

## The effect of planting dates and density on biomass and energy yield of giant miscanthus

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### ABSTRACT

The aim of the research was to assess the impact of planting dates and patterns and cultivation methods on the formation of individual productivity, raw yield and dry biomass and energy yield of giant miscanthus (*Miscanthus giganteus*) under field conditions in the forest-steppe zone of right-bank Ukraine. The article presents the results of three years of research. The field experiment was conducted using a three-factor experimental design: planting dates (second decade of October and first decade of May), cultivation methods (with and without ridge formation) and planting patterns 70 × 55 (25 thousand plants/ha and 70 × 70 (20.0 thousand plants/ha) with sequential placement of variants in the experiment with fourfold repetition. The highest yield of raw biomass (16.5 t ha<sup>-1</sup>), dry biomass yield (13.5 t ha<sup>-1</sup>) and energy yield (238.1 GJ ha<sup>-1</sup>) were obtained when the rhizomes were planted in October without ridge formation at a density of 25,000 plants ha<sup>-1</sup>. Plant survival and shoot density were significantly dependent on planting date and cultivation method. The dry biomass yield showed a strong positive correlation with the number of shoots per rhizome ( $r = 0.951$ ,  $R^2 = 0.9046$ ) and shoot height ( $r = 0.985$ ,  $R^2 = 0.9693$ ) according to Pearson's correlation analysis at a 0.01% significance level. These results demonstrate that optimising planting dates and density is crucial for maximising biomass productivity and energy yield of miscanthus in the conditions of the right-bank forest-steppe, thanks to improved early establishment and vegetative development in autumn planting conditions.

**Keywords:** miscanthus, scheme, planting dates, cultivation method, wet weight, energy.

### INTRODUCTION

The transition from fossil fuels to renewable energy sources is a strategic priority for many countries, including Ukraine (Roik, 2010; Palamarchuk and Telekalo, 2018; Palamarchuk et al., 2021). According to projections of the World Energy Council, renewable energy may supply up to 50% of global energy demand by 2050, with further growth to 80–90% by the end of the century (Roik et al., 2019). In this context, the

development of sustainable bioenergy systems is considered an important pathway for reducing greenhouse gas emissions and mitigating anthropogenic environmental impacts (Gumentyk, 2013; Kaletnik et al., 2020).

One promising approach is the cultivation of perennial bioenergy crops on marginal or low-productivity lands withdrawn from intensive agricultural use (Gumentyk, 2013; Kaletnik et al., 2020; Branitskyi et al., 2022; Bogomaz et al., 2025). In Ukraine, such lands include drained

peat soils (approximately 1 million hectares) and hayfields (about 0.8 million hectares), which are generally well supplied with moisture and nitrogen and therefore suitable for biomass production (Ryzhuk and Slyusar, 2006; Tkachuk and Verhelis, 2021; Pantsyryeva et al., 2023; Yatsenko et al., 2023; Korobko et al., 2024).

Species of the genus *Miscanthus* (Poaceae) include approximately 12 taxa, among which *Miscanthus sacchariflorus*, *Miscanthus sinensis*, *Miscanthus* × *giganteus* and *Miscanthus floridulus* are considered most valuable for biomass production (Hodkinson et al., 2002). In Europe, cultivation is predominantly focused on *M.* × *giganteus*, a high-yielding hybrid of tropical and subtropical origin (Zub and Brancourt-Hulmel, 2010). *Miscanthus* is a perennial C4 crop characterised by efficient photosynthetic capacity, low nutrient requirements, adaptability to marginal soils and long-term productivity (Sanderson et al., 1996; Christian and Elbersen, 1998; Christian et al., 2002). Dry matter yields of 25–28 t ha<sup>-1</sup> have been reported under favourable conditions (Deuter et al., 2000).

Beyond energy production, miscanthus biomass has multiple applications. It can be used for solid biofuel production (Bondar and Fursa, 2015), soil protection against water erosion (Schwarz et al., 1995; Prude et al., 1997; Pantsyryeva et al., 2023), wastewater phytoremediation (Frühwirth et al., 2005), building materials (Clifton-Brown and Lewandowski, 2000; Brosse et al., 2012;), and animal bedding due to its high absorbency (Schwarz et al., 1994; Deuter and Abraham, 2000). Its chemical composition, characterised by high cellulose (40–71%) and pentosan content, makes it suitable for pulp and paper production (Kyurchev et al., 2012; Gumentyuk et al., 2013; Geletyukha et al., 2016).

