BIOENERGETIC EVALUATION OF MISCANTHUS GIANT PRODUCTIVITY IN CONDITIONS OF WESTERN FOREST-STEPPE OF UKRAINE FOR USE AS SOLID FUEL

Ulyana Nedilska, Serhii Yermakov, Anatolii Rud, Oleg Kucher, Oleksandr Dumanskyi
Podillia State University, Ukraine
ermkov@gmail.com

Abstract. The regularities of dependence of conditions of growth, development and formation of productivity of a miscanthus giant and increase of productivity at the expense of influence of agrotechnical factors are established in the work: terms of planting and depth of wrapping in the conditions of the western forest-steppe in Podillya. The results of the research are obtained on the peculiarities of the formation of biometric indicators of giant miscanthus depending on the application of a set of technology elements - planting dates, depth of rhizome wrapping. It was found that the increase in land mass of plants in the formation of yield 55.7 $t \cdot ha^{-1}$ was obtained by planting in the first period (I-II decade of April) to a depth of rhizome wrapping 9 cm. Intensity of land mass increase affected the yield of solid biofuels. During the first planting period with a rhizome wrapping depth of 9 cm, the maximum calculated energy yield of 206.09 $GJ \cdot ha^{-1}$ was obtained. It is established that the highest yield of bioenergy productivity of perennial miscanthus of the giant variety Autumn Starflower was obtained taking into account soil and climatic factors in the first planting period at rhizome depths of 9 cm, which allows efficient use of soil moisture and temperature during planting.

Keywords: miscanthus; planting; energy yield; biomass.

Introduction

Ukraine is interested in the development of biological fuels, belonging to energy-dependent countries and having a significant resource of unused biomass, which will strengthen the energy sovereignty of the state. Ukraine has all the prerequisites for active production and use of biofuels.

Given the agrarian orientation of the country's economy and favorable soil and climatic conditions for growing plants, the most promising segment of renewable energy for Ukraine is bioenergy. The share of biofuels in the structure of RES production in Ukraine in 2017 was 79.8%. Solid biofuel production in Ukraine is growing every year. Thus, in 2017, about 3.6 million tons of AD were produced, various types of solid biofuels, 15% of which are exported to Western Europe [1; 2]. The share of solid biofuel use in the domestic market is actively growing. In connection with the increased demand for raw materials for solid fuel bioenergy, there is a need to increase the amount of biomass for these purposes. But, taking into account that the grown biomass depends on many factors, in this context it is important for each specific case to understand the conditions and means that must be provided to maximize the volume of raw materials in the mass equivalent, because when transforming biomass into energy, the indicators are reduced to a kilogram of products (in contrast to volumetric indicators) and most closely reflect the energy value of biomass. Therefore, in order to ensure the maximum energy effect, it is necessary to conduct a study of the impact on the total biomass yield of both the soil and climatic conditions in which this or that crop will be grown, as well as the parameters and methods of its planting, care and other agrotechnical measures.

Soil and climatic conditions of most regions of Ukraine are favorable for growing perennial energy plants of group C4, capable of intensively transforming solar energy into energy-intensive biomass. Such plants include species and forms of the genus miscanthus, which have been grown for many years in America and Western Europe as a source of bioenergy [3; 4]. Studies have shown that biomass from miscanthus plantations grown in the western forest-steppe of Ukraine in Podillya is a raw material for obtaining high-quality briquettes.

Prospects for growing miscanthus as an alternative source of biofuel (calorific value > 17.5 $MJ \cdot kg^{-1}$) and physical properties make this product a local commodity for bioenergy. The measures taken to obtain solid biofuels from raw materials of the obtained energy plantations create opportunities for the development of agriculture in Podillya [5].

