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Swet sorghum under the conditions of Ukraine: Patterns of yield formation and energy efficiency of biomass production

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ABSTRACT

In the context of intensifying global energy and environmental pressures, the expansion of alternative renewable energy sources has become increasingly important, with plant biomass remaining one of the most accessible options. For ecological engineering and national energy security – especially in countries undergoing reconstruction – identifying high-yield, climate-resilient bioenergy crops is critical. Sweet sorghum stands out as a species capable of producing large volumes of energy-rich biomass within a single growing season, the yield of which can be further increased through optimized cultivation technologies. This study provides the first production-scale data for Ukraine under the 2021–2023 climatic conditions, assessing the effect of foliar feeding on biomass formation and energy productivity. The field experiment involved the registered sweet sorghum variety *Favorit*, tested under four foliar fertilization treatments: control (no feeding), application at the seedling stage, at the tillering stage, and combined application at both stages, using Kristalon Special. Biometric measurements and biomass yield determinations were carried out according to approved scientific and methodological standards. Across three years, foliar feeding significantly increased plant biometric parameters compared to the control, particularly the number of internodes and leaves per plant, as well as the length and width of the upper leaf. Green mass yield showed a strong positive correlation with these morphological traits ($r > 0.71$), while dry biomass yield demonstrated a moderate correlation ($r = 0.48–0.62$). Foliar fertilization increased the total accumulated energy in sweet sorghum biomass from 596.6 to 665.0 GJ/ha, with the energy efficiency coefficient ranging from 1.37 to 1.84. The highest yields of green mass (97.6 t/ha) and dry biomass (33.8 t/ha) were obtained when Kristalon Special was applied twice – at the seedling and tillering stages. In practical terms, these findings demonstrate that optimized foliar nutrition can substantially enhance the productivity and energy efficiency of sweet sorghum, supporting its wider adoption in sustainable land-use systems and decentralized bioenergy production.

Keywords: sweet sorghum, yield, correlation, biomass, biofuel, energy efficiency.

INTRODUCTION

Sweet sorghum (*Sorghum saccharatum* (L.) Moench.) is a multipurpose crop cultivated for food, feed, technical, and bioenergy uses. The juice extracted from sorghum stems contains about 16–18% sugars, primarily sucrose, glucose, and fructose (Goshadrou et al., 2011).

Currently, one of the most pressing issues for both Ukraine and European countries is ensuring stable energy independence. The development of territorial communities based on the use of local bioenergy resources is a key factor in strengthening the state’s energy security (Kulyk & Padalka, 2020; Tryboi et al., 2024). A significant portion of Ukrainian land is degraded or disturbed but can be used for cultivating energy crops, which aligns with the principles of environmental sustainability and contributes to expanding the biomass resource base for bioenergy (Kulyk et al., 2020; Taranenko et al., 2021; Kulyk et al., 2022).

The use of domestic energy resources in the context of regional development has not only economic but also socio-environmental significance. The territories of Ukraine are characterized by a high potential for involving degraded and disturbed lands in energy crop cultivation, which will contribute not only to energy independence but also to the ecological restoration of these areas (Kozlenko et al., 2023; Kupchuk et al., 2023).

Due to its agronomic plasticity, adaptability to arid conditions, high photosynthetic activity, and significant biomass productivity potential, sweet sorghum is considered a promising crop for bioethanol production (Blaskó et al., 2008; Daliva-Gomez et al., 2011).

Biomass is widely recognized as a highly promising feedstock for biofuel production, primarily due to its low greenhouse gas emissions during utilization (Berndes et al., 2003; Antonopoulou et al., 2008). Scientific research has confirmed that bioethanol and other fuels derived from biomass are more environmentally safe compared to fossil energy carriers (Tillman et al., 2006). At the same time, current land-use trends emphasize the need for sustainable bioenergy production, taking into account rational land use and the impact on agro-landscapes (Bentsen & Felby, 2012).

Among the diverse energy crops investigated in Ukraine, sweet sorghum is highlighted as one of the most promising due to its high yield potential, high energy density of biomass, and strong adaptation to drought-prone environments (Bazaluk et al., 2021; Grabovskyi et al., 2023). Throughout the growing season, the crop forms substantial biomass, and its productivity increases under optimized agronomic practices and balanced nutrition (Kulyk et al., 2019; Havrysh et al., 2022). Its tolerance to drought, salinity, and temporary flooding makes it suitable for regions with limited water resources. Recent work on energy crops in various Ukrainian regions also confirms their strong adaptive properties under variable climatic conditions (Kaletnik et al., 2025). Additionally, broader ecological assessments of crop responses to harmful organisms highlight the importance of integrated agroecological management for maintaining biomass productivity under stress conditions (Kolisnyk et al., 2025).

