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Seed Yield and the Possibility of Biofuel Production from Sorghum (*Sorghum bicolor* L.) in Ukraine

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ABSTRACT

The influence of the elements of cultivation technology on the productivity of sorghum (*Sorghum bicolor* L.) as a feedstock for further processing is gaining relevance. The study was conducted in the Right-Bank Forest-Steppe of Ukraine at the Bila Tserkva Experimental Breeding Station of the Institute of Bioenergy Crops and Sugar Beets in the years 2016–2019. The studied factors were seed and sowings treatment with a growth regulator containing a complex of water-soluble fulvic acids, enzymes, vitamins, and phytohormones. The highest yield of grain (7.1 t/ha), biomass (35.9 t/ha), bioethanol (2.37 t/ha), solid biofuel (11.14 t/ha), and estimated energy output (240.65 GJ/ha) from biomass were obtained in the treatment where both seeds and sowings were treated with a growth regulator. A close relationship between yield and energy performance is found.

Keywords: growth regulator, grain quality, biofuel, energy, correlation.

INTRODUCTION

Agriculture plays a leading role in ensuring the food and energy security of Ukraine due to the significant bioenergy potential of the country. However, in fact, the agricultural sector of the country is developing quite slowly, and there is a slow growth in the capacity of enterprises engaged in the production of biofuel. This is a complex situation, as the use of the bioenergy potential of agriculture is seen as one of the components of the sustainable development strategy (Pryshliak et al., 2019).

The development of renewable energy sources, particularly the production of energy from biomass, is an important task in many countries of the world, as it has a high economic and environmental impact (Kudria, 2020). Many countries in North and South America, Europe, and Asia, solve the energy issue through the use of biofuel from plant biomass (Polianskyi et al., 2020). Therefore including the production of biomass for biofuel in the agricultural complex of Ukraine will contribute to improving the environment, reducing the energy dependence of the country, increasing its export potential, ensuring the sustainable development of rural settlements and creating new jobs (Kaletnyk et al., 2020).

Biomass as a product or waste in agriculture (both of vegetable and animal origin), forestry, and related industries, as well as components of industrial and household waste, is traditionally considered the main source for the production of alternative energy sources (Kiurchev et al., 2012). At the same time, traditional grain crops, including sorghum, are less considered in the context of their use for biofuel production.

Sorghum (*Sorghum bicolor* L.) is a food and feed crop, which, due to its significant photosynthetic potential, high resistance to drought and low water use, can form a high level of productivity (Ananda et al., 2020; Von Pinho et al., 2022).

In addition to the traditional use, the high content of starch in grain makes sorghum a valuable energy crop (Dicko et al., 2006; Hao et al., 2021) suitable for cultivation in Ukraine.

Sorghum grain can be used for the production of bioethanol (ethyl alcohol, as an additive to gasoline) and solid biofuel (briquettes and pellets) (Muindi and Mulinge, 2023). As the processing of biomass aims at obtaining biofuel, it is important to select adequate elements of cultivation technology. After all, in the case of processing biomass for biofuels, it is important to obtain desired biometric parameters of crops, especially through the use of biogenic elements of cultivation technology that have a significant and rapid effect on plants (Roik et al., 2020). Therefore, the study of the elements of the cultivation technology for sorghum, in particular, the influence of the growth regulator on the yield performance, quality of the grain, yield of biofuel and estimated energy output from biomass in the conditions of the Right-Bank Forest-Steppe of Ukraine is relevant.