According to average data [6], the productivity of three-year plantings of miscanthus in the conditions of England was: in miscantus giganteus – 13.8-18.7 $t \cdot ha^{-1}$, in Germany – 22.8-29.1, and in Portugal – 34.7-37.8. That is, the productivity of miscanthus biomass can vary significantly depending on the conditions, so it is important to study the feasibility and effectiveness of its cultivation for specific conditions (in this work, in the conditions of the western forest-steppe of Ukraine). However, in any

DOI: 10.22616/ERDev.2023.22.TF207

case, the yield of dry biomass of miscanthus remains quite high. Due to this, as well as taking into account the high calorific value (5 kW/h·kg^{-1} or 18 MJ·kg^{-1}), low natural humidity of the stems at the time of harvest (up to 25%) miscanthus is the most effective compared to others crops as a plant for the production of solid biofuels.

The issue of growing and increasing the yield of miscanthus is quite relevant in modern science. So, for example, H.W Zub, M. Brancourt-Hulmel studied the possibility of improving tolerance to frost and the influence of water supply during the cultivation of miscanthus [7]. D. G. Christian, A.B. Riche studied the influence of the amount of nitrogen fertilizers on productivity [8], F.E. Miguez, M.B. Villamil studied the response of dry biomass production to planting density and nitrogen (N) fertilizer [8]. Clifton-Brown, J.C. studied the influence of miscanthus genotype on biomass yield and quality [10]. E.A. Heaton, S.P. Long analysed the general experience of growing miscanthus in the European Union [11].

During the combustion of miscanthus biomass, less carbon dioxide is released than was absorbed by plants during photosynthesis, so the use of biofuels from miscanthus will not contribute to the greenhouse effect. In addition, the cultivation of miscanthus has a positive effect on soil fertility, because after four years of cultivation in the soil it accumulates 15…20 t·ha^{-1} of rhizomes, which is equivalent to 7.2… 9.2 t·ha^{-1} of carbon [12]. One ton of dry mass of miscanthus is equivalent to 419 kg of crude oil, 1.7 tons of wood, 515 m^3 of natural gas, or 900 kg of coal. Miscanthus stems can be up to 4 meters high and contain 64…71% cellulose, which causes its high energy value.

Note that due to different dispersion, hydrophobicity, low energy content, low bulk density and usually high moisture content in such materials, their direct use in the raw form is problematic and limited mainly to internal use within the enterprise. Such raw materials require additional processing to improve fuel characteristics [14; 15].

However, in the context of this work, we will focus on the issues of ensuring the volume of miscanthus biomass collection and further assessment of the energy potential of the collected material, based on theoretical calculations.

Therefore, the purpose of this work is to identify the possibilities of increasing the bioenergetic productivity of growing miscanthus giant in the conditions of the western forest-steppe of Ukraine, taking into account the timing of planting and the depth of planting. Identifying the factors affecting bioenergy productivity will allow to develop approaches for the most effective selection of dates and methods of planting plantations in order to achieve the best effect in the overall harvest of biomass, which proportionally affects the potential of energy production from the use of this raw material as a solid fuel.

Materials and methods

At the higher educational institution “Podillia State University” in the joint educational and scientific laboratory “DAK GPS” work continues within the scientific topic “Agrobiomass of Ukraine as an energy potential of Central and Eastern Europe” (registration number 0119U103056) [16-18]. The activity of the laboratory is to assess the bioenergy potential of agricultural and energy crops. The research was performed during 2017–2019 in the research field of the State Agrarian and Engineering University in Podilya, which is located in the southern part of Khmelnytsky region, south-warm humid region (Podillya).

Climatic resources of Podillya are characterized by the following indicators: the sum of temperatures during the growing season, which lasts an average of 165 days, is 2600-2700 ºC, the value of the hydrothermal coefficient (HTC) 1.4, the amount of precipitation during the growing season 330-380 mm. Last spring frosts ended on average on 19.IV, and the first began on 16.X. The duration of the frost-free period is 175-180 days. Stable snow cover is formed in the third decade of December, and collapses in the third decade of February. The average height of snow cover is 14-16 cm, which effectively promotes overwintering.