International research reports several advantages of sweet sorghum relative to other bioenergy crops. Compared with maize, sweet sorghum requires less irrigation and nitrogen inputs, lowering production costs for both biomass and bioethanol (Velmurugan et al., 2020). Although miscanthus and switchgrass are widely used for lignocellulosic biofuel production, sweet sorghum often shows a superior energy balance due to lower input requirements, rapid seasonal growth, and dual outputs – fermentable juice and lignocellulosic biomass (Ganzhenko et al., 2025). These characteristics support its use in optimized energy-crop cultivation systems (Kulyk et al., 2020). Recent studies also provide detailed insights into miscanthus productivity and energy efficiency under Eastern European conditions, offering useful benchmarks for comparing crop performance (Lohosha et al., 2025).

Sustainable agroecosystem development emphasizes the need to align biomass production with environmental safety. Organic fertilizers such as biosolids can maintain productivity while reducing net CO_2 emissions (Glab & Sowinski, 2019). Studies from Korea highlight sweet sorghum's high salinity tolerance and its suitability for reclaimed or marginal soils (Kim et al., 2017). Research also demonstrates that sweet sorghum improves soil structure and fertility when used in intercropping systems or on degraded land (Zhu et al., 2022). Broader sustainability analyses confirm the importance of bioenergy crops in enhancing resource efficiency and recycling organic waste streams, including agro-processing residues (Koval et al., 2025).

Romanian studies demonstrate high productivity of locally adapted sorghum varieties under Southeastern European climates when using optimized soil and crop management (Dumitru et al., 2018; Caba et al., 2018). In Ukraine, sorghum cultivation has shown strong potential on degraded, saline, or technogenically disturbed soils, where significant biomass yields make it suitable for biofuel production (Kharytonov et al., 2019; 2021). Ecological and economic studies of fertilizer use in crop production further emphasize the role of optimized nutrient supply for sustainable biomass systems (Berezyuk, et al., 2021). Research also highlights the strategic importance of biofuel production from agrobiomass for national energy security and long-term environmental policy (Pryshliak et al., 2022). In parallel, engineering advances related to miscanthus cultivation – such as optimized rhizome digger design – support more efficient establishment and management of perennial energy crops (Adamchuk et al., 2024).

Sweet sorghum is a key feedstock for bioethanol production, with conversion efficiency strongly influenced by pretreatment processes such as steam explosion or hydrothermal treatment (Sipos et al., 2009). Ukrainian studies show high concentrations of sugars, proteins, and minerals in sweet sorghum biomass, supporting its versatility in bioenergy pathways (Rakhmetov et al., 2018). Technological approaches integrating alcoholic fermentation with pyrolysis, or using in-situ alkali generation for pretreatment, improve conversion efficiency and diversify biofuel outputs (Nghiem & Toht, 2019; Nenciu et al., 2022). Research on switchgrass in Ukraine further demonstrates the benefits of optimized technology for energy-crop biomass processing (Kulyk et al., 2020).

Organic amendments such as sewage sludge significantly improve sorghum performance on nutrient-poor soils (Akdeniz et al., 2006; Zuo et al., 2019; Al-Jaloud, 1999). Ukrainian studies show that sweet sorghum performs well on reclaimed land affected by industrial activities, yielding biomass suitable for various biofuel types (Kharytonov et al., 2019; 2021). Heavy-metal accumulation remains within acceptable limits for energy use, as shown by studies in Uruguay and China (Arlo et al., 2022; Zuo et al., 2019). Additional Ukrainian research highlights the accumulation of chemical elements in energy crops grown on gray forest soils, further supporting their regional adaptability (Razanov et al., 2024).

Long-term U.S. trials confirm high ethanol potential of sweet sorghum varieties under different climates (Ekefre et al., 2017). Ukrainian data similarly demonstrate adaptability under risk-prone farming conditions, with productivity influenced by sowing rates and planting methods (Boiko, 2024). Foliar feeding plays an important role in enhancing nutrient uptake, photosynthesis, chlorophyll content, and drought resistance (Mahmoud et al., 2020; Rizwan et al., 2022). Research on the ecological and economic benefits of utilizing waste resources also reinforces the potential of biomass systems for circular-economy development (Berezyuk, et al., 2019).

Overall, Ukrainian and global studies confirm that sweet sorghum is a highly productive, resilient, and resource-efficient energy crop. However, despite extensive research on sorghum fertilization and environmental interactions, there remains a lack of multi-year production-scale data from Ukraine assessing how foliar micronutrient feeding affects both biomass formation and energy efficiency – especially under the climatic variability of 2021–2023 and in the context of post-war agricultural recovery. The present study addresses this gap.

Studies have demonstrated that the use of sweet sorghum as an energy crop enables the production of substantial amounts of biomass (Jet al., 2020; Piasetskyi et al., 2022; Gamayunova et al., 2022). It has been established that sweet sorghum is more drought-tolerant than sugarcane (*Saccharum officinarum*) and maize (*Zea mays*), which are currently the main feedstocks for global biofuel production (Almodares & Hadi, 2009). Moreover, the production and utilization of bioethanol derived from sweet sorghum biomass can reduce greenhouse gas emissions by more than 70% compared with fossil fuels (Cai et al., 2013).

