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Biomass Research of Energy Crops and Their Nature Restoration Potential

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Abstract : This scientific paper is dedicated to the study of the potential for using bioenergy crops, using the example of giant miscanthus on oil-polluted territories. Throughout the research, various fertilization schemes were applied to analyze their impact on the growth and development of miscanthus. The yield of energy and solid biofuel from the obtained biomass of giant miscanthus was determined. In addition, it was found that miscanthus has significant potential in the phytoremediation of contaminated lands and can contribute to the restoration of soil cover. The scientific work presents results from a three-year observation, demonstrating the widespread use of bioenergy crops, particularly miscanthus, for ensuring energy security and ecological balance.

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1 Introduction

Today, humanity is faced with new challenges that require an urgent solution: the exhaustion of traditional energy sources, the increase in the cost of their production, the pollution of the environment at an increasing rate as a result of their extraction, transportation and consumption; formation of an excessive amount of organic waste of industrial, agricultural and household origin [1, 2, 3]. All this has acquired threatening proportions and is a factor influencing global climate change.

One of the ways to partially overcome this kind of problems is to increase the share of renewable energy sources, in particular raw bioenergy resources, in the overall balance of energy resources. For Ukraine, bioenergy is one of the strategic directions of development of the sector of renewable energy sources [4-7]. A large number of plants were studied to determine their possible use as energy crops [3, 4, 8, 9]. Among other promising species, miscanthus is spreading, the cultivation of which on degraded soils can create conditions for slowing down degradation processes and stabilizing the ecological state of such soils for a long period of up to 20-25 years, with their subsequent revitalization, which will contribute to increasing the stability of soil systems and partially improving their basic agro-, bio-, physico-chemical, and ecological properties [3, 6, 10, 11].

Ukraine and Slovakia has a resource potential for the production of biomass for energy purposes. This encourages new approaches and the development of complex technologies in the cultivation of bioenergy crops, which will make a significant contribution to strengthening energy security, improving the condition of the soil cover, and improving the ecological situation [6, 11-14].

Oil pollution is one of today's global environmental problems, and restoration of oil-polluted ecosystems is a priority practical task for scientists. Phytoremediation is an integral part of a complex of measures aimed at improving the quality of the technogenic environment due to oil extraction and processing [1, 9, 12, 15, 16].

In this regard, promising phytoremediators are energy plants, among which miscanthus occupies a prominent place, which has the ability to absorb oil products, counteract soil erosion and enrich unproductive degraded soils. Among a wide range of pollutants, oil contains heavy metals that have a mutagenic, carcinogenic effect on living systems and lead to premature death of organisms [2, 4, 5, 8, 17, 13].

Therefore, the problem of detecting the accumulation of heavy metals by fast-growing energy plants-hyperaccumulators is urgent. Miscanthus is a species of perennial herbaceous plants that belongs to the grass family and is distinguished by the C4 type of photosynthesis process [1, 6, 9, 11, 16].

Almost 200 million tons of conventional fuel are consumed in Ukraine every year, while production from natural sources is only 80 million tons. With such an imbalance of own and imported energy raw materials, biofuel is a potential energy resource [3, 6]. By 2035, the Energy Strategy of Ukraine envisages increasing the share of renewable energy sources in the total primary supply of energy resources to 25%, and it is planned to increase energy production from biomass to 11 million tons in oil equivalent, or to increase it 4 times, compared to the existing volumes [3, 6, 9, 18].

Bioenergy crops are relatively new for Ukraine - herbaceous miscanthus and are characterized by a height of more than 1.5 - 2.5 m, a powerful root system that penetrates to a depth of 2.0 m and more, and leaves a large number of root and post-harvest seeds in the soil the rest. This makes it possible to grow such crops on areas that are not used in traditional crop production, on degraded and marginalized soils, including those with a low level of groundwater, ensuring not only the appropriate use of land resources, stabilization of the soil cover, prevention of its degradation processes and man-made pollution [11, 15, 19 - 21]. Other researchers also note that miscanthus crops are not picky about soil conditions, so they can be grown on disturbed, unproductive and sloping lands [4, 6, 16].