The research was performed with the variety Miskantus Giant Autumn Starflower (Institute of Bioenergy Crops and Sugar Beet of NAAS of Ukraine), in which the frequency of harvesting of raw material - annually, from the second year of the growing season was studied.

Field research was conducted according to generally accepted scientific and special agronomic methods: Volkodava V.V. [19], and vegetation research - by the methods of Gritsayenko Z.M. [20].

The placement of options in the experiment is consistent. The estimated area of the plot is 50 m^2. The experiment included 2 factors: factor A – planting dates: I term (I-II decade of April), II term (II-III decade of April) and III term (I decade of May); factor B – depth of wrapping with a shirt: 6, 9 and 12 cm (Table 1).

Table 1

Scheme of the experiment

Factor A – planting time	Factor B – depth of rhizome wrapping
I term, A1	6 cm, B1
	9 cm, B2
	12 cm, B3
II term, A2	6 cm, B1
	9 cm, B2
	12 cm, B3
III term, A3	6 cm, B1
	9 cm, B2
	12 cm, B3

Accounting, observations and analyzes in the studies were conducted annually during the growing season of giant miscanthus (Fig. 1).

Fig. 1. **Execution of accounting and observation**

During the period of experiments the following analyses, accounting and observations were performed.

1. Phenological observations were carried out in the main phases of the plant growth and development. The main phases of the plant growth and development were noted. The beginning of the phase was recorded when it occurred in 10% of plants and completed – in 75% of plants.
2. Analysis of plant structure was performed on test sheaves and rhizomes, which were selected before harvesting from two non-adjacent repetitions in two places of the site, on the basis of: plant height, number of stems, number of leaves, number of rhizomes, mass of rhizomes, weight of the plant biomass.
3. The yield of dry leaf-stem mass was determined by the continuous method.
4. The yield of solid biofuel and energy from the obtained solid biofuel was calculated by the formulas: [18].

$$T = \frac{U \cdot c \cdot (100 + w)}{10000}, \quad (1)$$

where T – yield of solid biofuels, $t \cdot ha^{-1}$;
U – biomass yield of miscanthus stems, $t \cdot ha^{-1}$;
c – dry matter of stem biomass, %;
w – humidity of solid biofuel, %.

$$ET = T \cdot eT, \quad (2)$$

where ET – energy yield from solid biofuel, $GJ \cdot ha^{-1}$;
eT – energy consumption of solid biofuel, $MJ \cdot kg^{-1}$.

Results and discussion

Among the different approaches to assessing the bioenergetic potential of biomass, we highlight the approach of S.G. Atienza and Z. Satovic, who analyzed the agronomic properties of miscanthus, including the plant biomass, plant height, number of bushes, and stem diameter, in order to assess its potential as a bioenergy crop [21].

All vegetative organs of the plant are put in the form of buds by a shirt. When germinating, the root appears first, which is directed vertically to the lower layers of the soil, and then the seedling of the plant, which reaches the soil surface. For some time, the seedling uses the nutrients of the rhizome, and after germination young plants switch to their own root nutrition, form leaves and through photosynthesis form organic matter necessary for their growth and development (Table 2).

Table 2

Biometric and structural parameters of miscanthus plants depending on planting dates and depth of rhizome wrapping

Terms of planting	Wrapping depth rhizomes, cm	Height of the main shoot, cm	Number of leaves on the main shoot, pcs	Number of stems, pcs.	Stem diameter, mm	Number of internodes on the stem, pcs.
I	6	242.5	13.1	9.4	11.4	7.2
	9	254.8	14.8	11.8	11.5	7.3
	12	239.6	14.2	11.5	11.3	7.1
II	6	246.4	13.0	8.8	11.2	6.4
	9	251.6	14.0	10.4	11.4	6.6
	12	241.3	14.5	9.4	11.1	6.2
III	6	241.6	12.3	7.9	10.8	6.0
	9	237.8	13.0	9.8	11.0	6.1
	12	229.3	13.3	9.0	10.7	5.9

According to the obtained results of biometric indicators according to the research options, the height of the main shoot was first noted, which was 254.8 cm, the highest manifestation in the first planting period at a depth of 9 cm, while the in second planting period at the depths of both 6 and 12 cm it was shorter. Even lower height of the main shoot was characterized by the third planting period, which was at a wrapping depth of 9 cm only 237.8 cm, while in other variants of the third planting period at depths like 6 cm – 241.6 cm and 12 cm – 229.3 cm. The main shoot is characterized by high mechanical strength, it is a container of spare nutrients.