This, in turn, contributes to reducing Ukraine's energy dependence while fostering the development of territorial communities through job creation and economic growth (Kulyk et al., 2021; Kalinichenko et al., 2024).

The suitability of energy crop biomass for conversion into biofuels can be assessed by several key indicators that reflect its energy content, raw material density, renewability, and overall energy productivity (McLaughlin et al., 1996; Kulyk et al., 2019; Jankowski et al., 2020; Hanzhenko, 2021).The aim of this study is to provide a scientifically grounded assessment of the effects of differentiated foliar fertilization regimes using the chelated micronutrient formulation Kristalon Special on the biomass formation, energy output, and energy-efficiency parameters of sweet sorghum (*Sorghum saccharatum* (L.) Moench, var. Favorit) under the soil-climatic conditions of the central Forest-Steppe zone of Ukraine during 2021–2023. Specifically, the study seeks to determine the extent to which foliar applications at the seedling stage, tillering stage, or their combined application contribute to enhancing green mass productivity, dry matter accumulation, and the technological potential of biomass for liquid, solid, and gaseous biofuel production.

MATARIAL AND METHODS

The experiment was conducted during 2021–2023 at the "Abramivske" farming enterprise, located in the central part of the Forest-Steppe zone of Ukraine. The experimental plots were established on typical chernozem soils characterized by a humus content of 3.21%, alkaline-hydrolyzable nitrogen at 140.0 mg/kg of soil, phosphorus at 313.0 mg/kg, potassium at 224.0 mg/kg, and a salt pH of 6.9.

The average monthly precipitation during the study period was variable, with increased rainfall recorded in the summer months of 2021 and 2022. Excessive precipitation was observed in April 2022 and 2023, while considerably lower rainfall was recorded in July 2021 and May 2022. During May–June 2023, only minor precipitation was noted. Regarding temperature patterns, deviations from the long-term averages were registered in August across all study years.

The establishment and implementation of field experiments were carried out in accordance with the *Methodology of Experimental Practice in Agronomy* (Rozhkov et al., 2016) and the scientific recommendations of Ukrainian researchers on the technology of cultivation and processing of sweet sorghum as a biofuel feedstock (Hanzhenko et al., 2017).

The technological measures for cultivating sweet sorghum were carried out in accordance with scientific recommendations, except for the factors under investigation. Sowing of sweet sorghum was performed in the first ten days of May, when the soil temperature reached 13–15 °C. The seeding rate was 6–9 kg/ha (Dremlyuk et al., 2013). Observations and plant monitoring were conducted following the methodology of the State Scientific and Technical Examination of Plant Varieties. The yield of sweet sorghum biomass was determined by plot-based weighing within each of the four replications and recalculated per hectare.

The research material consisted of the registered sweet sorghum variety *Favorit*, which was tested under different variants of foliar fertilization. Within each of the four replications, the experimental variants included: variant 1 – control (no treatment); variant 2 – foliar application at the seedling stage; variant 3 – foliar application at the tillering stage; and variant 4 – combined treatment at both the seedling and tillering stages. The foliar fertilizer used was Krist Special. The chelated preparation Kristalon Special used in the experiment contains a balanced composition of macro-, meso-, and microelements corresponding to its NPK 18 formulation. It is recommended to apply the product during the tillering stage, at 4–6 leaves, and throughout the vegetation period of Poaceae crops via foliar fertilization. On the day of application, a working solution was prepared by adding 1.5 kg/ha of the product to 100 L of water.

The determination of green mass yield and the dry matter content of sweet sorghum biomass was carried out according to the recommended methodology (Kulyk & Halytska, 2018). Statistical processing of experimental data was performed in accordance with the methodology of agronomic data analysis (Ermantraut et al., 2007), using the STATISTICA 6.0 software package.

The energy assessment of sweet sorghum biomass was conducted following established methodological recommendations, taking into account the indicators presented in Table 1 (Kalinichenko & Kulyk, 2019).

The coefficient of energy efficiency for the production of the *i*-th type of product was calculated using the following formula (Medvedovskyi & Ivanenko, 1988):

This coefficient reflects the ratio between the energy obtained from biomass and the total energy invested in its production, serving as a key indicator of the efficiency of bioenergy crop cultivation systems.

$$K_e = \frac{E_{out}}{E_{in}},$$

where: E_{out} – the energy accumulated in the *i*-th type of product, GJ; E_{in} – the energy input for producing the *i*-th type of product, GJ.