In the initial periods of vegetation, the need of miscanthus plants in the application of mineral fertilizers is relatively low, thanks to the root system, which branches intensively and penetrates deep enough into the soil. This allows nutrients to be assimilated, including from the deeper layers of the soil. In addition, the nutrients that accumulate in the rhizomes of miscanthus can be reused in subsequent vegetation cycles [6, 11, 13, 21]. However, due to their high productivity and biomass yield, these crops require nutrients in an accessible form during the growing season. Taking into account the long-term cycles of the use of plantations of these crops, their fertilization system should provide for the introduction of fertilizers into the stock, in particular in organic form, which minimizes the risks of agrochemical contamination of the soil cover [3, 11]. Under the current conditions of the development of agricultural production in Ukraine, given the significant insufficient amount of organic fertilizers for traditional crop production, non-traditional types of organic raw materials can serve as sources of increasing the resources of organic matter in the soil under bioenergy crops. Waste from municipal enterprises, namely sewage sludge, which is accumulated in excess amounts in Ukraine, can be used as fertilizers, provided they are ecologically safe and have an acceptable content of heavy metals, pollutants, and other polluting substances [3, 6, 11].

It is important to study the regularities of the formation of the productivity of bioenergy crops due to the introduction of sewage sludge in different ways in order to further increase the volume of biomass production and stabilize the energy balance of the country. The purpose of the research is to develop the productivity of bioenergetic herbaceous crops under different fertilization systems in combination with sewage sludge (SS) and composts based on it on oil-contaminated soils of the western part of Ukraine.

2 Research materials and methods

The research was conducted on the territory of the oil and gas pipeline in the village of Bytkiv, Nadvirnyan district. Field experiments were conducted with miscanthus. Miscanthus was planted on an area of 25 m^2. The plot of the experimental field in the village. Tsenzhiv of the Tysmenytsky District of the Yamnytsk United Territorial Community (control option 1). Schemes of field experiments were the same and included the following options: 2. $N_{60}P_{60}K_{60}$; 3. $N_{90}P_{90}K_{90}$; 4. SS – 20 t/ha + $N_{50}P_{52}K_{74}$; 5. SS – 30 t/ha + $N_{30}P_{33}K_{66}$; 6. SS - 40 t/ha + $N_{10}P_{14}K_{58}$; 7. Compost (SS + straw (3:1)) – 20 t/ha + $N_{50}P_{16}K_{67}$; 8. Compost (SS + straw (3:1)) – 30 t/ha + $N_{30}K_{55}$. Options 3-8 are adjusted for the introduction of basic power elements.

The content of humus in the soil was determined according to the Tyurin method, hydrolytic acidity and the amount of absorbed bases were determined according to the Kappen method, according to the Kirsanov method, the content of mobile compounds of phosphorus and potassium, the content of ammonium and nitrate forms of nitrogen compounds according to the Cornifield method [4, 6, 7, 11].

In the conditions of the experiment, miscanthus was planted by hand according to the scheme of 0.5 x 0.7 m. At the same time, rhizomes with 5-6 growth buds were used for better rooting. The depth of the rhizomes was 0.12-0.15 m. During the first 16-18 months, the plant usually forms a strong root system, but the plants in the rows do not close together. At plant heights of 0.15-0.20 m, inter-row loosening was carried out to control the spread of weeds. Next year, thanks to a good root system, a significant increase in the rhizome and the number of above-ground shoots, a stable grass stand is formed. During this period, the energy crop is very competitive with weeds and does not require additional inter-row cultivation. Plants develop over three years [3, 5, 11]. After the third year of vegetation, vegetative mass was collected. The period of harvesting the vegetative mass of miscanthus is December. During this period, the humidity of the stems decreases within 17%. It was in December that the plants were mowed, weighed and samples were taken for laboratory analysis. In early spring, after the end of late frosts, the interrows were processed and SS was applied according to the experimental scheme. The area of the accounting plot in each experiment is 35 m^2. Experimental plots are placed in triplicate. Over the course of three years, plant development was observed. The energy potential of the test samples was determined using the Calorimeter IKA C 1 (Fig. 1).

Figure 1 Calorimeter IKA C 1

The Statistica 6.0 computer program was used for statistical processing of the research results.