Plant growth regulators are traditionally used to increase germination energy, intensify rooting and formation of the above-ground biomass of plants, regulate the transition to the stages of flowering, fruit formation and seed maturation, increase productivity, regulate dormancy period and other processes (Hrytsaienko et al., 2008; Khodanitska et al., 2021). The plant growth regulators are used on various types of crops − grain, vegetable, fodder, oil, fruit, and ornamental (Polivanii and Kuriata, 2016). The data available in the literature indicate a positive effect of plant growth regulators application, specifically, increased plant resistance to stress and adverse conditions of the environment, and better use of water and nutrients (Bilitiuk and Skurotivska, 2000). Therefore, growth regulators can help adjust the structure of yield to certain pathways of biomass processing. Given this, the purpose of the research was to study the effect of the growth regulator on the productivity of sorghum, yield of biofuel and estimated energy output from biomass in the conditions of the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The research was carried out at the Bila Tserkva Experimental Breeding Station of the Institute of Bioenergy Crops and Sugar Beet National Academy of Agrarian Sciences of Ukraine in the years 2016–2019, in a zone of unstable moisture.

The soil of the experimental field is the typical chernozem with a low content of humus. The chemical characteristics of the plough soil layer (0–30 cm) were the following: the content of humus 3.5%, total nitrogen 0.31%, alkaline hydrolysable nitrogen 134 mg/kg, P_2O_5 276 mg/kg, K_2O 98 mg/kg, hydrolytic acidity 2.41 mg-eq. The degree of alkali saturation was 90%. It was a two-factor experiment: seed treatment with plant growth regulator and treatment of sowings with plant growth regulator (Table 1).

A single experimental plot area was 50 m^2 (accounting area of 25 m^2). Sorghum seeds were sown to a depth of 4–6 cm at a row spacing of 45 cm and a plant density of 200,000 plants per hectare. Observations and records of crop parameters, as well as calculations of the yield of bioethanol and solid biofuel, and estimated energy output were performed according to the methodology developed at the Institute of Bioenergy Crops and Sugar Beet.

The yield of bioethanol was calculated taking into account the yield of sorghum grain, which at harvest contains about 86% of dry matter and starch; the yield of solid biofuel was calculated taking into account the yield of biomass, dry matter content of biomass and the moisture content of solid biofuel (10%) (Roik et al., 2020; Pravdyva et al., 2021).

Weather conditions of the vegetation season were favourable for the growth and development of sorghum, although they had some deviations from long-term data inherent in the zone of unstable moisture (Figures 1 and 2).

In the experiment, we used a growth regulator Vermistim − extract of biohumus. It contains a complex of water-soluble fulvic acids, enzymes, vitamins, and phytohormones. The growth regulator was applied according to the experimental design.

Table 1. Design of the experiment

Factor A – seed treatment	Factor B – treatment of sowings with growth regulator
1. Treated with water (control)	1. Seeds not treated + spraying crops with growth regulator
2. Treated with growth regulator	2. Seeds treated + spraying crops with growth regulator

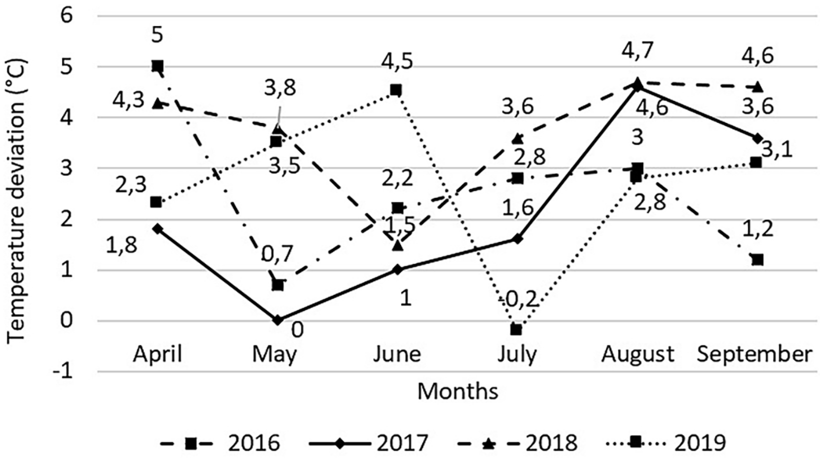
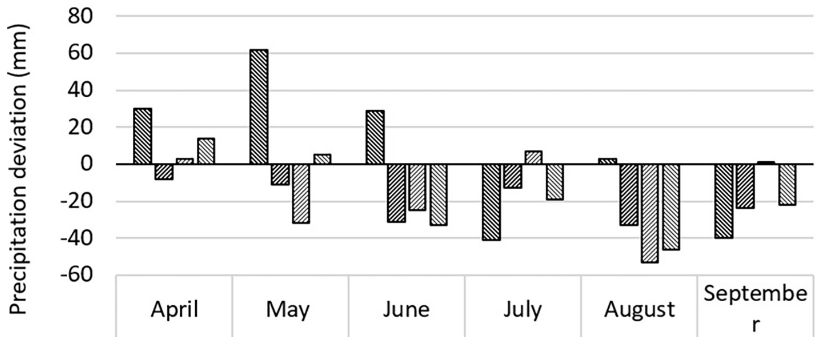