Table 1. Unit of measurement for indicators of energy efficiency in sweet sorghum biomass production

Indicator	Name	Calculated per	Unit	Purpose
S_{by}	Solid biofuel yield	1 ha	t/ha	Amount of biofuel obtained from a given area
E_b	Energy in biomass	1 ha	GJ/ha	Energy obtainable from biomass per hectare
Eout	Total accumulated energy in biomass	1 ha	GJ/ha	Total energy content of biomass per hectare
Ein	Total energy input	1 ha	GJ/ha	Energy consumed for biomass production
Ec	Energy intensity of technology	1 t	GJ/t	Energy required to produce 1 ton of biomass
Epr	Energy consumption	ha	GJ/ha	Difference between total accumulated and consumed energy (Epr − Es)
Ke	Energy efficiency coefficient	–	dimensionless	Ratio of total accumulated energy to total input energy (Epr / Es)

RESULTS

Green and dry biomass yield

Analysis of the yield of green mass and the yield of dry matter (biomass) of sweet sorghum showed that these indicators varied both across the years of research and among the experimental variants studied (Table 2).

According to the data presented in Table 2, in 2021 the yield of sweet sorghum plants ranged from 85.4 to 99.3 t/ha for green mass and from 28.4 to 33.8 t/ha for dry biomass. In 2022, these values varied from 84.2 to 98.7 t/ha for green mass and from 28.1 to 35.0 t/ha for dry biomass. In 2023, the productivity of sweet sorghum was slightly lower, ranging from 76.4 to 94.8 t/ha for green mass and from 20.2 to 31.4 t/ha for dry biomass. The highest yields of both green and dry biomass were obtained in the fourth experimental variant, where foliar feeding with the chelated fertilizer *Kristalon Special* was applied twice – at the seedling and tillering stages (Figs. 1, 2).

The average yield of the aboveground vegetative mass of sweet sorghum over the study years ranged from 82.0 to 97.6 t/ha. The highest values were obtained in the variants where a double foliar treatment with the chelated fertilizer *Kristalon Special* was applied–at both the seedling and tillering growth stages.

Considering the moisture content of the plant material, the average yield of dry biomass of sweet sorghum over the three-year period ranged from 25.5 t/ha in the control plots to 33.8 t/ha in the plots where *Kristalon Special* was applied at both the seedling and tillering stages (variant 4). Based on correlation–regression analysis, significant relationships were identified between the biometric parameters of the plants and the yield of green mass and dry biomass of sweet sorghum (Figs. 3–6).

Thus, the yield of green mass in sweet sorghum largely depends on the linear dimensions of the flag leaf (length and width), as well as on the average number of internodes and leaves per plant, with a correlation coefficient of $r > 0.71$. The yield of dry biomass showed a moderate positive correlation with these parameters, with r values ranging from 0.48 to 0.62.

Productivity of sweet sorghum biomass

Taking into account the yield of green mass, its moisture content, and conversion coefficients,

Table 2. Yield of green mass and dry biomass of sweet sorghum, 2021–2023

Year (Factor A)	Variant (Factor B)*	Green mass yield, t/ha	+/– vs. control	Dry biomass yield, t/ha	+/– vs. control
2021	Variant 1	85.4	–	28.4	–
	Variant 2	93.5	8.1	31.3	2.9
	Variant 3	95.1	9.7	32.1	3.7
	Variant 4	99.3	13.9	33.8	5.4
Average		93.3	10.6	31.4	4.0
2022	Variant 1	84.2	–	28.1	–
	Variant 2	93.1	8.9	31.5	3.4
	Variant 3	95.8	11.6	32.6	4.5
	Variant 4	98.7	14.5	35.0	6.9
Average		92.95	29.8	31.8	4.9
2023	Variant 1	76.4	–	20.2	–
	Variant 2	83.2	6.8	23.0	2.8
	Variant 3	89.6	13.2	26.7	6.5
	Variant 4	94.8	18.4	31.4	11.2
Average		86.0	28.7	25.3	10.2
LSD_{05} (FactorA)		4.30	–	3.67	–
LSD_{05} (Factor B)		3.04	–	4.03	–
LSD_{05} (Factor AB)		0.21	–	5.81	–

Note: Variant 1 – control (no treatment); Variant 2 – foliar application of Kristalon Special at the seedling stage; Variant 3 – foliar application of Kristalon Special at the tillering stage; Variant 4 – foliar application of Kristalon Special at both the seedling and tillering stages.

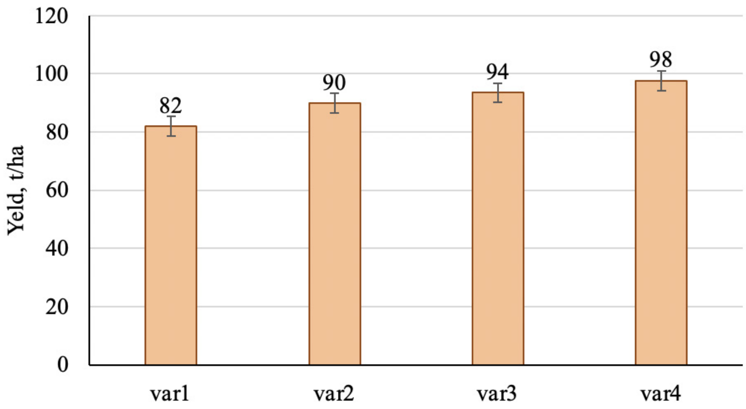

Fig. 1. Yield of the aboveground vegetative biomass of sweet sorghum, average for 2021–2023: Variant 1 – control (no treatment); Variant 2 – treatment of plants with "Kristalon Special" at the seedling (emergence) stage; Variant 3 – treatment of plants with "Kristalon Special" at the tillering stage; Variant 4 – treatment of plants with "Kristalon Special" at both the seedling (emergence) and tillering stages.