3 Results and discussion

On average, for the years 2018-2021, the weather conditions were characterized by typical deviations from the average multi-year indicators. Compared to the multi-year average indicators for the 2018-2019 calendar year, 494.1 - 546.8 mm of precipitation fell, in 2020 - 2021 - 389.5 - 321.5 mm. Biometric indicators of miscanthus plants, depending on the weather conditions of the growing season and the type of fertilizers, were marked by certain changes. During the years of research, the average height of miscanthus plants varied from 1.33 to 2.04 m. In the variants where mineral fertilizers were applied in doses of $N_{60}P_{60}K_{60}$ and $N_{90}P_{90}K_{90}$, respectively, the height of the plants increased by 0.14 and 0.25 m compared to the control.

Table 1 The content of mobile forms of heavy metals in oil-contaminated soil, soil for growing miscanthus

Options	Mobile form, mg/kg soil				Strongly bound form, mg/kg of soil			
	Pb	Cd	Ni	Co	Pb	Cd	Ni	Co
Without fertilizers - control	4.22	0.24	1.19	2.19	14.38	1.09	27.41	23.73
$N_{60}P_{60}K_{60}$	4.36	0.26	1.37	2.37	14.69	1.34	28.32	23.98
$N_{90}P_{90}K_{90}$	4.54	0.32	1.39	2.42	17.43	1.3	29.36	23.82
SS - 20 t per ha + N_{50} $P_{52}K_{74}$	4.68	0.35	1.45	2.71	20.65	1.33	30.52	24.63
SS -30 t per ha + $N_{30}P_{33}K_{66}$	4.87	0.37	1.58	2.79	22.04	1.48	31.75	25.02
SS - 40 t per ha + N_{10} $P_{14}K_{58}$	4.59	0.39	1.55	2.68	17.86	1.39	30.19	26.11
Compost (SS + straw (3:1)) – 20 t per ha + $N_{50}P_{16}K_{67}$	4.44	0.37	1.38	2.39	15.85	1.25	29.15	22.38
Compost (SS + straw (3:1)) – 30 t per ha + $N_{30}K_{55}$	4.46	0.34	1.27	2.39	16.19	1.29	29.22	23.10

The content of heavy metals nickel, lead, copper, zinc, and cobalt is the highest in the green mass of energy willow, which grows on the soil with the introduction of SS at a concentration of 80 t per ha (Table 2).

Table 2 The content of heavy metals in the green mass and in the roots, of miscanthus

options	Cd	Ni	Pb	Cu	Cd	Ni	Pb	Cu
	The content of HM in the green mass, mg.kg^{-1}				The content HM in the roots, mg.kg^{-1}			
1	1.21	1.06	0.53	2.52	1.65	1.74	1.18	2.64
2	1.28	1.13	0.65	2.61	1.91	1.79	1.33	2.75
3	1.58	1.51	0.76	3.06	2.24	2.06	1.49	3.28
4	1.69	1.56	0.88	4.01	2.41	2.27	1.57	3.57
5	1.77	1.67	0.99	4.16	2.44	2.57	1.79	3.77
6	1.65	1.49	0.88	3.89	2.30	1.90	1.81	3.46
7	1.47	1,29	0.73	3.61	2.12	2.01	1.49	3.14
8	1.56	1.48	0.85	3.79	2.11	2.14	1.53	3.31
NIR $_{0.05}$	0.01	0.07	0.02	0.09	0.05	0.05	0.04	0.1

Variants, where sewage sludge was applied in doses of 20-40 t per ha, the height of plants increased, compared to the control, by 0.17-0.42 m, respectively. When applying composts based on sewage sludge and straw (3 : 1)) – 20 t per ha + $N_{50}P_{16}K_{67}$, the height of plants grew by 0.57 m, compared to the control, and was 1.9 m. Over all years of research, the highest height indicator Miscanthus stems were provided by the option where compost was applied (SS + straw (3:1)) – 30 t per ha + $N_{30}K_{55}$ (option 8), which was an average of 2.04 m, which was 0.7 m higher than the indicator of the control option [6]. On average, over the years of research with the use of organic fertilizers and composts based on them, differences in the productivity indicators of the vegetative mass of bioenergy crops were noted.