In general, the size and strength of the bush depends on the number of stems in it. These indicators are determined by the planting time and wrapping depth, as well as the quality of the planting material and the size of the planted rhizome. The formation of new shoots and the nature of their location determines the appearance of the plant. As a result of the estimated indicators on terms of landing the greatest quantity of 11.8 pieces stems marked the first planting period for wrapping depth of 9 cm, slightly less – 11.5 stems is typical for the first term for wrapping depth of 12 cm, other variants of the second term are marked by an even smaller number of stems 8.8 and 9.4 pcs. The number of stems in the third term was marked by the highest manifestation in the variant at a wrapping depth of 9 cm, while in other variants there were only 7.9 pieces and 9.0 pieces.

The strength of the stem and yield formation during the development phase of biomass drying is provided by the stem diameter, which is the largest 11.5 mm. Observations were found in the first term at a planting depths of 9 cm. Also, the strength of the stem can be maintained by the number of internodes, which in general, according to the experiment of observations, in the first term of planting is also noted – 7.3 pcs.

As it is a perennial plant in which the herbaceous stems are cut annually, and the rhizome remains in the soil, after a certain period of dormancy, growth and vegetation resume, giving rise to the development of new plants. Miscanthus is able to grow in one place for a long time, but in winter under the influence of low temperatures, the rhizome is damaged, especially in the first year of overwintering.

Therefore, according to the analyzed biometric indicators of giant miscanthus, depending on the planting dates and depth of wrapping rhizomes, the highest manifestation of indicators was analyzed, which will further form the biomass productivity for planting in the first term on the 9 cm wrapping variant.

For the comparative evaluation of the data, we will take this indicator as a reference, i.e. 100% of productivity according to various indicators. After converting the indicators of other terms and wrapping depths into percentages to these values, we will get a diagram (Fig. 2), from which it can be seen that, in general, the indicators have the ability to decrease in later terms, and there is also a trend towards better indicators at a wrapping depth of 9 cm, compared with 6 and 12 cm.