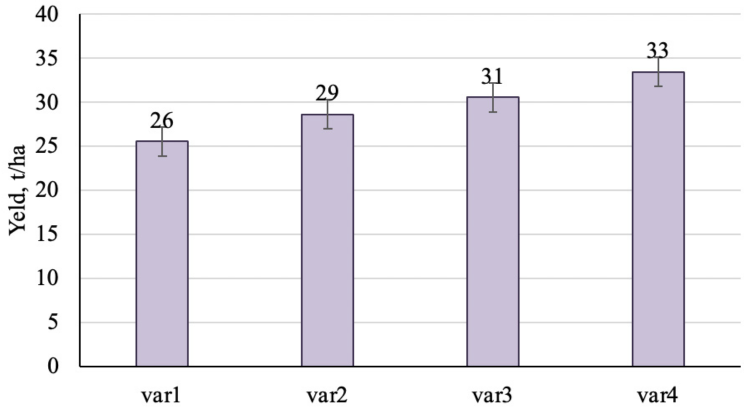

Fig. 2. Yield of dry biomass of sweet sorghum, average for 2021–2023: Variant 1 – control (no treatment); Variant 2 – treatment of plants with "Kristalon Special" at the seedling (emergence) stage; Variant 3 – treatment of plants with "Kristalon Special" at the tillering stage; Variant 4 – treatment of plants with "Kristalon Special" at both the seedling (emergence) and tillering stages.

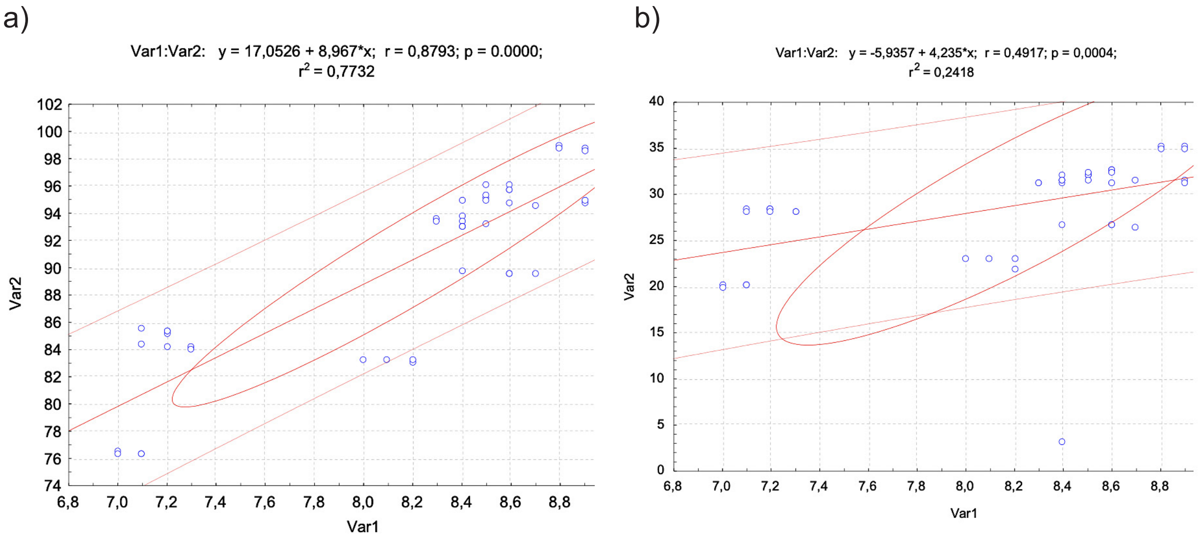

Fig. 3. Correlation between the average number of internodes per plant and the yield of green biomass (a) and dry biomass (b) of sweet sorghum, average for 2021–2023 (correlations are significant at the 5% significance level)