When pellets are burned, the gross energy yield per hectare is about 450 GJ/ha. *Miscanthus* is characterised by minimal loss of dry matter at the end of the growing season and is resistant to lodging. This crop does not require significant costs for its cultivation, and the miscanthus harvest is collected using a conventional forage harvester, and at the same time, the mass can be immediately delivered for the production of fuel pellets, briquettes or briquettes. This is a significant advantage, as the biomass of other energy crops requires additional drying (Kurilo et al., 2010; Jones and Walsh, 2001).

*Miscanthus* biomass has an energy value of 18–19 MJ kg<sup>-1</sup> and can provide gross energy

yields of up to 450 GJ ha<sup>-1</sup> when processed into pellets (Jones and Walsh, 2001; Kurilo et al., 2010). A key advantage of this crop is its ability to naturally reduce moisture content at the end of the growing season due to nutrient translocation to rhizomes, thereby lowering post-harvest drying costs (Kurilo et al., 2010). Harvest timing influences biomass quality, as demonstrated under Polish conditions, where late winter or early spring harvest ensures low moisture content and high calorific value (Bondar and Fursa, 2015).

Despite the well-documented productivity of miscanthus, biomass yield is strongly influenced by agronomic practices and environmental conditions (Baxter et al., 2014; Macák et al., 2015). Planting date affects morphological development, growing season duration, field establishment and final biomass yield (Pari, 1996; Ruan et al., 2009). Optimal planting is typically recommended when soil temperature at 5 cm depth reaches 10–12 °C (Melnichuk et al., 2019).

Plant density is another critical factor determining yield formation, particularly during the establishment phase. Recommended densities vary considerably depending on soil conditions, rhizome size and regional practices. Many authors consider 10,000 plants ha<sup>-1</sup> optimal (Geletyukha et al., 2020), whereas other studies report satisfactory results at 4 plants m<sup>-2</sup> (Khivrich et al., 2011). In the United Kingdom, recommended densities range from 10,000 to 20,000 plants ha<sup>-1</sup> (Bullard, 2006), while DEFRA suggests approximately 20,000 plants ha<sup>-1</sup> (McKervey et al., 2008).

However, data on the combined effects of planting time, planting density and cultivation method under Ukrainian soil and climatic conditions remain limited. In particular, the influence of autumn versus spring planting and ridge formation on biomass productivity and energy yield has not been sufficiently quantified.

It was hypothesized that (i) autumn planting would enhance plant establishment and result in higher biomass yield compared to spring planting due to improved early root development; (ii) increased planting density would promote greater shoot formation per unit area and thereby increase dry biomass yield; and (iii) ridge formation would influence plant establishment and productivity through modifications of soil moisture and temperature regimes.

The aim of the research was to assess the impact of planting dates and patterns and

cultivation methods on the formation of individual productivity, raw yield and dry biomass and energy yield of giant miscanthus in field conditions in the forest-steppe zone of Right-Bank Ukraine.

## MATERIALS AND METHODS

The research was conducted between 2022 and 2024 at the Uladovo-Lyulinets Research and Selection Station of the Institute of Bioenergy Crops and Sugar Beets of the National Academy of Agrarian Sciences of Ukraine (49°36'54'N 28°18'30'E) in Vinnytsia Oblast, Ukraine.

The climate is temperate continental. Sunny weather with moderate humidity and light winds prevails. Spring is sometimes prolonged. Summer is always warm, but not hot. Autumn is mostly dry, and winter is mild with frequent thaws. Hydrothermal conditions during the years of research were contrasting, which in turn made it possible to establish their influence on the growth and development processes of giant miscanthus.

In 2022, 431 mm of precipitation fell throughout the year, which is 71.9% of the long-term

average. In 2023, there was 513 mm of precipitation, which is 84.5% of the norm. 2024 turned out to be drier than previous years, with precipitation during the growing season at 382 mm, or 62.9% of the long-term average. The average air temperature in 2022 was 10.2 °C, in 2023 – 10.4 °C, and in 2024 – 10.8 °C, which is higher than the long-term average by 2.7, 2.9, and 3.3 °C, respectively.

