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Prospectives of Growing Energy Crops for the Production of Different Types of Biofuel

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ABSTRACT

The depletion of traditional energy sources and the increase in the cost of energy resources have a negative impact on the determination of the cost of production of agricultural and industrial products, which leads to a decrease in its competitiveness at the international level. Thus, the main task of the state is to ensure the efficient use of its own fuel and energy reserves and to diversify the sources and routes of supply of energy resources. Ukraine has all the necessary prerequisites for the widespread introduction and application of advanced technologies for growing and processing biomass and energy crops. The development of bioenergy technologies will help solve the problem of providing the country with energy resources, improve the environmental situation in the regions and help increase the employment of the local population. The fundamentals of growing less common energy crops are considered, the works of both domestic and foreign scientists are analysed, including the selection of the optimal place and soil, the establishment of optimal types of promising sparsely distributed energy crops, as raw materials for the energy sector of the state. Particular attention is paid to the need to improve the elements of technology in order to achieve a greater increase in biomass.

Keywords: bioenergy crops, perennial sida, perennial sorghum, camelina, spring rapeseed, productivity, macrofertilizers, biomass.

INTRODUCTION

The development and use of biofuels derived from renewable energy sources, in particular plant biomass play an important role in reducing Ukraine's energy dependence. As the cost of energy resources increases, biomass, which falls into the category of renewable energy, is becoming increasingly important worldwide. Currently, almost 80% of the world's energy supply is made up of non-renewable fossil fuels [Gupta et al., 2014; Hryhoriv et al., 2023a]. In global production, biomass used as fuel ranks fourth, accounting for 10% of total primary energy production. In the countries of the European Union, the share of biomass in total energy consumption is 7% [Tytko and Kalinichenko, 2010; Hryhoriv et al., 2023b]. In the leading EU countries, such as Latvia, Finland, Sweden, Denmark, and Austria, the share of biomass in gross energy consumption is 16–28%, while in Ukraine this share is slightly more than 1%. In particular, among all types of biomass, solid biomass makes up the largest percentage – 80%, and its distribution ranges from 0% to 94% depending on the country. The highest percentage of solid biomass use is observed in Finland. Ukraine has significant potential for the use of biomass for energy purposes, and all the necessary prerequisites for the widespread adoption of this renewable energy source [Juodka et al., 2022; Riaz et al., 2022; Hryhoriv et al., 2022]. During martial law, the impact of the energy situation has a negative impact not only on the economy, ecology and well-being of Ukrainian citizens, but also on dependence on imported energy. This becomes a prerequisite for Ukraine to actively consider alternative energy sources [Ryzhuk et al., 2002; Heletukha et al., 2014; Hryhoriv et al., 2022). According to the calculations, there are significant potential opportunities for the production of energy plant bioresources in Ukraine. The theoretical potential of biomass is almost 50 million tons of fuel equivalent, while the economically feasible volume ranges from 2 to 27 million tons. As for non–traditional herbaceous perennial energy crops, such as silphium, Jerusalem artichoke, miscanthus and sida, their production is estimated at 0.60 and 0.35 million tons, respectively [Kurgak et al., 2013; Kurgak et al., 2021; Radchenko et al., 2023]. The use of new high–yielding herbaceous energy crops, which are not yet widely used in the agricultural sector of Ukraine, has obvious advantages. The yield of thermal energy per hectare of energy crops is different [Kurgak and Tkachenko, 2016]. In particular, sida and miscanthus produce the largest amount of energy for the production of solid fuels [Heletukha et al., 2010; Rieznik et al., 2021].

When withdrawing from active cultivation of lands located in areas of agricultural landscapes that are subject to erosion (where they are allocated for natural forage lands and afforestation), part of these areas can be used for the cultivation of perennial herbaceous crops, including less common ones. These crops will not only effectively protect the soil from erosion, but will also serve as a source of bio-raw materials for the production of solid fuels, such as fuel briquettes or pellets, in rural areas [Petrychenko et al., 2014; Kurgak et al., 2020]. According to the analysis of literary sources [Roik et al., 2011; Heletukha et al., 2013; Heletukha et al., 2013; Dumych et al., 2013; Liu et al., 2023] it can be determined that research on the energy potential of perennial herbaceous phytocenosis of Ukraine and measures to increase their energy productivity has been carried out rather limitedly. The relevance of further research on this issue increases due to the increase in the cost of non-renewable primary energy sources and the decrease in the need for grass feed, as the number of livestock decreases [Kurgak, 2010; Woźniak, 2019; Lys et al., 2023].

An important task for researchers and agricultural producers is the development and optimization of cultivation technologies, economic and energy justification of technological processes, taking into account soil and climatic conditions [Fedorchuk et al., 2017]. The use of energy crops in production in Ukraine is currently at the stage of experimental research. For the successful integration of the cultivation of energy crops in Ukraine, purposeful work is required [Bentsarovskiy and Datsko, 2004; Tsyuk et al., 2022; Voitovyk et al., 2023].