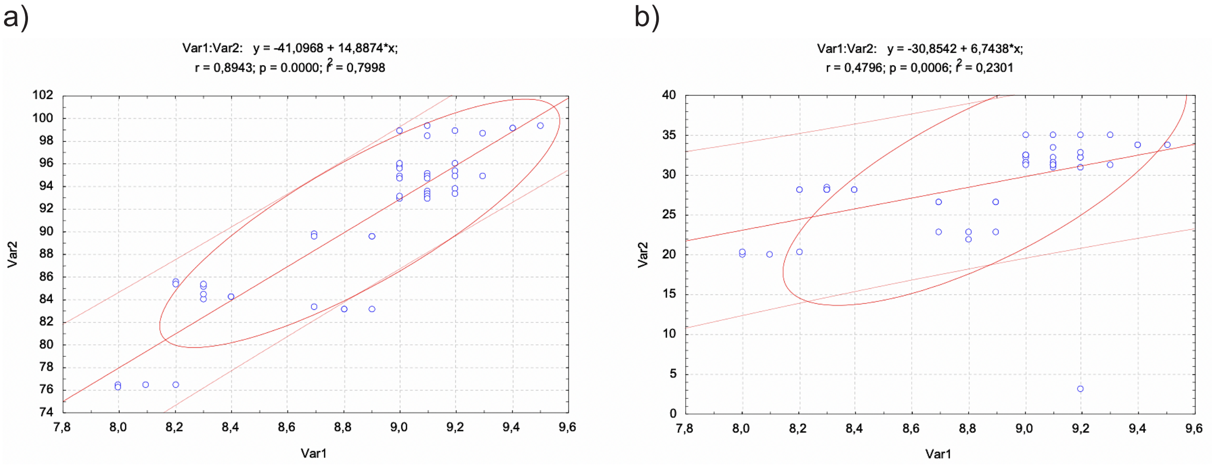

Fig. 4. Correlation between the average number of leaves per plant and the yield of green biomass (a) and dry biomass (b) of sweet sorghum, average for 2021–2023 (correlations are significant at the 5% significance level)

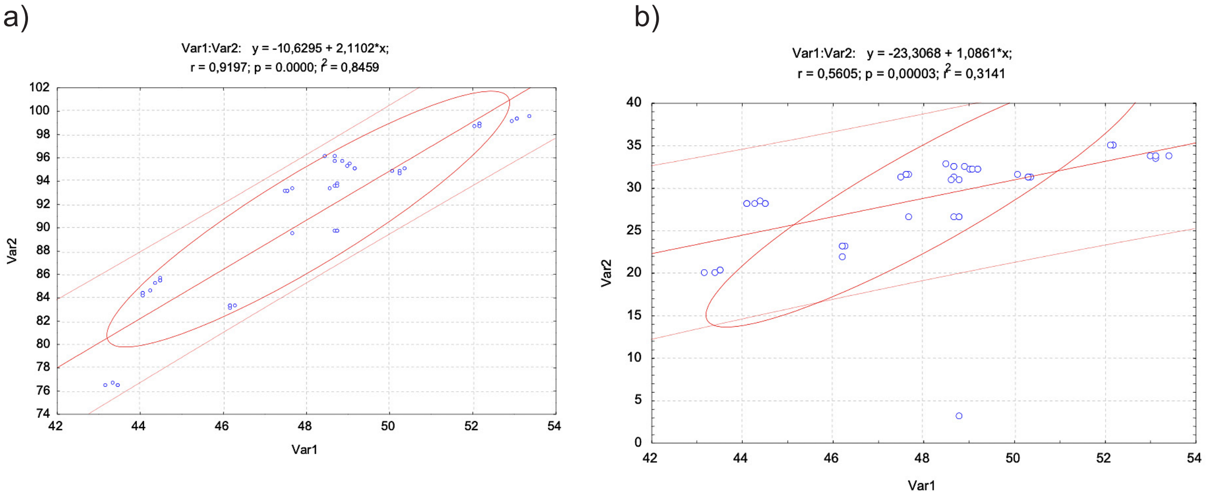

Fig. 5. Correlation between the average length of the flag leaf and the yield of green biomass (a) and dry biomass (b) of sweet sorghum, average for 2021–2023 (correlations are significant at the 5% significance level)