The field experiment was conducted according to a three-factor experimental design: planting dates (second decade of October and first decade of May), cultivation methods (with and without ridge formation) and planting patterns 70 × 55 (25,000 plants/ha) and 70 × 70 (20,000 plants/ha) with sequential placement of variants in the experiment with four replicates (Figures 1, 2).

The area of the sowing plot is 50 m<sup>2</sup>, the accounting area is 32 m<sup>2</sup>. The total area of the experiment is 0.24 ha (Table 1).

Soil at the experimental site was deep, low-humus, leached chernozem with medium loamy texture. The humus horizon depth was 50–60 cm. Soil properties in the arable layer were: humus content 3.9–5.2% (Tyurin method), pH 5.9–6.6 (KCl extract), base saturation 86–91%,



**Figure 1.** Miscanthus planting scheme: on the left – planting without ridge formation; on the right – planting with ridge formation



**Figure 2.** Number of miscanthus plants under autumn planting conditions, 2022

**Table 1.** Experimental design

Experiment options	Planting season	Planting time	Growing method	Cutting planting pattern
1	Autumn	Second half of October	Normal	70 × 55 (25.000 plants/ha)
2				70 × 70 (20.000 plants/ha)
3			With ridge formation	70 × 55 (25 thousand plants/ha)
4				70 × 70 (20.0 thousand plants/ha )
5	Spring	The first ten days of May	Normal	70 × 55 (25 thousand plants/ha)
6				70 × 70 (20.0 thousand plants/ha)
7			with ridge formation	70 × 55 (25 thousand plants/ha)
8				70 × 70 (20.0 thousand plants/ha)

total nitrogen 0.24% (Kjeldahl method), available phosphorus 1.21–4.4 mg/100 g soil (Fransson method), exchangeable potassium 9.3–12.5 mg/100 g soil (Maslova method).

Soil moisture content was determined gravimetrically following DSTU ISO 11465 (DSTU, 2001). Bulk density was measured using cylindrical core sampling (Yeshchenko et al., 2004; Dubrovina et al., 2009). A giant miscanthus cultivar developed within the national bioenergy breeding program of Ukraine was used. The cultivar is characterized by an average dry matter yield of [approx. 20 t ha<sup>-1</sup>], a plantation lifespan of up to 20 years, and a biomass calorific value of 18 MJ kg<sup>-1</sup>. Ash content ranges from 0.5 to 1.5%.

Plant emergence dynamics were monitored from initial shoot appearance to full stand establishment using the IBKiCB methodology (Doroin et al., 2014). Phenological stages were recorded visually. Stage onset was defined when 10% of plants reached the stage, and mass occurrence was recorded at 75%. Monitored stages included: single and full emergence, third leaf stage, tillering, stem elongation, panicle appearance, and flowering initiation (Zinchenko et al., 2012).

Plant survival was calculated as the proportion of viable individuals relative to the number of planted rhizomes. Plant population density was determined after tillering and five days prior to harvest via direct counting within the accounting area.

Plant height, number of shoots per rhizome, leaf number, leaf area, shoot biomass per plant, and leaf biomass per shoot were measured at defined growth stages (Adati, 1962; Fisher, 2006).

Changes in moisture content and dry matter concentration were evaluated using a

thermogravimetric method (Kurylo et al., 2012). Rhizome and root biomass were assessed via soil monolith sampling from June to October, with five plants sampled per treatment per replication (Kravchenko et al., 2003). Winter survival was calculated as the proportion of plants that successfully overwintered relative to the number entering dormancy (Pysarenko et al., 2012).

Dry leaf and stem biomass was determined through total harvest sampling within the accounting area (Kurylo et al., 2010). Energy characteristics of the biomass, including gross energy yield, were analyzed following standardized methodological recommendations (Dubrovin et al., 2013). Harvest timing was aligned with the stage when plants had minimal moisture content to optimize calorific value ([e.g., late winter / early spring]).

The experimental data were processed using dispersion and correlation methods of analysis on a personal computer using special application programmes for Windows – 2003/2010: Excel-7.0, Mathcad 2000 (Moiseychenko and Yeshchenko, 1994).