An analysis of recent scientific studies and literature sources indicates a tendency to favor plant–based renewable biofuels. In recent years, a large number of scientists have been working to improve technologies for growing less common energy crops. In countries with a high level of economic development, technologies for growing and using energy crops are already widely used. However, studies aimed at studying the dynamics of biomass growth in energy crops have not been carried out before. Thus, the purpose of our study was to develop a technology for growing energy crops and analyze the impact of growth regulators on the growth of their productivity.

MATERIAL AND METHODS

In 2023, a study was conducted at the experimental site of the Botanical Garden of Vasyl Stefanyk Precarpathian National University. Soils at the experimental site are represented by sod-podzolic surface-gleyed type. In terms of mechanical composition, it is a heavy clay soil with a coarse dusty structure and a thick humus horizon (45 cm). Agrochemical indicators of the soil include acidity (pH – 4.5), and according to the degree of acidity it belonged to acidic soils, humus content (2.72%). As for the main macronutrients (NPK), the nitrogen and phosphorus content of the soil of the experimental plot was at a low level and amounted to 79.0 (mg kg^{-1}), phosphorus – 44.0, and the potassium content was at an average level – 99.0 mg kg^{-1}.

The study included the study of four bioenergy crops: Perennial Sida (*Sida hermaphrodita Rusby)* – Phytoenergy variety, Perennial Sorghum (*Sorghum almum Parodi) – Columbo variety, Camelina (Camelina Sativa Grantz) – Mountain variety, spring rapeseed (Brassica napus* L.) – Mykytynetsky variety. The crops were grown on the same background of $N_{50}P_{50}K_{50}$+ N_{30} fertilization. The experiment was carried out with quadruple replication and randomized placement of 24 separate plots. The total area of the experiment was 350 m^2, and the accounting area was 15 m^2.

As part of the experiment, the effect of macrofertilizers on the productivity of bioenergy crops was analysed. The agricultural technique of growing bioenergy crops was generally accepted, with the exception of technological measures that were studied [Syvyryn and Reshetnykov, 1988]. According to the study plan, the recommended doses of phosphorus-potassium fertilizers were applied, such as superphosphate P_2O_5 with a content of 18.4% of the active ingredient and potassium magnesia (K_2O – 40.2%), as well as nitrogen fertilizers in the form of ammonium nitrate with a nitrogen content of 34.4%. In the spring, fertilizers were applied to the experimental plots manually in accordance with the established doses.

Phenological observations were carried out on all variants of the experiment in accordance with the methodology recommended by the State Commission for Variety Testing of Crops. The assessment of the yield was carried out using the method of a continuous accounting plot, followed by recalculation per hectare. The competitiveness of cultivated technologies was assessed in accordance with the methodology developed by Garkav, Petrichenko and Spirin [2003]. Conditions in the Western region of Ukraine are influenced by three main factors: geographical location, circulation of air masses and relief. The Carpathians have a great influence on the formation of the climate of this region, which determine the distribution of air currents close to the earth's surface. Precarpathia is characterized by a moderately warm and humid climate. Meteorological analysis of the conditions formed during the growing season of bioenergy crops was carried out on the basis of the data of the Ivano-Frankivsk Regional Meteorological Station. Meteorological indicators of 2023 for the growing season of energy crops in Table 1.

In the analysis of meteorological conditions, covering all the months included in the research period. It was found that the year of the research was marked by a high level of thermal conditions and humidity. It should be noted that all the months that were the object of analysis were characterized by increased values of temperature and humidity compared to the norm. Particularly high temperatures were observed in July, August and September. These atmospheric conditions contributed to the rapid process of maturation of the crop.

RESULTS AND DISCUSSION

In Ukraine, out of all 32 million hectares of agricultural land, there are about 4 million hectares of infertile land that can be used to grow energy crops. An important task for researchers and agricultural producers is the development and improvement of cultivation technologies, as well

Table 1. Meteorological indicators of 2023 for the growing season of energy crops