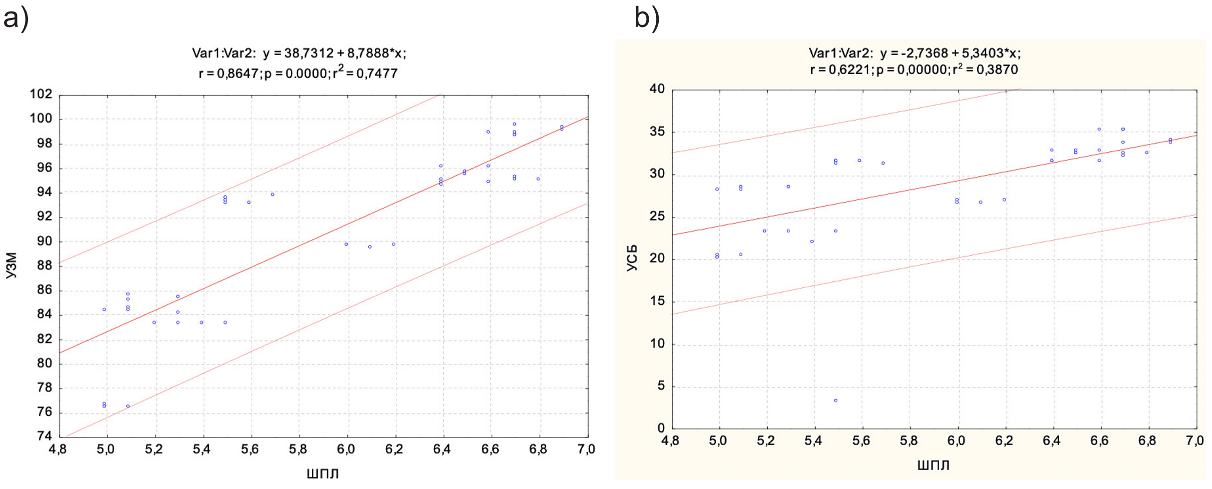

Fig. 6. Correlation between the average width of the flag leaf and the yield of green biomass (a) and dry biomass (b) of sweet sorghum, average for 2021–2023 (correlations are significant at the 5% significance level)

the output of biofuels–liquid, solid, and gaseous – was calculated (Table 3).

The maximum biogas yield was obtained under double foliar feeding of sweet sorghum plants in 2022–24.5 thousand m³/ha, with a corresponding bioethanol yield of 3.74 t/ha. In 2021, under the same experimental treatment, these indicators reached 23.7 t/ha and 3.51 t/ha, respectively. All other experimental variants resulted in considerably lower values.

During the cultivation of sweet sorghum biomass, the energy intensity of the production technology amounted to 12.59 GJ/t in 2021, 9.36 GJ/t in 2022, and 9.93 GJ/t in 2023,

Table 3. Biofuel yield from sweet sorghum biomass depending on crop fertilization

Year (Factor A)	Variant (Factor B)*	Green mass yield, t/ha	Sugar content, %	Calculated biofuel output		
				Biogas, thousand m³/ha	Bioethanol, t/ha	Solid biofuel, t/ha
2021	Variant 1	85.4	10.7	19.88	2.18	31.20
	Variant 2	93.5	11.4	21.91	2.54	34.40
	Variant 3	95.1	13.5	22.47	3.06	35.30
	Variant 4	99.3	14.8	23.66	3.51	37.20
Average		93.3	12.6	22.0	2.8	34.5
2022	Variant 1	84.2	12.3	19.67	2.47	28.1
	Variant 2	93.1	12.7	22.05	2.82	31.5
	Variant 3	95.8	14.2	22.82	3.24	32.6
	Variant 4	98.7	15.9	24.50	3.74	35
Average		93.0	13.8	22.0	3.07	31.8
2023	Variant 1	76.4	11.2	14.14	2.04	20.2
	Variant 2	83.2	11.9	16.10	2.36	23
	Variant 3	89.6	13.8	18.69	2.95	26.7
	Variant 4	94.8	15.1	21.98	3.41	31.4
Average		86.0	13.0	17.73	2.7	25.3

Note: Variant 1 – control (no treatment); Variant 2 – foliar application of Kristalon Special at the seedling stage; Variant 3 – foliar application of Kristalon Special at the tillering stage;

Table 4. Energy efficiency of sweet sorghum biomass production depending on crop fertilization, 2021–2023

Year (Factor A)	Variant (Factor B)*	Yield, t/ha	Energy efficiency indicators*					
			Solid biofuel yield, t/ha	Energy in biomass, GJ/ha	Energy input per 1 ha of crops, GJ/ha	Energy consumption, GJ/t	Energy profit, GJ/ha	Energy efficiency coefficient
2021	Variant 1	28.4	31.2	539.6	412.3	13.21	127.3	1.31
	Variant 2	31.3	34.4	594.7	420.5	12.23	174.2	1.41
	Variant 3	32.1	35.3	609.9	495.3	14.03	114.6	1.23
	Variant 4	33.8	37.2	642.2	468.4	12.59	173.8	1.37
2022	Variant 1	28.1	30.9	533.9	360.0	11.65	173.9	1.48
	Variant 2	31.5	34.6	598.5	370.4	10.71	228.1	1.61
	Variant 3	32.6	35.9	619.4	380.5	10.60	238.9	1.63
	Variant 4	35.0	38.5	665.0	360.3	9.36	304.7	1.84
2023	Variant 1	20.2	22.2	383.8	250.1	11.27	133.7	1.53
	Variant 2	23.0	25.3	437.0	270.8	10.71	166.2	1.61
	Variant 3	26.7	29.4	507.3	302.8	10.30	204.5	1.67
	Variant 4	31.4	34.5	596.6	342.5	9.93	254.1	1.74

Note: Variant 1 – control (no treatment); Variant 2 – foliar application of Kristalon Special at the seedling stage; Variant 3 – foliar application of Kristalon Special at the tillering stage; Variant 4 – foliar application of Kristalon Special at both the seedling and tillering stages.

