lussi, Branko, Supersile 20, KSH 6301 and Supersile, were comparable to those in corn. Therefore, sweet sorghum can be used as an alternative to corn for biogas production.

In Wannasek et al. (2017) experiments, new data on the development of biomass yields, maturation and biogas production of five varieties of sorghum were received. The yield of dry matter (DM) ranged from 15.7 to 20.67 t·ha^{-1}. In the sorghum variety SOR 4, the methane output was 6500 m^{3}·ha^{-1}. There was also no decrease in methane output when increasing the maturation group and yield of dry matter of sorghum.

At the same time, there is practically no data concerning the effect of crops weediness levels on sweet sorghum and weeds control measures on the productivity of this crop and on biogas and methane output.

CONCLUSIONS

In the absence of crop protection measures, weeds are rivals of sweet sorghum plants in relation to the main factors of plant life (water, light, nutrients), which leads to reduce yield of green and dry mass and, accordingly, the output of biogas. The use of agrotechnical and chemical measures for the protection of weeds in sorghum crops contributes to a significant improvement in plant growth, eliminates the competition of weeds and significantly reduces their number. The using only mechanical soil cultivation is less effective, which reduces green and dry mass yields and the estimated output of biogas, compared with chemical measures. The higher values of these indicators were obtained in the Dovista hybrid in the application of Prosulfuron (69.1 t·ha^{-1}, 16.5 t·ha^{-1}, 6.74 thsd m^{3}·ha^{-1}), with no significant difference with the variant of applying S-metolachlor.

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