## RESULTS AND DISCUSSION

In accordance with the study design, miscanthus was established during two planting seasons – autumn and spring. Bulk density within the 0–30 cm soil layer was evaluated, since this factor affects uniform shoot emergence by ensuring adequate contact between the rhizome and the upper soil horizon. Assessments were carried out both at planting and throughout the full vegetation period (Table 2).

**Table 2.** Soil bulk density across various planting schemes, seasons, and cultivation methods, g/cm<sup>2</sup>

Experiment options	Soil layer, cm			Average value
	0–10	10–20	20–30	
Planting miscanthus 22 October 2022				
1	1.22	1.26	1.32	1.27
2	1.23	1.27	1.33	1.28
3	1.19	1.23	1.27	1.23
4	1.21	1.26	1.30	1.26
Planting miscanthus 11 May 2023				
5	1.23	1.27	1.33	1.28
6	1.24	1.29	1.34	1.29
7	1.18	1.24	1.28	1.23
8	1.21	1.27	1.34	1.27

A progressive increase in soil density was observed with greater sampling depth. It is important to note that soil bulk density decreased under ridge planting conditions, whereas in the treatments without ridge formation it was higher. Furthermore, between the experimental variants and depended on the depth of the analyzed soil layer: bulk density ranged from 1.18 g/cm<sup>3</sup> in the 0–10 cm layer under ridge planting to 1.24 g/cm<sup>3</sup> in the 0–70 cm profile where ridges were not formed. Cultivating miscanthus on ridges in both autumn and spring led to decreased soil bulk density (variants 3 – 1.23 and 4 – 1.26; 7 – 1.23 and 8 – 1.27 g/cm<sup>2</sup>) compared with plots where rhizomes were planted on level ground without ridge formation (variants 1 – 1.27 and 2 – 1.28; 5 – 1.28 and 6 – 1.29 g/cm<sup>2</sup>).

By 05.08.23, soil bulk density indicators had become nearly uniform, particularly within the upper 0–10 cm horizon, fluctuating between 1.20 and 1.26 g/cm<sup>2</sup> (Table 3). Such changes are likely

associated with relatively adverse hydrothermal conditions during the subsequent growing season.

Nevertheless, a consistent pattern of reduced soil bulk density was observed under ridge cultivation of miscanthus in both autumn and spring plantings (variants 3 – 1.26 and 4 – 1.29; 7 – 1.26 and 8 – 1.30 g/cm<sup>2</sup>). In contrast, treatments established without ridge construction demonstrated higher bulk density values (variants 1 – 1.29 and 2 – 1.30; 5 – 1.31 and 6 – 1.33 g/cm<sup>2</sup>).

The productive moisture content in the upper and metre-deep soil layers was higher during autumn planting in ridges, experiment variants 3 – 139.4 (10–30+30–100 cm) and 2 – 142.4 mm (10–30+30–100 cm), as well as spring planting in ridges, experiment variants 7 – 123.0 (10–30+30–100 cm) and 8 – 127 mm (10–30+30–100 cm) (Table 4).

When planting without ridge formation, the productive moisture content decreased, as in autumn planting, experiment variants 1 – 134.5 (10–30+30–100 cm) and 2 – 132.2 mm

**Table 3.** Soil density on 05.08.23 for different cultivation techniques, g/cm<sup>2</sup>

Experiment options	Soil layer, cm			Average value
	0-10	10-20	20-30	
1	1.24	1.28	1.36	1.29
2	1.25	1.29	1.37	1.30
3	1.21	1.25	1.32	1.26
4	1.23	1.28	1.36	1.29
5	1.25	1.30	1.38	1.31
6	1.26	1.33	1.39	1.33
7	1.20	1.27	1.32	1.26
8	1.23	1.30	1.37	1.30

**Table 4.** Moisture content indicators in the soil layer under crops at different planting times, seasons, and cultivation methods, mm

Experiment options	Soil layer, cm				Average value
	0–10	10–20	20–30	30–100	
1	2	3	4	5	6
Planting miscanthus 22 October 2022					
1	8.6	9.9	12.5	103.5	134.5
2	8.2	9.7	12.1	102.2	132.2
3	7.9	9.8	12.6	109.1	139.4
4	7.8	9.9	13.4	111.2	142.4
Planting miscanthus 11 May 2023					
5	6.5	8.7	11.5	93.3	120.0
6	7.1	8.5	12.1	88.5	116.2
7	6.7	8.8	12.4	95.1	123.0
8	7.3	8.4	11.7	99.6	127.0

(10–30+30–100 cm), and when planting in spring, experiment variants 5 – 120.0 (10-30+30-100 cm) and 6 – 116.2 mm (10–30+30–100 cm). Throughout the vegetation period, soil moisture indicators across the treatments became relatively stable, varying between 74.3 mm (variant 1) to 84.5 mm (variant 6) (Table 5).