Figure 1. Deviation from the average long-term air temperature (2016–2019)



	April	May	June	July	August	September
2016	30	62	29	-41	3	-40
2017	-8	-11	-31	-13	-33	-24
2018	3	-32	-25	7	-53	1
2019	14	5	-33	-19	-46	-22

Figure 2. Deviation from the average long-term precipitation data (2016–2019)

Statistical analysis

To determine the statistical significance of the effect of experimental treatment (< $p = 0.05$), after the first analysis of variance (ANOVA), all data were analysed with the use of the software SAS (SAS Institute Inc., USA). Significant differences between individual means were determined using the least significant difference (LSD) test.

RESULTS AND DISCUSSION

According to the results of our study, we found that the growth regulator influenced the quality indicators of grain. The highest contents of protein (11.9%), fat (3.47%), ash (1.79%), and starch (68.7%) were obtained in the treatment where both seeds and sowings were treated with the growth regulator (Table 2). In the control treatment, grain quality indicators were the lowest. In the treatments where only seeds were treated or only sowings were sprayed with the growth regulator, the protein content was 10.1−10.3%, fat 3.19−3.31%, ash 1.56−1.62%, and starch 65.8−66.4%.

The application of the growth regulator significantly increased grain and biomass yields compared to the control, where the lowest productivity was obtained: grain yield was 4.4 t/ha, biomass yield 29.2 t/ha, dry matter content in grain and biomass 85.2% and 23.4%, respectively (Table 3). A significant improvement in these parameters was in the treatment where both seeds and sowings of sorghum were treated with the growth regulator: grain yield was higher by 2.7 t/ha (7.1 t/ha), and the biomass yield by 6.5 t/ha (35.9 t/ha). The dry matter content of grain and biomass also increased and amounted to 86.9% and 28.2%, respectively.

Table 2. Quality indicators of sorghum seeds in the experimental treatments (average for 2016–2019)

Treatment		Grain quality			
		Content (%)			
		Protein	Fat	Ash	Starch
Seed treatment (factor A)	Control	9.5	2.93	1.48	64.2
	Seeds treated with growth regulator	10.1	3.19	1.56	65.8
Treatment of sowings (factor B)	Seeds not treated + spraying crops with growth regulator	10.3	3.31	1.62	66.4
	Seeds treated + spraying crops with growth regulator	11.9	3.47	1,79	68.7
$LSD_{0.05}$		0.36	0.03	0.02	1.43

Table 3. Yield and dry matter content of sorghum under the effect of seed treatment and spraying crops (average for 2016–2019)

Treatment		Yield (t/ha)		Dry matter content (%)	
		Grain	Biomass	Grain	Biomass
Seed treatment (factor A)	Control	4.4	29.2	85.2	23.4
	Seeds treated with growth regulator	5.2	32.8	86.3	24.8
Treatment of sowings (factor B)	Seeds not treated + spraying crops with growth regulator	5.9	33.4	86.8	26.1
	Seeds treated + spraying crops with growth regulator	7.1	35.9	86.9	28.2
$LSD_{0.05}$		0.33	1.45	2.11	1.04

The largest yield of bioethanol (2.37 t/ha) and the estimated energy output (59.13 GJ/ha) were obtained when both seeds and sowings were treated with the growth regulator (Table 4). In the treatments where only seeds were treated or only sowings were sprayed with the growth regulator, the yield of bioethanol dropped to 1.72 t/ha and 1.96 t/ha, respectively, and the estimated energy output was also reduced accordingly to 43.01 GJ/ha and 49.08 GJ/ha, respectively.