On average, during the 2018-2021 research years, the productivity of vegetative mass of miscanthus in options with the addition of sewage sludge (options 4 - 6) was 23.5 - 25.1 t per ha, which dominated by 0.5 - 2.1 t per ha indicators of options where only mineral fertilizers were applied in a dose of $N_{60\text{-}90}P_{60\text{-}90}K_{60\text{-}90}$ (options 2 and 3). Using composts based on SS (options 7 - 8), the productivity of vegetative mass was 26.0 - 26.9 t per ha, which is 3.9 - 4.8 t per ha more than the indicators of the control option. The yield of dry matter of miscanthus was 10.0 - 13.0 t per ha, depending on the fertilizer options. With the introduction of sewage sludge (options 4 - 6), the yield of dry matter was 10.6 - 12.2 t per ha, which is 0.6 - 2.2 t per ha more than the indicator of the control option. Application of compost on the basis of SS (options 7 - 8) resulted in the yield of dry matter at the level of 12.8 - 13.0 t per ha, which is 2.2 - 2.4 t per ha more than the indicators of options where only sewage sludge was applied waters [6, 11].

The results obtained during the research allow us to state that the height of the miscanthus plant is 1.45 - 1.56 m in the variants with the addition of sewage sludge in the dose of SS - 40 t per ha + N_{10} P_{14} K_{58} (option 6) and with the addition of compost (SS + straw (3:1)) – 30 t per ha + N_{30} K_{55} (option 8) (Fig. 2).

It was found that the productivity of miscanthus plants depending on the height of the plant and the number of stems is expressed by the equation:

$$z = 9.2014 + 0.1496x + 0.0056y \quad (1)$$

z – yield of miscanthus dry matter, t per ha;
x – plant height, cm;
y – the number of plants, units per m^2.

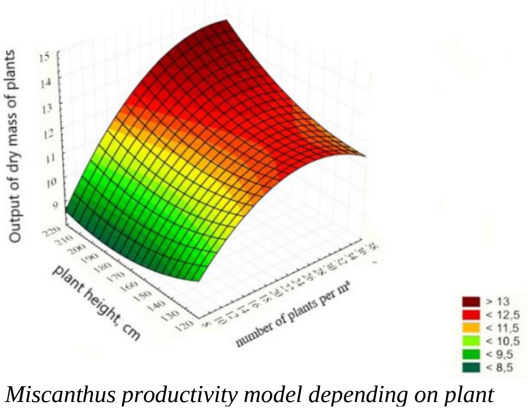

Figure 2 Miscanthus productivity model depending on plant height and number of plants per m^2

Studies of the energy potential of the selected biomass samples were conducted (Fig. 3). Since the options for the introduction of SS directly affected the change in gross energy output with the yield of giant miscanthus, the regression model of gross energy output can be described by the following equation:

$$y = 22.229x + 400.95,$$

where y is the output of gross energy with yield, $GJ.ha^{-1}$; x – rules for introduction of SS.

Figure 3 Selected biomass samples for laboratory research

Table 3 presents the output of energy and solid biofuel from the obtained biomass of giant miscanthus, the average value for 2020-2022.

Table 3Output of energy and solid biofuel from the obtained biomass of giant miscanthus, average value for the years 2020-2022

options	Yield of dry biomass t per ha	Yield of solid biofuel, t per ha	Gross yield of energy, GJ per ha
Without fertilizers - control	19.1	21.01	367.67
$N_{60}P_{60}K_{60}$	23.6	25.96	454.34
$N_{90}P_{90}K_{90}$	25.8	28.38	496.65
SS - 20 t per ha + N_{50} $P_{52}K_{74}$	26.4	29.04	508.24
SS -30 t per ha + $N_{30}P_{33}K_{66}$	27.8	30.58	535.15
SS - 40 t per ha + N_{10} $P_{14}K_{58}$	29.8	32.78	573.65
Compost (SS + straw (3:1)) – 20 t per ha + $N_{50}P_{16}K_{67}$	27.3	30.03	525.525
Compost (SS + straw (3:1)) – 30 t per ha + $N_{30}K_{55}$	28.4	31.24	546.76
HIP $_{0,05}$	1.33	3.66	13.68

The multiple coefficient of determination was R^2 = 0.7117, which indicates a close relationship between the application rates of SS and gross energy output with the yield of giant miscanthus.