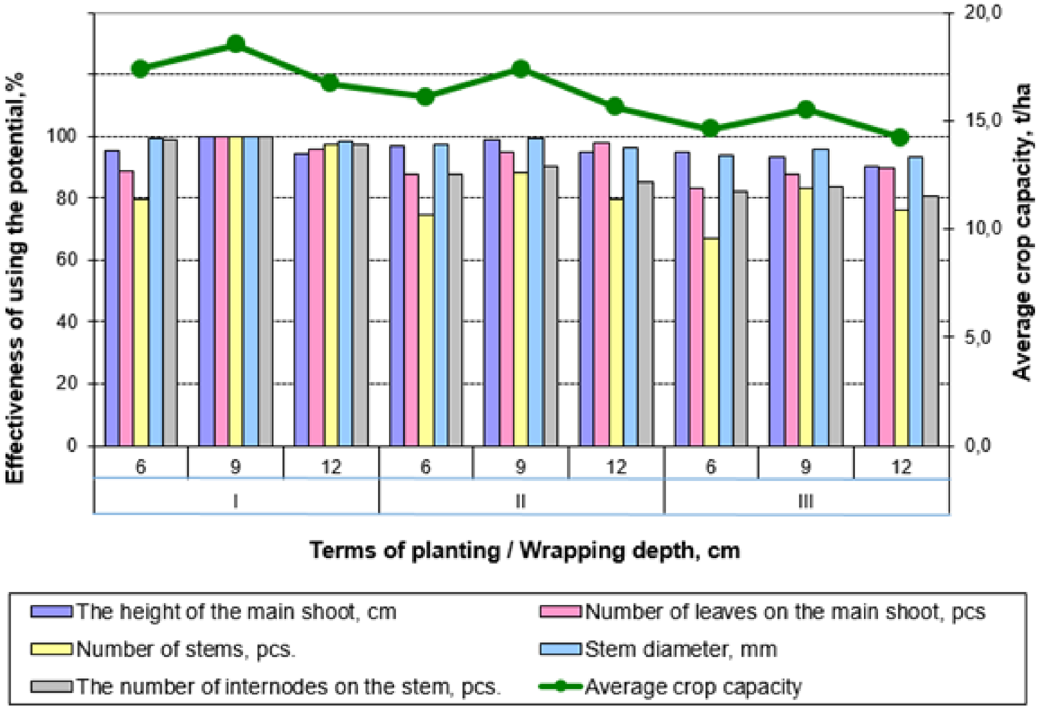

Fig. 2. **Comparative diagram of biometric and structural parameters of miscanthus plants depending on planting dates and depth of rhizome wrapping**

The main indicator of giant miscanthus in terms of economically valuable features as biomass is the yield. However, the yield of miscanthus plants depends on the timing of planting, accompanied by the consumption of organic matter and the depth of wrapping of rhizomes as the planting material. The final harvest may depend on the growth of the corresponding planting dates and this phenomenon is associated with the redistribution of assimilates, the formation and development of the plant.

According to the analysis of indicators (Table 3) of the yield of giant miscanthus for the years of the research according to the research options, it is noted that the maximum yield was analyzed in the first planting period (16.7-18.5 $t \cdot ha^{-1}$).

Accordingly, according to the criterion of the wrapping depth, the maximum yield of 18.5 $t \cdot ha^{-1}$ was analyzed, the variant of 9 cm was analyzed. Slightly less than at 12 cm and 6 cm, 16.1 $t \cdot ha^{-1}$ was also noted for the second term at the planting depths of 6 cm and even less in this planting period was found at the planting depth of 12-15.6 $t \cdot ha^{-1}$. The yield of the third planting period compared to the previous analyzed planting dates is less pronounced, which indicates the value of the wrapping depth option 9 cm and is 15.5 t·ha^{-1}, while the yield of the third planting period at the wrapping depth option 12 and 9 cm is 14.2-14.6 t·ha^{-1}. This is also due to the climatic conditions and reduced moisture content.

Table 3

Yield of giant miscanthus depending on planting dates and depth of rhizome wrapping, t·ha^{-1}

Planting time	Depth of wrap, cm	2017 year	2018 year	2019 year	Total	Average crop capacity
I	6	14.5	17.4	20.2	52.1	17.4
	9	15.8	18.6	21.3	55.7	18.5
	12	13.6	16.9	19.7	50.2	16.7
II	6	12.4	16.3	19.6	48.3	16.1
	9	14.8	16.9	20.4	52.1	17.4
	12	12.2	15.3	19.3	46.8	15.6
III	6	11.6	14.9	17.2	43.7	14.6
	9	12.3	15.6	18.5	46.4	15.5
	12	11.5	14.8	16.3	42.6	14.2
HIP05 A 0.32 B 0.32 AB 0.56						

The timing of planting and the depth of wrapping of rhizomes also affected the formation of the biomass yield of giant miscanthus. Yields by vegetation years of the research are marked by different values, which indicates the uniqueness of perennial crops. The lowest yields by years were observed in 2019. In general, under certain conditions, the yield of the first year was the maximum value of 15.8 t·ha^{-1} in the first planting period at the depth of wrapping rhizomes 9 cm.

In the conducted research, the tendency of decrease in biomass productivity at later planting was traced. In terms of years, the difference between the yield levels of giant miscanthus depending on the timing of planting was different. In the most favorable 2019, the difference between the first and second terms in terms of the yield was 0.9 t·ha^{-1} on the rhizome wrapping depth option, and 2.8 t·ha^{-1} between the first and the third. The difference between the second and third terms for the depths of rhizome wrapping 9 cm was also significant – 1.9 t·ha^{-1}.

