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ENERGY PRODUCTIVITY OF COMMON BICOLOR SORGHUM (*SORGHUM BICOLOR* (L.) MOENH) AND SORYZ (*SORGHUM ORYSOIDUM*) DEPENDING ON SEEDING RATES

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Topicality. *Recently, attention is being increasingly focused on the search for energy resources produced from renewable energy sources, namely from plant raw materials. There are increasingly relevant studies on the influence of elements of cultivation technology, in particular, seeding rates, on the formation of productivity of common bicolor sorghum and soryz used for biofuel production. There are increasingly relevant studies on the influence of elements of cultivation technology, in particular, seeding rates, on the formation of productivity of common bicolor sorghum and soryz used for biofuel production. In the eastern Forest-Steppe of Ukraine, the productivity of these crops largely depends on the variety, environmental conditions and elements of cultivation technology. Optimisation of seeding rates is one of the ways to increase grain and biomass yield and biofuel and energy output. P**urpose.** Our research aimed to determine the impact of sowing rates on the energy productivity of common bicolor sorghum and soryz in the conditions of the eastern Forest Steppe of Ukraine. **Methods.** In 2016–2020, the research was carried out at the Ivanivka Research and Breeding Station of the Institute of Bioenergy Crops and Sugar Beet of NAAS in the unstable moisture zone of the eastern Forest-Steppe of Ukraine The experimental design included: factor A – varieties Dniprovskyi 39 (common bicolor sorghum) and Samaran 6 (soryz); factor B – seeding rates: 1) 150 ths. seeds/ha; 2) 200 ths. seeds/ha; 250 ths. seeds/ha. **Results**. It was found that the different seeding rates have an impact on grain and biomass yield of sorghum and soryz, respectively, and on the estimated yield of bioethanol from grain, solid fuel yield from aboveground mass and total energy output. The maximum grain and biomass yield was obtained at a seeding rate of 200 ths. seeds/ha and was 6.8 and 39.2 t/ha for common bicoloured sorghum of Dniprovskyi 39 variety and 5.9 and 36.1 t/ha for soryz of Samaran 6 variety. **Conclusions.** Dniprovskyi 39 variety provided the highest output of bioethanol (2.24 t/ha) and energy (56.04 GJ/ha), and Samaran 6 variety – 1.95 t/ha and 48.63 GJ/ha, respectively. Sorghum has the highest output of solid fuel and energy – 9.06 t/ha and 147.6 GJ/ha, and soryz – 8.34 t/ha and 135.93 GJ/ha, respectively. For the production of biofuel and energy resources, the cultivation of common bicolor sorghum with a seeding rate of 200 ths. seeds/ha is more efficient.*

Key words: *variety, yield, grain, biomass, bioethanol, solid fuel, energy*

Introduction. In recent years, the search for new pollution-free energy sources from renewable raw materials for use as fuel has become increasingly important due to the deterioration of the environmental situation. Today, many countries in North and South America, as well as in Europe and Asia, are solving energy problems by producing biofuels of plant origin [1].

In Ukraine, agriculture plays a leading role in ensuring food and energy security of the country due to its bioenergy potential. However, despite the significant availability of agricultural biomass, the agricultural sector demonstrates slow development of enterprises and production of final products in the form of biofuels. Implementation of the bioenergy potential of agriculture is one of the components of sustainable development [2].

Development of renewable energy sources, in particular, bioenergy production, which will have a high economic and energy as well as environmental impact, is an important task for many countries [3].

The use of first-generation feedstock for biofuel production is being opposed by NGOs and government institutions in a number of countries, motivated by the possible competition between food and fuel and the negative impact on food security. Finding the most cost-effective strategies that ensure food and energy security is an impor-

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tant task for any country [4].