3.1 Advantages and disadvantages of using miscanthus

On the basis of the conducted research, the advantages and disadvantages of using energy crops on the example of miscanthus are determined. The advantages of using miscanthus include: In Ukraine, thanks to the cultivation of giant miscanthus, at least two problems can be solved: to use unproductive lands for cultivation, which according to various estimates in Ukraine number from 3 to 4 million hectares, and to reduce dependence on fossil energy sources - gas and coal, because under favorable weather conditions conditions, the yield of dry biomass can exceed 20 t per ha.

Ukraine, having an extremely high potential for the cultivation of giant miscanthus, has not been able to increase its cultivation over the past 10 years, although scientists present many arguments in favor of such a popular energy crop in Europe and the USA. Giant miscanthus is a hybrid perennial plant that can grow in one place for more than 20 years. Recently, the practice of using miscanthus to restore territories that have suffered degradation as a result of military activity, due to the extraction of some minerals or former landfills, etc., has been spreading. This allows, in addition to obtaining high-quality biomass, to preserve the humus layer from erosion and gently restore the fertility of such soils. Research on the cultivation of miscanthus in areas of radioactive contamination, where the cultivation of food crops is limited, showed a low tendency of plants to accumulate radioactive elements.

The peculiarity of this hybrid is that it is not propagated by seeds, but by parts of rhizomes - rhizomes.In the technology of growing giant miscanthus, the preparation of the soil for planting and the planting itself are the most time-consuming and expensive parts of the work. As a rule, rhizomes are obtained from one- or two-year-old miscanthus plants. The rhizomes are dug up in the spring, just before planting, and manually divided into rhizomes, which will be the planting material for the next planting. From 10 to 30 hectares of new land can be planted with rhizomes obtained from 1 hectare of two-year miscanthus. In the conditions of the Ukrainian climate, the giant miscanthus begins to germinate when the soil warms up to 10-12°C. Late spring frosts are dangerous for the plant, as a result of which the shoots die and the overall growth period of the crop is shortened. The highest vulnerability of plants is revealed during the first overwintering.

The disadvantages of using miscanthus are: Despite the listed advantages of using miscanthus biomass both as a renewable energy source and as a raw material for manufacturing industrial products, this plant is practically not grown on an industrial scale in Ukraine. Periodically, relatively small plantations appear on which "fuel" is grown to provide heat for individual farms, there are practically no large plantations to ensure the operation of large industries and, even more so, to obtain profit from the sale of biomass. This is due to a fairly long payback period, which is 5-7 years. To establish an industrial plantation, it is necessary to immediately buy a significant amount of rhizomes - 18.5 thousand per 1 hectare. That is, in only 3-4 years it is possible to harvest biomass in sufficient quantity, which will be used as its own energy raw material. An industrial plantation can exist for 20 years or more, but the maximum yields are obtained during the first 10 years. Further, the productivity will decrease slightly without applying the minimum appropriate amount of nutrients.

4 Conclusions

The dependence of miscanthus productivity on plant height and the number of stems was established. Calculated correct models of miscanthus productivity depending on the rates of sewage sludge application. For miscanthus, the correlation coefficient is r=0.952, indicating a high linear relationship between plant height, number of stems and productivity. According to the obtained research results, on average, during the years of research, the yield of dry matter in energy crops changes according to the application of fertilizers. The productivity of miscanthus agrophytocenosis is much higher than that of other phytoenergy crops. With the introduction of sewage sludge at the rate of 40 t per ha, the yield of dry matter under the same growing conditions in miscanthus agrophytocenosis is 12.2 t per ha. The application of composts based on SS + straw (3:1)) – 30 t/ha + $N_{30}K_{55}$ – has a significant impact on productivity, which provides the highest miscanthus productivity indicators – 13.0 t per ha. To obtain a stable productivity of biomass of energy crops (miscanthus), it is advisable to use composts of sewage sludge and straw in a ratio of 3:1 at a rate of 30 t per ha. Thus, two important problems are partially solved - increasing the productivity of energy crops and utilization of municipal waste (sewage sludge).

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