In 2017, there were quite difficult agrometeorological conditions, which negatively affected crop yields. For planting in the first term miscanthus giant formed an average of 13.6-15.8 t·ha^{-1}, and for planting after 10 and 20 days it was less by 1.0-2.1 t·ha^{-1}, respectively, at the depth of wrapping rhizomes 9 cm…12 cm characterized by lower yields. In 2018, the difference in the yield between the first and second term of planting giant miscanthus was 1.7 t·ha^{-1}, a delay of 20 days caused a decrease in the yield by 1.7 t·ha^{-1} compared to the early spring period. The difference between the second and third terms at the depth of rhizome wrapping at 9 cm was significant and amounted to 1.3 t·ha^{-1}.

On average, a three-day delay with planting by 10 days caused a decrease in the crop yields by 1.1 t·ha^{-1}, and a 20-day delay by 3.0 t·ha^{-1}.

Thus, we can conclude that in the formation of the productivity of giant miscanthus the greatest influence had the interaction of climatic features over the years and planting dates on the depth of rhizome wrapping in the technology of growing giant miscanthus.

The values of these indicators differed slightly depending on the weather and climatic conditions of the year, but the general trend persisted in all years of the research - the greatest influence on the formation of productivity of miscanthus giant had the interaction of factors such as the planting time and depth of rhizome wrapping.

Thus, the yield of giant miscanthus was the highest in the variants of studies performed during the first planting period and the depth of wrapping of rhizomes 9 cm.

Figure 2 shows a graph of the yield of miscanthus giant depending on the biometric and structural parameters of miscanthus plants depending on the planting dates and depth of rhizome wrapping. The graph confirms the conclusions made earlier regarding the influence of miscanthus planting conditions and shows a general tendency to decrease the bioenergetics productivity of the crop when planting dates are shifted and there is deviation from the optimal depth of 9 cm.

Under market conditions, it is important to obtain high profitability at optimal costs for agricultural production. On the basis of effective technological measures that promote the productivity of bioenergy plants, it is possible to ensure greater production per unit of land area at the lowest cost and increase profits and profitability in crop production.

In the course of calculations, we separated the effectiveness of specific agricultural measures from a range of others, evaluated the products from the experimental options and calculated the yield of solid biofuel and energy (Table 4). The dry matter was 62%.

Table 4

Miscanthus yield and estimated yield of solid biofuels and energy depending on planting dates and rhizome wrapping depths (average for 2017–2019)

Planting time	Depth of wrapping	Crop capacity $t \cdot ha^{-1}$	Yield of solid biofuel, $t \cdot ha^{-1}$	Energy output, $GJ \cdot ha^{-1}$
I	6	17.4	11.97	193.79
	9	18.5	12.73	206.09
	12	16.7	11.49	186.02
II	6	16.1	11.08	179.38
	9	17.4	11.97	193.79
	12	15.6	10.73	173.71
III	6	14.6	10.04	162.54
	9	15.5	10.66	172.58
	12	14.2	9.77	158.17

The highest solid biofuel output of 12.73 $t \cdot ha^{-1}$, respectively, and energy output of 206.09 $Gj \cdot ha^{-1}$ was determined on the variant of the first planting period at a depth of 9 cm of rhizome wrapping.