The yield of solid biofuel also varied significantly and reached a maximum of 11.14 t/ha in the treatment where the growth regulator was applied to both seeds and sowings. The estimated energy output in the treatment was also the highest and reached 181.52 GJ/ha. The application of the growth regulator only for seed treatment or only for spraying crops led to a decrease in the yield of solid biofuel by 1.55−2.19 t/ha and estimated energy output by 25.22−35.67 GJ/ha. In the control treatment, the yield of bioethanol, solid biofuel and estimated energy output were the lowest.

Correlation and regression analysis of the data revealed a strong correlation between bioethanol

Table 4. Estimated yield of biofuel and estimated energy output under the effect of seed treatment and spraying crops with plant growth regulator (average for 201–2019)

Treatment		Yield of bioethanol (t/ha)	Yield of solid biofuel (t/ha)	Energy output from bioethanol (GJ/ha)	Energy output from solid biofuel (GJ/ha)	Total energy output (GJ/ha)
Seed treatment (factor A)	Control	1.44	7:52	35.93	122.51	158.44
	Seeds treated with growth regulator	1.72	8.95	43.01	145.85	188.86
Treatment of sowings (factor B)	Seeds not treated + spraying crops with growth regulator	1.96	9.59	49.08	156.30	205.38
	Seeds treated + spraying crops with growth regulator	2.37	11-14	59.13	181.52	240.65

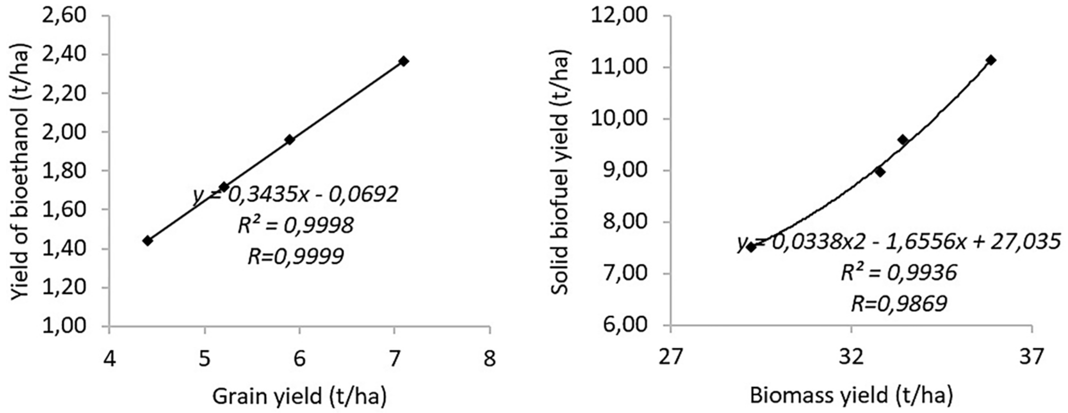


Figure 3. Correlation-regression relationship (a) between bioethanol yield and grain yield, and (b) between solid biofuel yield and biomass yield