Indicators	April	May	June	July	August	September	During the growing season
Precipitation, mm (average long-term)	90.0	67.0	90.0	84.0	75.0	55.0	461.0
Year 2023	53.7	33.7	174.2	42.1	75.1	21.6	400.4
I decade	11.8	31.9	37.8	3.3	34.7	7.7	127.2
II decade	2.0	1.8	80.8	10.5	0.0	13.6	108.7
III decade	39.9	-	55.5	28.3	40.4	0.3	164.4
Air temperature, °C (average long-term)	+8.4	+13.8	+17.0	+19.1	+18.2	+13.1	-
Year 2023	12.3	13.9	17.3	25.8	22.5	18.2	-
I decade	7.2	11.0	16.7	25.9	19.7	16.9	-
II decade	13.3	13.7	15.8	27.0	20.9	19.5	-
III decade	16.4	18.4	19.4	24.5	22.5	18.3	-
Sum of active temperatures, °C	617.8	128.6	515.3	422.4	653.4	546.5	2884.0
Sum of effective temperatures, °C	317.8	278.1	305.3	152.4	498.4	391.5	1943.5

as the economic and energy justification of technological processes, taking into account soil and climatic conditions. Currently, about 13.1 million hectares of land are available for growing bioenergy crops in the European Union. According to the European Commission, approximately 10% of the total area of agricultural crops should be used for energy crops.

Strong research work on energy crops is being carried out in Ukraine. To date, scientists are studying more than 20 types of fast-growing energy crops, which are advisable to grow to obtain plant biomass. As you know, energy crops include oilseeds, the raw materials of which are used to produce biofuels, and perennial herbaceous plants, which are raw materials for the production of fuel pellets and briquettes. It is known that today in Ukraine there are about 3.5 million hectares of land withdrawn from agricultural use due to their low fertility, susceptibility to erosion, etc. Therefore, on such lands, it is the cultivation of high-yielding, fast-growing bioenergy crops that will save soils from erosion, increase the capacity of the fertile humus layer, and generally improve the energy and environmental condition of our country. According to the results of our research, we can see that among the oilseeds from the cabbage family, spring rapeseed had the highest seed yield and was 0.08 t ha^{-1} higher than that of camelina. However, it should be noted that the oil content in camelina grain was at the level of 46.55%, which is 4.09% more than rapeseed. As a result, the oil yield from the camelina seed yield was almost the same (1.02 t ha^{-1}) as that of rapeseed (0.92 t ha^{-1}). Grain yield and oil yield from spring cabbage crops in Figure 1.

Our studies are in line with other literature data related to Romanian, Canadian, and Polish genotypes of camelina [Ciurescu et al., 2016; Krzyżaniak et al., 2019; Zając et al., 2020; Sikora et al., 2020; Trotsenko et al., 2023]. These data showed higher protein and fat content, but a slightly lower fiber content for Italian breeding [Peiretti and Meineri, 2007]. Ciurescu [2016] observed similar protein, fat, and ash content, but with a lower fiber content (approximately 11%) than in our studies. Zhang [2021] assessed the quality of two camelina varieties grown in different climates of different regions of China and reported that the protein and fat content was in the range of 21–36% and 26–35%, respectively [Zhang et al. 2021; Tanchyk et al. 2021]. It should be noted that promising energy crops are perennial herbaceous plants that are adapted to cultivation in Ukraine. It was found that during the study period, the lowest yield was observed in perennial sorghum (31.0 and 40.1 t ha^{-1}), respectively, according to fertilization options. At the same time, the yield of perennial seed was at the level of 36.8 t ha^{-1} in the control without fertilizers and 49.9 t ha^{-1} in the variant with the use of fertilizers. Yield of green mass of bioenergy crops in Figure 2.

At the same time, it was determined that during the period of the study, the yield of bioenergy crops on fertilized cultivation options differed from the yield of these crops on the control plots without fertilizers and was higher. In the cultivation of perennial seed, the difference was 35.6%, perennial sorghum, respectively, 29.5%. It was proved that perennial seed plants responded better to fertilizers compared to perennial sorghum, because

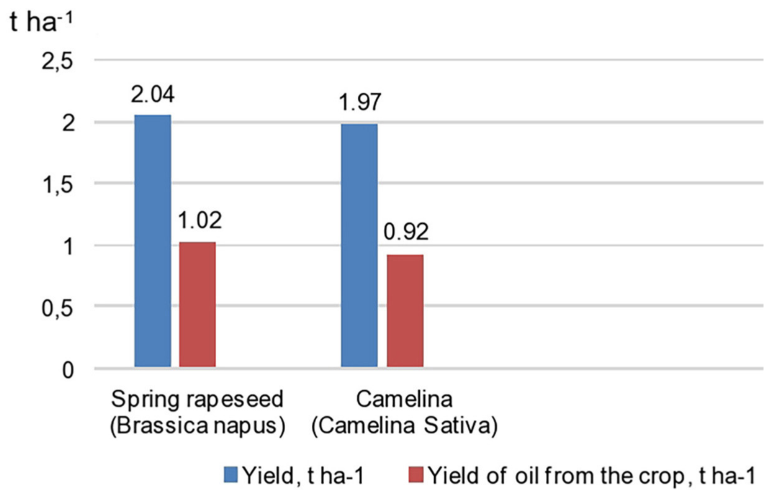

Figure 1. Grain yield and oil yield from spring cabbage crops (2023) (on the background of N50P50K50 + N30), t ha^{-1}