According to the Energy strategy of Ukraine for the period up to 2030 approved by Order of the Cabinet of Ministers of. Ukraine No. 145-p dd. 15.03.2006, the energy utilisation of all types of biomass is capable of replacing fossil fuels (9.2 million tonnes of equivalent fuel) annually, including through processing of agricultural residues, in particular, straw (2.9 million tonnes of equivalent fuel), firewood and wood waste (1.6); peat (0.6), municipal solid waste (1.1), biogas production (1.3) and production of fuel ethanol and biodiesel (1.8 million tonnes of equivalent fuel) [5].

Given that our world has largely depleted natural fuel resources, their consumption is both environmentally and economically unprofitable. Therefore, humanity faces the need and opportunity to harness renewable energy accumulated by plants, i.e. bioenergy [6].

Common bicolor sorghum (*Sorghum bicolor* (L.) Moenh) and soryz (*Sorghum orysoidum*) are promising energy crops for biofuels, namely bioethanol (ethyl alcohol as an additive to petrol) and solid biofuels (briquettes and pellets). Therefore, the study of the elements of technology for growing these crops in the eastern part of the Forest-Steppe of Ukraine is relevant.

Sorghum is a high-energy crop adapted for cultivation in Ukraine due to its high photosynthetic potential and drought tolerance, as well as its low water consumption and high starch content in its grain [7, 8].

Numerous scientists have studied the elements of sorghum cultivation technology [9–14], however, the issue of optimal seeding rates for energy purposes requires detailed research.

The purpose of the research was to determine the influence of seeding rates on the energy productivity of common bicolor sorghum and soryz in the eastern part of the Forest-Steppe of Ukraine.

Materials and Methods. In 2016–2020, the research was carried out at the Ivanivka Research and Breeding Station of the Institute of Bioenergy Crops and Sugar Beet of NAAS in the unstable moisture zone of the eastern part of the Forest-Steppe of Ukraine.

The experimental design included: varieties (factor A): Dniprovskyi 39 (common bicolor sorghum) and Samaran 6 (soryz), and seeding rates (factor B): 1) 150 ths. seeds/ha; 2) 200 ths. seeds/ha; 250 ths. seeds/ha.

The area of the sowing plot was 50 m^2, the record plot was 30 m^2, and the experiment was repeated four times. The experiment was laid out by the method of systematic repetitions, i.e. in each repetition; the experimental variants were placed sequentially in the plots. Sowing was carried out in May at a depth of 4–6 cm, row spacing was 45 cm.

The soil is typical slightly alkalinized heavy loamy chernozem. The agrochemical parameters of the arable layer (0–30 cm) were as follows: humus content was 4.5–4.7 % (according to Tiurin); pH was 7.2–7.4; alkaline hydrolysed nitrogen was 180 mg/kg of soil; P_2O_5 was 19–20 mg/kg; K_2O was 100–110 mg/kg of soil (according to Machigin). The absorption capacity of exchangeable cations is 26–31 mg-eq. per 100 g of soil.

Over the years of the study, meteorological conditions were typical for the area, but had some deviations from the long-term average. The highest temperature was observed in 2018, which was 3.5 °C higher than long-term data. In 2016, 2017, 2019, and 2020, the air temperature was 1.8–2.4 °C higher than the long-term average. The amount of precipitation varied over the years and was lower than long-term data.

The energy productivity, i.e. the yield of bioethanol, solid biofuels and energy, was determined according to the methodology developed by the Institute of Bioenergy Crops and Sugar Beet of NAAS. The bioethanol yield was calculated considering the grain yield of sorghum, which contains about 86 % dry matter and 75 % starch content at harvest; the solid fuel yield was calculated considering the biomass yield, its dry matter and solid biofuel moisture content of 10 % [15].

Results and Discussion. Plant density is an important factor that regulates plant assimilation of nutrients, moisture, light consumption and the assimilation intensity, and the formation of crop yield. The optimal plant density allows to achieve high yields with excellent grain and biomass quality. At different seeding rates, the plant density varies, and, as a result, unequal nutrition and lighting conditions are provided for the crops, which affect the productivity of grain and aboveground mass in general. High seeding rates result in increased relative and absolute humidity and reduced carbon dioxide concentration in crops, which is associated with deterioration of air exchange [16].