Earlier findings (Table 4) indicate that the highest levels of plant-available moisture within both the topsoil and the one-meter soil profile were associated with autumn ridge establishment. As of 05.08.23, moisture reserves amounted to 77.0 and 81.0 mm in variants 3 and 4 (10–30+30–100 cm), whereas in spring plantings the corresponding values reached 78.6 and 82.9 mm in variants 7 and 8 (10–30+30–100 cm). When planting without ridge formation, the productive moisture content as of 05.08.23 was almost the same as when planting in autumn, experiment

variants 1 – 74.3 (10–30+30–100 cm) and 2 – 74.9 mm (10–30+30–100 cm); and when planting in spring, experiment variants 5 – 78.1 (10–30+30–100 cm) and 6 – 84.5 mm (10–30+30–100 cm).

Throughout the 2023–2024 winter season, some of the established plants in both autumn and spring – particularly those grown on ridges – were partially affected by frost. At the onset of rhizome regrowth in spring 2024 and again 90 days thereafter, the plant population within the corresponding plots was assessed. The obtained data are presented in Table 6.

The highest plant density per two linear meters was recorded in treatments where rhizomes were established on a flat surface without ridge construction (variants 1 – 3.6; 2 – 3.5; 5 – 2.5; 6 – 2.5 plants). In contrast, plots with ridge-based planting demonstrated a pronounced reduction in plant density over the

**Table 5.** Moisture content indicators as of 05.08.23 in the soil layer under crops at different planting times, seasons, and cultivation methods, mm

Experiment options	Soil layer, cm				Average value
	0–10	10–20	20–30	30–100	
1	2	3	4	5	6
Mid-growing season 05.08.2023					
1	3.2	5.5	8.3	57.3	74.3
2	3.9	5.3	8.8	56.9	74.9
3	3.5	5.6	9.2	58.7	77.0
4	7.1	5.2	8.5	60.2	81.0
5	4.2	6.2	8.2	59.5	78.1
6	4.7	6.3	8.8	64.7	84.5
7	4.5	6.4	9.3	58.4	78.6
8	4.6	6.5	10.1	61.7	82.9

**Table 6.** Productivity indicators for miscanthus plants

Experiment options	Biometric indicators					
	Plant density per 2 running metres, pcs.		Number of miscanthus shoots from one rhizome, pcs.		Height of miscanthus shoots, cm	
	12.07.24	For the period of harvest accounting	12.07.24	For the period of harvest accounting	12.07.24	For the period of harvest accounting
1	3.6	3.6	6.6	7.3	80.9	167.8
2	3.5	3.5	6.3	7.0	76.8	164.5
3	1.7	1.7	4.4	5.1	57.7	133.4
4	1.5	1.5	4.2	4.9	54.9	131.7
5	2.5	2.5	4.5	5.0	40.8	127.4
6	2.5	2.5	4.3	4.8	37.5	126.3
7	1.0	1.0	2.4	3.0	41.3	105.9
8	1.0	1.0	2.2	2.7	40.6	104.7

same length (variants 3 – 1.7; 4 – 1.5; 7 – 1.0; 8 – 1.0 plants per 2 m).

The findings demonstrate a general increase in the number of shoots per plant in every experimental variant relative to the figures recorded at the initial regrowth stage and at mid-season. Miscanthus exhibited more vigorous development under autumn establishment. In particular, autumn planting without ridge formation resulted in 7.3 and 7.0 shoots per plant, with shoot heights reaching 167.8 and 164.5 cm. When ridges were used in autumn, shoot production decreased to 5.1 and 4.9, while plant height reached 133.4 and 131.7 cm, respectively.

Spring planting also ensured vegetation recovery; however, both shoot production and plant height remained inferior to that observed in autumn plantings. In spring plantings without ridges, 5.0 and 4.8 shoots per plant were documented, with corresponding heights of 127.4 and 126.3 cm. Under ridge cultivation in spring, shoot numbers decreased further to 3.0 and 2.7, and shoot height reached 105.9 and 104.7 cm, respectively.