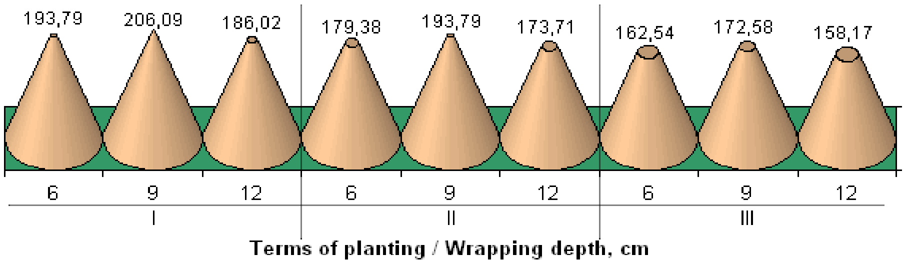

Fig. 3. **Theoretical energy output in terms of dry matter output, $GJ \cdot ha^{-1}$**

The diagram presented in Figure 3 shows the terms and depth of wrapping, at which the bioenergy potential is realized to the maximum. It is clear from the fullness of the cones that the optimal parameters for planting giant miscanthus are all indicators of the first planting period, as well as rhizome wrapping at 9 cm when planting in the second period.

Conclusions

As a result of the study the regularities of the dependence of the yield on the growth conditions, development and formation of miscanthus productivity increase due to the influence of agrotechnical factors: planting dates and depth of wrapping in the conditions of the forest-steppe.

1. Biometric indicators of giant miscanthus plants during the first planting period were the highest - shoot height reached 254.8 cm and with each subsequent planting period decreased by 3-5 cm. Maximum number of leaves on the main shoot of the first planting period 14.2 pcs. Number of stems in plants 11.8 pcs.
2. The maximum yield of miscanthus biomass of 55.7 $t \cdot ha^{-1}$ was obtained when planting in the first term to the depth of wrapping with a rhizome 9 cm. In the variants of the following planting dates the yield was 46.4-52.1 $t \cdot ha^{-1}$.

3. In terms of the estimated yield of solid biofuel miscanthus dominated variants of the first planting period and wrapping depth of 9 cm, respectively, and the second term of this depth, which was the highest yield, respectively, 12.73, 11.97 $t \cdot ha^{-1}$.
4. The maximum estimated energy yield was found in variants with a rhizome depth of 9 cm of the first planting period, which was 206.09 $GJ \cdot ha^{-1}$.

Author contributions

All the authors have contributed equally to creation of this article.