Research conducted in the zone of unstable humidity has shown that with the change in seeding rates, crop yields, bioethanol yield from grain, solid fuel yield from aboveground mass and energy yield also changed. The maximum grain and biomass yields were at a seeding rate of 200 ths. seeds/ha and reached 6.8 and 39.2 t/ha, respectively, for common bicolor sorghum of Dniprovskyi 39 variety, and 5.9 and 36.1 t/ha for soryz of Samaran 6 variety (Fig. 1).

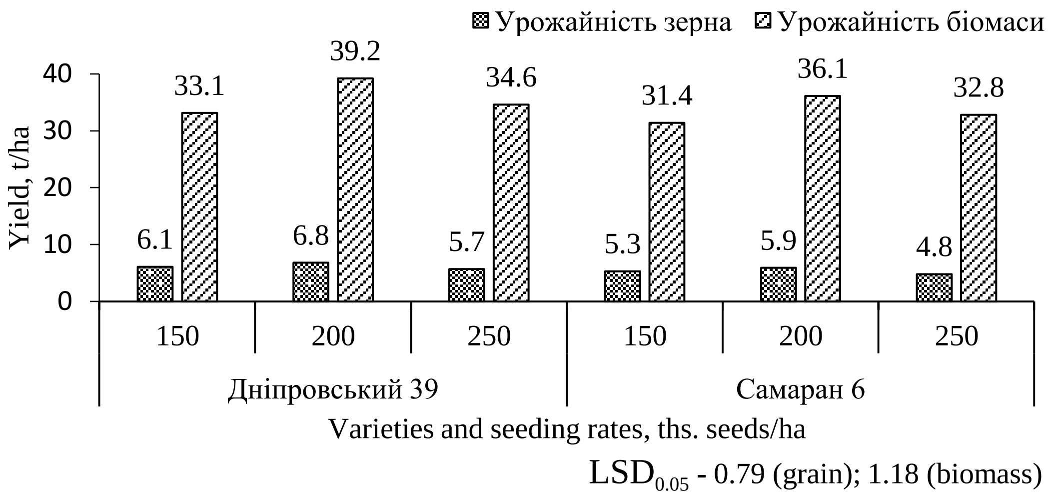

Fig. 1. Yield of common bicolor sorghum and soryz depending on seeding rates, t/ha (2016–2020).

The yield was lower at seeding rates of 150 and 250 ths. seeds/ha. At same time, at seeding rate of 150 ths. seeds/ha, the grain yield of sorghum was 6.1 t/ha, and that of sorghum was 5.3 t/ha, and the biomass yield was 33.1 t/ha, and that of sorghum was 31.4 t/ha. At a seeding rate of 250 ths. seeds/ha, the grain yield was 5.7 t/ha for Dniprovskyi 39 and 4.8 t/ha for Samaran 6; biomass yield was 34.6 and 32.8 t/ha, respectively.

The highest biofuel yield per unit area was obtained using seeding rate of 200 ths. seeds/ha for common bicolor sorghum and soryz (Table 1).

Table 1. Biofuel and energy yields depending on seeding rates of common bicolor sorghum and soryz, 2016–2020

Variety	Seeding rate	Yield of bioethanol, l/ha	Yield of solid fuel, t/ha	Energy yield from bioethanol, GJ/ha	Energy yield from solid fuel, GJ/ha	Total energy yield, GJ/ha
Dniprovskyi 39	150	2.01	7.65	50.27	124.63	174.91
	200	2.24	9.06	56.04	147.60	203.64
	250	1.88	7.99	46.98	130.28	177.26
Samaran 6	150	1.75	7.25	43.68	118.23	161.91
	200	1.95	8.34	48.63	135.93	184.55
	250	1.58	7.58	39.56	123.50	163.06

At the same time, Dniprovskyi 39 yielded 2.24 t/ha of bioethanol, and Samaran 6 yielded 1.95 t/ha. At the seeding rate of 150 and 200 ths. seeds/ha, the bioethanol yield decreased and was equal to 2.01 and 1.88 t/ha for Dniprovskyi 39, and 1.75 and 1.58 t/ha for Samaran 6.