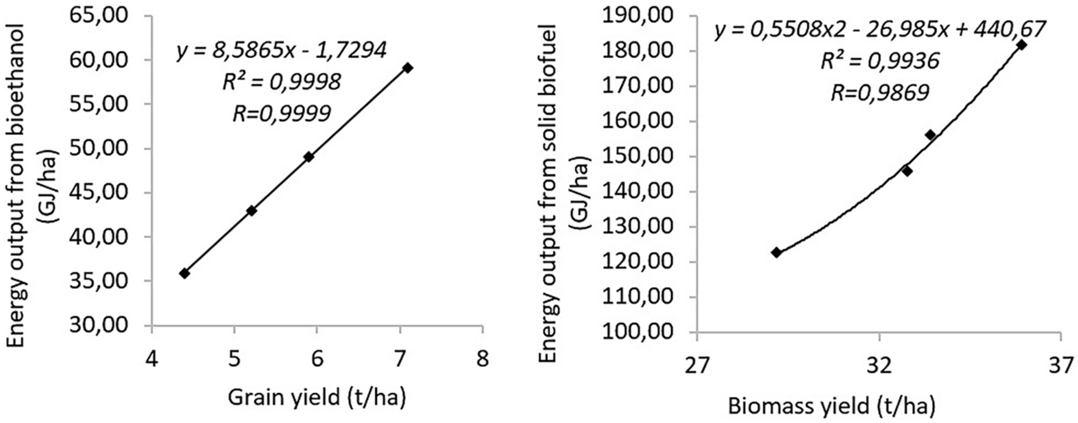


Figure 4. Correlation-regression relationship (a) between estimated energy output from bioethanol and grain yield, and (b) between estimated energy output from solid biofuel and biomass yield

yield and grain yield (Figure 3a). The correlation coefficient was R=0.99 and the determination coefficient was R^2=0.99.

The correlation relationship between the yield of solid biofuel and the yield of biomass (Figure 3b) can be described by a polynomial equation of the second order $y = 0.0338x^2 – 1.6556x + 27.035$, with the correlation coefficient R=0.9936 and the determination coefficient R^2=0.9869.

A strong linear correlation R=0.99 and the determination coefficient R^2=0.99 were also obtained for the estimated energy output from bioethanol and the grain yield (Figure 4a).

The dependence between the energy output from solid biofuel and biomass yield can also be described by a second-order polynomial $y = 0.5508x^2 - 26.985x + 440.67$, with the correlation coefficient R=0.99 and the determination coefficient R^2=0.98 (Figure 4b).

Diversification of sorghum processing pathways is an important issue since due to the increase in the population, it is impossible to allocate significant land area exclusively for the cultivation of bioenergy crops. Therefore, scientists note the need to search for universal crops suitable for processing for both food and bioenergy purposes. Such crops should not only be resistant to diseases but also effectively tolerate global warming and resist drought that can destroy crops (Rivero et al., 2022). In our research, the features of the growth and development of sorghum – a crop of versatile application that serves both food and bioenergy goals – are investigated.

Other scientists indicate that the use of crops with high biomass yield, which not only provide grain products and feed but also feedstock for the production of biofuel, in particular the production of starch, sugar and lignocellulosic substances, is a promising area of research (Takanashi, 2023; Bollam et al., 2021; Kazungu et al., 2023). Accordingly, the results of our study of the productivity formation patterns of sorghum in the zone of unstable moisture of the Right-Bank Forest-Steppe of Ukraine allow us to recommend the best practices for the application of growth regulators in agricultural production. Obtaining the planned growth parameters (whether increased grain yield or increased biomass yield or increased both ones) is relevant to the proper planning of crops at known pathways of their utilization.

CONCLUSIONS

It is proved that the cultivation technology, specifically the use of plant growth regulators for seed treatment and spraying crops of sorghum has a positive effect on the formation of grain and biomass yield, and accordingly, on the yield of bioethanol, solid biofuel and the estimated energy output from them.

It was found that the highest crop yield is formed with the application of plant growth regulator for both seed and sowings treatment. Slightly lower productivity was observed when only seeds or only sowings were treated. The lowest crop productivity was obtained in the control (without any treatment). The use of plant growth regulator had a positive effect on the physiological processes in plants resulting in more intensive plant growth and improved grain quality.

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