References

[1] Гелетуха Г., Крамар В., Епік О., Антощук Т. Комплексний аналіз українського ринку пелет з біомаси (Comprehensive analysis of the Ukrainian biomass pellet market) (In Ukrainian). [online] [11.02.2023]. Available at: http://bioenergy.in.ua/media/filer_public/4a/02/4a0236b5-a30b-4167-8c3b-7fd4 bcae 8926 /kompleksnii_analiz_ukrayinskogo_rinku_pelet_z_biomasi.pdf
[2] Енергетичний баланс України за 2017 рік. (Energy balance of Ukraine for 2017). Державна служба статистики України (State Statistics Service of Ukraine) 2018. (In Ukrainian).
[3] Wang C, Kong Y, Hu R, Zhou G. Miscanthus: A fast-growing crop for environmental remediation and biofuel production. GCB Bioenergy. 2020. pp. 58-69. DOI: 10.1111/gcbb.12761
[4] Роїк М.В., Курило В.Л., Ганженко О.М., Гументик М.Я. Методичні рекомендації з технології вирощування і переробляння міскантусу гігантського (Methodical recommendations on the technology of growing and processing giant miscanthus). Київ, 2015. 55p. (In Ukrainian).
[5] Ivanyshyn V., Nedilska U., Khomina V., Klymysnena R. Prospects of Growing Miscanthus as AlternativeSource of Biofuel. Renewable Energy Sources: Engineering, Technology, Innovation: ICORES 2017, 2018. pp.801-812. DOI: 10.1007/978-3-319-72371-6_78.
[6] Lewandowski I., Clifton-Brown J.C., Andersson B. Environment and harvest time affects the combustion qualities of Miscanthus genotypes. Agr. J. V.95. Is.5, 2003, pp.1274-1280. DOI: 10.2134/agronj2003.1274.
[7] Zub H.W., Brancourt-Hulmel M. Agronomic and physiological performances of different species of Miscanthus, a major energy crop. A review. Agronomy for Sustainable Development 30, 2010, pp. 201-214.
[8] Christian D.G., Riche A.B., Growth N.E. Yield and mineral content of Miscanthus×giganteus grown as a biofuel for 14 successive harvests. Industrial Crops and Products. V.28. 2008, pp. 320-327. DOI: 10.1016/j.indcrop.2008.02.009.
[9] Miguez F.E., Villamil M.B., Long S.P., Bollero G.A. Meta-analysis of the effects of management factors on Miscanthus×giganteus growth and biomass production. Agricultural and Forest Meteorology. V.148, 2008, pp. 1280-1292. DOI: 10.1016/j.agrformet.2008.03.010.
[10] Clifton-Brown J. C. Screening Miscanthus genotypes in field trials to optimize biomass yield and quality in Southern Germany. European Journal of Agronomy, 16(2), 2002, pp. 97-110.
[11] Heaton E.A., Long S.P., Voigt T.B. Miscanthus for Renewable Energy Generation: European Union Experience and Projections for Illinois. Mitigation and Adaptation Strategies for Global Change 9, 2004, pp.433-451. DOI: 10.1023/B:MITI.0000038848.94134.be
[12] Зінченко В.О. Міскантус - джерело енергетичної біомаси (Miscanthus is a source of energy biomass). Новини Агротехніки (News of Agrotechnics). 2008. V.3(63). pp.40-41. (In Ukrainian).
[13] Brosse N., Dufour A., Meng X., Sun Q., Ragauskas, A. Miscanthus: a fast-growing crop for biofuels and chemicals production. Biofuels, Bioprod. Bioref., 6, 2012, pp.580-598. DOI: 10.1002/bbb.1353
[14] Yermakov S., Hutsol T., Glowacki S., Hulevskyi V., Pylypenko V. Primary Assessment of the Degree of Torrefaction of Biomass Agricultural Crops. Environment. Technologies. Resources. 2021, pp.264-267. DOI: 10.17770/etr2021vol1.6597
[15] Yermakov S., Hutsol T., Rozkosz A., Glowacki S., Slobodian S. Evaluation of Effective Parameters Of Biomass Heat Treatment in Processing for Solid Fuel. Engineering for Rural Development. 2021. DOI: 10.22616/ERDev.2021.20.TF241
[16] Korchak M., Yermakov S., Hutsol T., Burko L., Tulej W. Features of Weediness of the Field by Root Residues of CornEnvironment. Technologies. Resources. 2021, pp.122-126 DOI: 10.17770/etr2021vol1.6541

[17] Tryhuba A., Komarnitskyi S., Tryhuba I. Planning and Risk "Analysis in Projects of Procurement of Agricultural Raw Materials for the Production of Environmentally Friendly Fuel" International Journal of Renewable Energy Developmentthis, V.11(2), 2022. pp. 569-580. DOI: 10.14710/ijred.2022.43011

[18] Yermakov S., Hutsol T., Ovcharuk O., Kolosiuk I. Mathematic simulation of cutting unloading from the bunker. Independent journal of management & amp; production (IJM&P). Vol. 10, No. 7. 2019. pp. 758-777. DOI: 10.14807/ijmp.v10i7.909

[19] Волкодав В.В. Методика державного сортовипробування сільськогосподарських культур. Загальна частина. (Methodology of state variety testing of agricultural crops. General part) В. - Київ, 2000. 100 p. (In Ukrainian).

[20] Грицаєнко З.М., Грицаєнко А.О., Карпенко В.П. Методи біологічних та агрохімічних досліджень рослин і ґрунтів (Methods of biological and agrochemical research of plants and soils). Київ. 2003. 320 p. (In Ukrainian).

[21] Atienza S.G., Satovic Z., Petersen K.K. Identification of QTLs influencing combustion quality in Miscanthussinensis Anderss. II. Chlorine and potassium content. Theor. Appl Genet 107, 2003, pp.857-863. DOI: 10.1007/s00122-003-1218-z