Solid fuels in form of briquettes and pellets can be produced from the aboveground mass, namely sorghum stems and leaves. For example, common bicolor sorghum of the Dniprovskyi 39 variety produced 9.06 t/ha of solid fuel. The maximum yield of solid fuel for soryz of the Samaran 6 variety was 8.34 t/ha.

When seeding rate decreases to 150 ths. seeds/ha or increases to 250 ths. seeds/ha, the yield of solid fuel per unit area decreased in both varieties.

Correlation and regression analysis of the data showed a strong linear relationship between grain yield and energy yield from bioethanol, as well as between biomass yield and energy yield from solid biofuels. The correlation and determination coefficient was equal to 1 (Fig. 2).

Common bicolor sorghum and soryz are

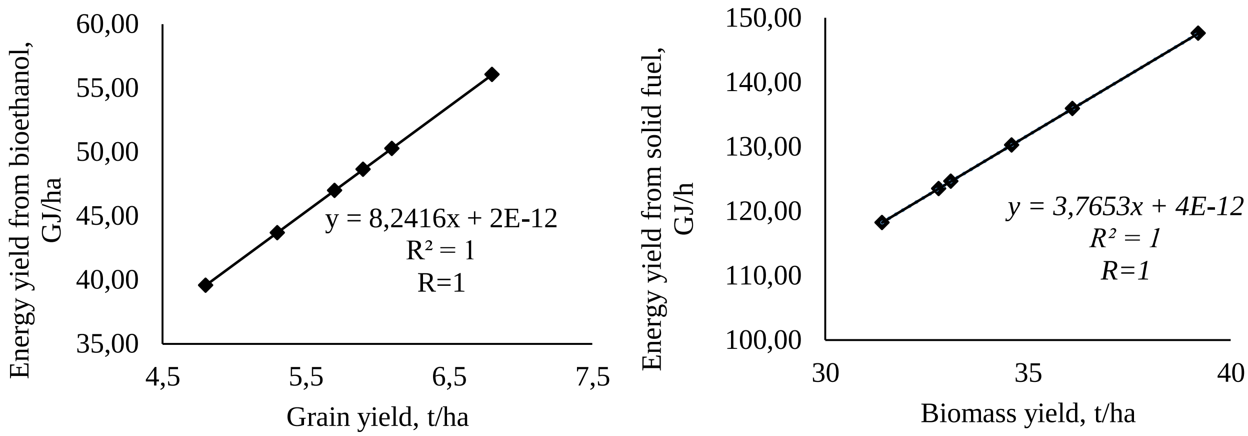

Fig. 2. Correlation and regression relationship between grain yield and energy yield from bioethanol and between biomass yield and energy yield from solid fuels, 2016–2020.

crops characterised by high productivity in difficult soil and climatic conditions and utilization flexibility [17].

Ukraine has all the objective prerequisites for large-scale bioethanol production. However, progress in scientific research into the possibilities, prospects and efficiency for biofuel utilisation is limited, and key issues in this area remain open for research. The feasibility of organising large-scale production will be determined by the availability of affordable and cheap plant feedstock. From this point of view, the most promising crops are sorghum characterised by high productivity potential and increased drought and heat resistance and salt tolerance. Most of the energy in sorghum is contained in substances that are easily converted into ethanol. The starch yield in sorghum grain is significantly higher than, for example, the starch yield from maize. In the US, sorghum is the main crop in bioethanol production, providing 25–30 % higher alcohol yields than maize and wheat [18].