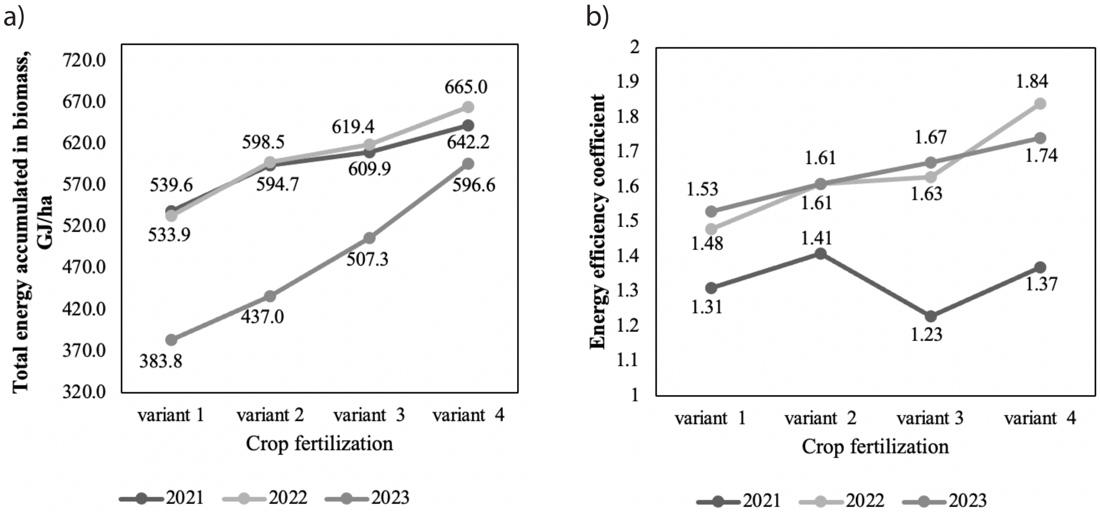

Fig. 7. Indicators of energy efficiency: a) total accumulated energy in biomass; b) energy efficiency coefficient of sweet sorghum biomass production depending on foliar feeding, 2021–2023

indicating a general trend toward reduced energy consumption. The highest net energy gain was achieved in 2022 – 304.7 GJ/ha – while the lowest was recorded in 2021, at 114.6 GJ/ha. Overall, the greatest energy gain was obtained from the treatment with *Kristalon Special* applied twice – at the seedling and tillering stages – yielding 304.7 GJ/ha in 2022 and 254.1 GJ/ha in 2023 (Table 4).

Figure 7 presents a comparison of the total energy accumulated in biomass and the energy efficiency coefficient under different foliar feeding treatments. The energy output from biomass with the application of *Kristalon Special* at both the seedling and tillering stages amounted to 642.2 GJ/ha in 2021, 665.0 GJ/ha in 2022, and 596.6 GJ/ha in 2023. The corresponding energy efficiency coefficients were 1.37, 1.84, and 1.74, respectively.

Therefore, to enhance the efficiency of sweet sorghum biomass production, it is advisable to apply foliar treatment with *Kristalon Special* at both the seedling and tillering stages. This approach contributed to an increase in profitability, reaching 87.3% in 2021, 80.7% in 2022, and 74.1% in 2023. The applied foliar feeding also improved the overall energy performance, particularly by increasing the total accumulated energy in biomass from 596.6 GJ/ha to 665.0 GJ/ha. The energy efficiency coefficient during the study period ranged from 1.37 to 1.84. The threshold value of energy feasibility is achieved when the energy efficiency coefficient equals or exceeds 1.0.

CONCLUSIONS

Based on the results of the conducted research, it was established that the energy efficiency of biomass production from the sweet sorghum variety *Favorit* increased during 2021–2023, primarily due to higher biomass yields under foliar fertilization. The highest dry biomass yields were obtained when Kristalon Special was applied twice – at the seedling and tillering stages – reaching 33.8 t/ha in 2021, 35.0 t/ha in 2022, and 31.4 t/ha in 2023, exceeding other variants by 5–11 t/ha. This treatment also provided the greatest net energy gain (up to 304.7 GJ/ha) and the highest energy efficiency coefficient (up to 1.84).

The results demonstrate that double foliar feeding enabling more stable yields under variable weather conditions, improving nutrient use efficiency, and increasing the profitability of sweet sorghum cultivation.. Given the crop's strong performance on degraded or marginal soils, the findings also highlight important ecological benefits, including the productive use of disturbed land resources and the potential to reduce greenhouse gas emissions by replacing fossil-based fuels with biomass-derived alternatives.

The demonstrated increase in bioethanol, biogas, and solid biofuel output also indicates that optimized foliar nutrition supports the development of localized, community-level energy systems, which is particularly relevant for regions seeking decentralized and resilient energy solutions.

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