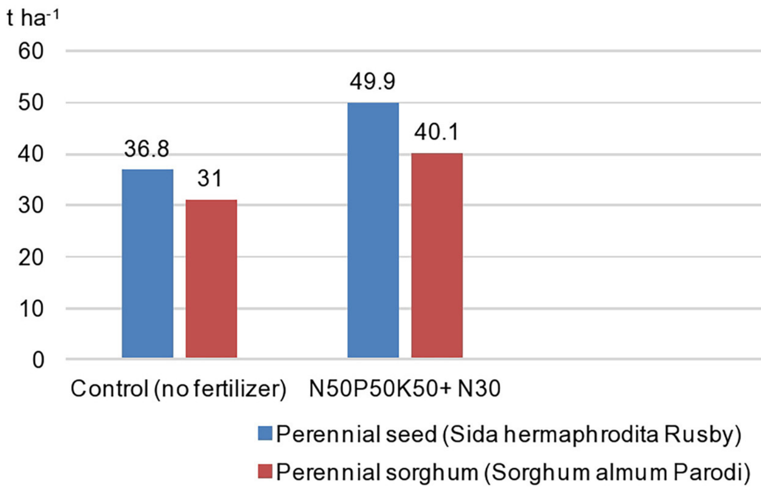

Figure 2. Yield of green mass of bioenergy crops (2023)

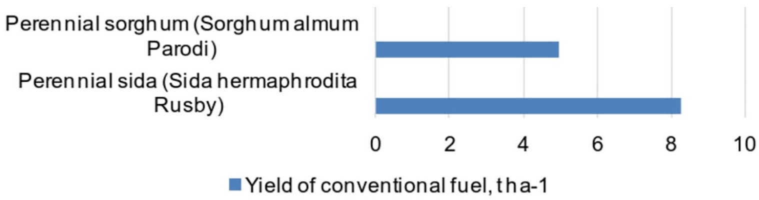

Figure 3. Yield of conventional fuel from phytoraw materials of perennial energy crops when grown in the conditions of the Western region of Ukraine (on the background of N50P50K50 + N30), t ha^{-1}

the yield increase was 6.1% higher. Based on the conclusions on the yield, the yield of the equivalent fuel was determined. Notional energy resources are measured in a quantity known as conventional fuel, which is the amount of fuel and energy expressed in total energy units. In Ukraine, a ton of conventional fuel is used as a unit of energy measurement, which is equivalent to a ton of coal equivalent (TCE).

Conventional fuels are used to evaluate the efficiency and overall accounting of different fuels. Nominal fuel is calculated using 1 kg of fuel, which has a heat consumption of 7000 kcal kg^{-1} when burned. In oil and gas geology, it is standard practice to convert 1 billion m^3 of natural gas into 1 million tons of fuel equivalent. We calculated the necessary raw materials from energy crops for the production of 1 kg of fuel equivalent based on experimentally obtained data. Yield of conventional fuel from phytoraw materials of perennial energy crops when grown in the conditions of the Western region of Ukraine in Figure 3. The recalculation was carried out under the condition that the dry weight of the stems was used for the production of biofuels. The highest yield of conventional biofuel was determined in perennial seed 8.27 t ha^{-1}. The yield of conditional biofuels from perennial sorghum was noticeably lower than that of perennial sida. This is due to the limited formation of stem mass in plants and is the result of the biological characteristics of these crops. The initial conventional biofuel for perennial sorghum was 4.98 t ha^{-1}. In Ukraine, plant varieties have been created in the phytoenergy direction, intended for cultivation for various types of biofuels, such as liquid (ethanol, biodiesel and others), gas, solid (briquettes, pellets, etc.). For the production of biofuels, it is more expedient to grow not only traditional, but also less common energy crops, mainly perennials. Such crops are more productive, less energy-intensive, and can be grown on land that is not suitable for traditional crops.

CONCLUSIONS

The application of mineral fertilizers on sod-podzolic soils in relation to all bioenergy crops was effective and ensured an increase in the yield of both seeds and green mass of the studied plants. Camelina is a species with impressive biological adaptability to agroecological conditions, showing great resistance to drought, unpretentiousness to soils and especially to the use of chemicals to protect against pests and diseases. The seed productivity of camelina is not inferior rapeseed, and in the conditions of the Western region of Ukraine can be approximately 2.0 tons per hectare with an oil yield sufficient to produce 1.0 tons of biodiesel.

The most productive perennial plant was perennial sida, the average yield of which during the study period was 49.9 t ha^{-1}. It is proved that an important direction of bioenergy is the use of high-yielding crops for the production of solid biofuels and the production of biodiesel.

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