Therefore, given the value of these crops, the study of elements of their cultivation technologies in specific soil and climatic conditions of Ukraine is promising and appropriate.

Conclusions

It was found that the highest grain and biomass yields of common bicolor sorghum of Dniprovskyi 39 variety and soryz of Samaran 6 variety in the eastern part of the Forest-Steppe of Ukraine were obtained at a seeding rate of 200 ths. seeds/ha. The grain and biomass yields of the Dniprovskyi 39 variety were 6.8 t/ha and 39.2 t/ha, and of the Samaran 6 variety were 5.9 t/ha and 36.1 t/ha, respectively.

In the same variant of the experiment, high bioenergy productivity of crops was observed. The highest estimated yield of bioethanol and solid fuel was observed in the Dniprovskyi 39 variety (2.24 and 9.06 t/ha) and in the Samaran 6 variety (1.95 and 8.34 t/ha). The total energy yield was 203.64 and 184.55 GJ/ha, respectively.

The correlation and regression analysis of the data showed a strong linear relationship between the productivity indicators and the estimated biofuel yield. The correlation and determination coefficient was equal to 1.

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Правдива Л. А. Енергетична продуктивність сорго звичайного двокольорового (Sorghum bicolor (L.) Moenh) та соризу (Sorghum orysoidum) залежно від норм висіву насіння.

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Актуальність. Останнім часом все більше уваги приділяється пошуку енергетичних ресурсів, які отримують із відновлюваних джерел енергії, а саме за рахунок рослинної сировини. Актуальності набувають дослідження з вивчення впливу елементів технології вирощування, зокрема, норм висіву на формування продуктивності посівів сорго звичайного двокольорового та соризу, необхідної для виробництва біопалива. У східній частині Лісостепу України продуктивність цих культур значною мірою залежить від сорту, зовнішніх умов та оптимальних елементів технології вирощування. Оптимізація норм висіву насіння є одним із шляхів підвищення урожайності зерна та біомаси, виходу біопалива та енергії з нього. **Метою досліджень** було визначення впливу норм висіву насіння на енергетичну продуктивність сорго звичайного двокольорового та соризу в умовах східної частини Лісостепу України. **Матеріали і методи.** Дослідження проводили в 2016–2020 рр. на Іванівській дослідно-селекційній станції Інституту біоенергетичних культур і цукрових буряків НААН – це зона нестійкого зволоження східної частини Лісостепу України. Схема досліду включала: сорти (фактор А): Дніпровський 39 (сорго звичайне двокольорове) та Самаран 6 (сориз), і норми висіву (фактор В): 1) 150 тис. шт./га; 2) 200 тис. шт./га; 250 тис. шт./га. **Результати.** Встановлено, що з різною нормою висіву змінювалась урожайність зерна та біомаси сорго і соризу, відповідно, змінювався і розрахунковий вихід біоетанолу із зерна, вихід твердого палива із надземної маси та загальний вихід енергії. Максимальна урожайність зерна та біомаси отримана за норми висіву насіння 200 тис. шт./га і становила 6,8 та 39,2 т/га у сорго звичайного двокольорового сорту Дніпровський 39 і 5,9 та 36,1 т/га у соризу сорту Самаран 6. **Висновки.** Найбільший вихід біоетанолу (2,24 т/га) та енергії з нього (56,04 ГДж/га) отримано у сорту Дніпровський 39 та 1,95 т/га і 48,63 ГДж/га – відповідно у сорту Самаран 6. Найвищий вихід твердого палива та енергії з нього отримано у сорго 9,06 т/га і 147,6 ГДж/га, а також у соризу – 8,34 т/га та 135,93 ГДж/га відповідно. З енергетичної точки зору більш ефективним, для виробництва біопалива та енергії з нього є вирощування сорго звичайного двокольорового з нормою висіву 200 тис. шт./га.

Ключові слова: *сорт, урожайність, зерно, біомаса, біоетанол, тверде паливо, енергія*