Accordingly, treatments 1–4, established during the autumn period, produced an average of 5.4 shoots per rhizome, while mean plant height was 149.4 cm. In contrast, spring establishment (variants 5–8) was characterized by reduced shoot production of 3.4 per rhizome and an average height reaching 116.1 cm. The results confirm a statistically significant effect on both fresh biomass productivity and dry matter accumulation in miscanthus.

Miscanthus species belong to a group of long-lived perennial grasses suitable for multi-year cultivation. During the establishment year, plants develop their root system and typically produce only modest biomass yields. This pattern is consistently highlighted in scientific publications, which describe relatively low yields of various Miscanthus genotypes in the first year of cultivation. A substantial rise in productivity typically occurs beginning in the third year, when yields reach 10 t/ha and may exceed 20 t/ha (Gumentyk, 2013).

Specifically, under autumn establishment without ridge construction, fresh biomass production reached 16.5 and 15.7 t/ha, while dry matter yield amounted to 13.5 and 13.0 t/ha (Table 7). The corresponding energy output from the resulting solid biofuel was 238.1 and 229.3 GJ/ha. In contrast, ridge-based planting in autumn led to lower productivity indicators: fresh biomass decreased to 11.8 and 11.2 t/ha, dry biomass to 9.8 and 9.5 t/ha, and energy yield declined to 172.4 and 167.6 GJ/ha. When planted in spring without ridges, the plants grew well, but their performance was lower than when planted in autumn. Under spring establishment without ridge formation, fresh biomass production reached 10.2 and 9.9 t/ha, while dry matter yield amounted to 8.7 and 8.3 t/ha. The corresponding energy output from solid biofuel was 152.6 and 146.4 GJ/ha. When ridges were applied in spring, productivity indicators declined: fresh biomass decreased to 8.8 and 8.5 t/ha, dry biomass to 7.4 and 7.3 t/ha, and energy yield to 130.1 and 128.7 GJ/ha.

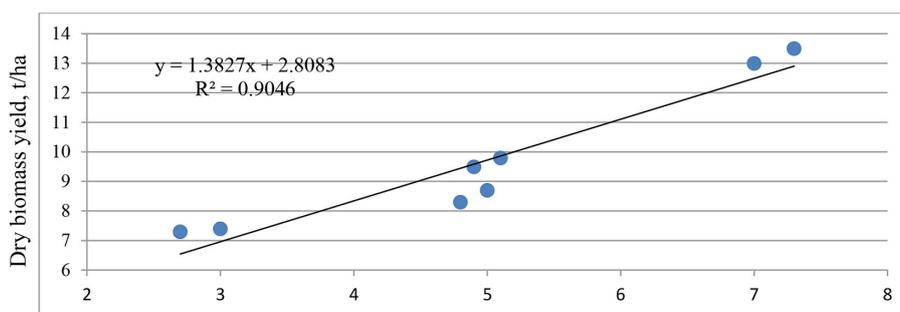
**Table 7.** Miscanthus productivity in the experiment, 2024

Variants of the experiment	Yield of raw mass, t/ha	Yield of dry biomass, t/ha	Energy yield from the solid biofuel obtained, GJ/ha
1	16.5	13.5	238.1
2	15.7	13.0	229.3
3	11.8	9.8	172.4
4	11.2	9.5	167.6
5	10.2	8.7	152.6
6	9.9	8.3	146.4
7	8.8	7.4	130.1
8	8.5	7.3	128.7
HCP <sub>05</sub> terms (A)		0.46	
HCP <sub>05</sub> cultivation method (B)		0.32	
HCP <sub>05</sub> planting scheme (C)		0.32	
HCP <sub>05</sub> AB		0.65	
HCP <sub>05</sub> AC		0.65	
HCP <sub>05</sub> BC		0.46	
HCP <sub>05</sub> ABC		0.93	

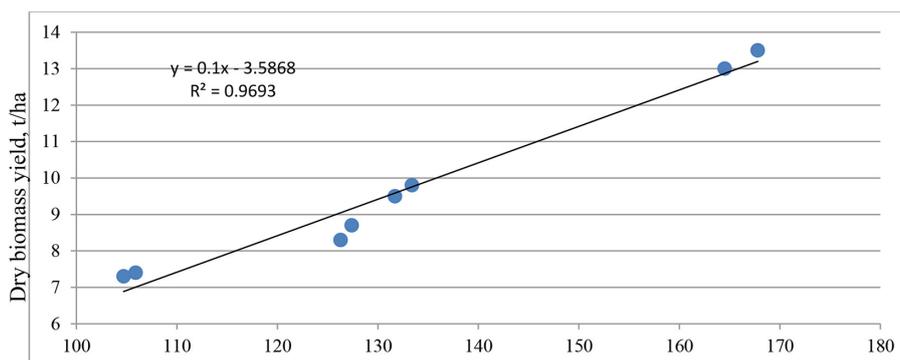
**Table 8.** Regression model describing the relationship between dry biomass productivity and both shoot number per rhizome and shoot height in miscanthus and the height of miscanthus shoots–  $r=0.985$ ,  $R^2=0.9693$

Dry biomass yield (Y), t/ha	Regression equation
	$y = 1.3827x_1 + 2.8083$ ( $r=0.951$ , $R^2 = 0.9046$ , $p<0,001$ )
	$y = 0.1x_2 - 3.5868$ ( $r=0.985$ , $R^2 = 0.9693$ )

**Note:** The values of the parameters X1 – number of miscanthus shoots from one rhizome, pcs.; X2 – height of miscanthus shoots, cm; r – correlation coefficient; R – coefficient of determination.



**Figure 3.** Analysis of the dependence of dry matter yield on shoot count per individual miscanthus rhizome



**Figure 4.** Regression model showing the relationship between dry biomass output and plant height of miscanthus shoots

In contrast, experimental variants 1–4, established in autumn, demonstrated substantially higher performance, with fresh biomass yield reaching 13.8 t/ha, dry matter accumulation 11.5 t/ha, and energy production from solid fuel amounting to 201.9 GJ/ha. In spring plantings, fresh biomass production averaged 9.4 t/ha, while dry matter yield reached 7.9 t/ha. The associated energy output from the harvested biomass amounted to 139.5 GJ/ha.

Enhanced development of above-ground traits – including plant height, leaf number, and total leaf area – promotes greater photosynthetic capacity and, consequently, increases overall productivity. These

morphological characteristics influence not only shoot biomass accumulation but also the formation of the root system and total biomass yield. Previous studies have confirmed strong direct relationships between above-ground biometric parameters and root mass. During the first year after establishment, correlation coefficients were reported at 0.84–0.92 for plant height, 0.76–0.82 for leaf number and leaf area, and 0.97–0.99 for root mass (Roik, 2010). The studies revealed strong correlations between dry biomass yield and the number of miscanthus shoots from a single rhizome during the harvest period:  $r = 0.951$ ,  $R^2 = 0.9046$  (Table 8, Figures 3 and 4).

## CONCLUSIONS

To obtain the highest yield of raw mass – 16.5 and, accordingly, dry biomass – 13.5 t/ha and energy output from the solid fuel obtained – 238.1 GJ/ha, miscanthus rhizomes must be planted in October, preceding the next growing season.

Establishing miscanthus rhizomes on ridges does not result in higher fresh biomass productivity, given the lower plant density after overwintering (experimental variants 3 – 1.7 and 4 – 1.5; 7 – 1.0 and 8 – 1.0 pcs.). Therefore, planting miscanthus rhizomes in ridges should be excluded. The plant density per 2 running metres in the experimental variants where rhizomes were planted without forming ridges was higher (experimental variants: 1 – 3.6 and 2 – 3.5; 5 – 2.5 and 6 – 2.5 pcs.). The maximum values of fresh biomass (16.5 t/ha) and dry matter yield (13.5 t/ha) were obtained in the variant featuring a 70 × 55 cm planting scheme (25,000 plants per hectare), where rhizomes were established in October without ridge construction.

Dry biomass accumulation in miscanthus showed a pronounced positive relationship with major biometric traits, especially shoot number per rhizome ( $r = 0.951$ ;  $R^2 = 0.9046$ ) as well as plant height ( $r = 0.985$ ;  $R^2 = 0.9693$ ), indicating a high degree of statistical association.

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