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Influence of Growing *Miscanthus x giganteus* on Ecosystem Services of Chernozem

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Abstract: The paper investigates the optimization of ecosystem services of podzolized heavy loamy chernozem (black soil) as a result of the cultivation of the perennial energy culture of *Miscanthus x giganteus*. The research was conducted on an experimental land plot during 2016–2021. No fertilization was applied to the soil during the experiments, and over the years of research, the growing seasons were accompanied by abnormal droughts, but even under such conditions, the plants of *Miscanthus x giganteus* gradually increased their yield. At the initial stage of research, in the third year of cultivation, dry biomass of *Miscanthus x giganteus* was obtained at 14.3 t/ha, in the fourth year–18.6 t/ha, and already in the fifth and sixth years, 21.7 and 24.5 t/ha, respectively. That is, energy-wise, the harvest for the last year was equivalent to 15.9 tons of coal or 12,618 m^3 of natural gas. Cultivation of *Miscanthus x giganteus* on black soil for six years has improved the provision of its ecosystem services, regulation, and ecosystem maintenance services. The possibility of growing perennial energy crops on agricultural soils has been proven by obtaining a significant amount of biomass and a positive phytoremediation effect on the soil by reducing erosion, preserving biodiversity, sequestering carbon, and sustainably improving the ecological situation.

Keywords: *Miscanthus x giganteus*; biomass; energy crops; soil; ecosystem services; carbon sequestration; podzolized chernozem; black soil

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1. Introduction

The importance of a stable energy supply is increasing in the global perspective, as the energy demand is expected to grow at a fast pace in the next decades [1–3] along with population and economic growth [4,5]. Recent geopolitical events associated with the Russian aggression against Ukraine [6] revealed the vulnerability of the current energy supply structure [7], where dependency not only on fossil fuels but also on its particular unstable suppliers, has the potential to distort the global energy security in case of unforeseen political shocks, thus undermining the feasibility of substantiated and set development paths [8] worldwide.

In the past years, key factors influencing the energy policies of the developed countries have been arising mainly from the climate change agenda [9,10], thus targeting to increase the share of renewable energy generation [11,12] and search for ways to limit the greenhouse gas emissions [13,14] from the economic sectors. In current conditions, the role of renewable energy generation representing decentralized and local sources [15,16] of sustainable energy is gaining additional importance and puts the energy transformation agenda on top of development priorities.

Energy based on the use of biomass is among the key sustainable approaches [17] to its generation, allowing us to obtain clean energy in terms of associated greenhouse gas emissions. Additionally, the cultivation of energy crops has numerous economic, environmental, and even social effects, which combined show the importance of substantiated development of this approach in theory and its implementation in practice.

These effects can also be assessed within the concept of ecosystem services, the benefits of which are within reach due to their integrative and interdisciplinary nature as they include economic, environmental, and social dimensions [18]. The services provided by such ecosystems could have a positive effect on climate regulation (through the level of carbon sequestration), structure and quality of soils, as well as water availability and cycling [19,20].

Applying and valuing ecosystem services is seen as an innovative step toward sustainable land use. Assessing these services can reveal the impact of energy crops and add objectivity to the renewable energy debate. The concept of sustainable land management should take into account the current and possible future impacts of energy crop production as well as people's preferences for achieving long-term sustainable solutions [18]. Increased demands on renewable energy are likely to result in the allocation of more land for the production of bioenergy plants. Therefore, land-use change is being increasingly verified through environmental impact assessments, which [21] propose to include a more complete study of ecosystem services.

For a comprehensive assessment of the sustainability of energy production from biomass, it is necessary to take into account the entire life cycle of production and combustion of crops for a wide range of indicators of ecosystem services. Therefore, Lovett et al. [22] in their article present the basis for such an assessment based on the synthesis of a large amount of data on the impact on ecosystem services of bioenergy crops (for example, low vegetation and *Miscanthus x giganteus*), which makes it possible to compare the impact on ecosystems between energy systems.

Ecosystem services are the bridge that exists between nature and people [23], as they can be defined as the direct or indirect contribution of ecosystems to human well-being [24]. Soils provide and regulate a large number of ecosystem services, yet imbalanced or non-sustainable practices can as well produce disservices and lead to soil degradation [25]. Thus, it is important to utilize experimental approaches to verify agricultural practices in set conditions, which allow for substantiated results and grounded policy and practical recommendations.

The Ukrainian background is especially important in this research, as for this country, the latest geopolitical developments further limit the availability of traditional energy sources based primarily on fossil fuels. While the renewable energy generation in Ukraine took place in past decades in a rather slow manner [26], current conditions further amplify the need to diversify the energy sources, yet also continue transformation towards more sustainable energy generation. Thus, the current deficit of fossil fuels in Ukraine contributes to the even more urgent necessity for the development of "green energy", among others, through the cultivation of energy crops with a low-carbon footprint, which opens up opportunities for sustainable biofuel production and, together with the development of wind and solar energy production, steadily reduces the release of greenhouse gases into the atmosphere. Increasing the supply volume of such fuels is extremely important and relatively easily achievable due to the assimilation of large areas not only of sown plantations but also of low-productive "problem" lands, as alternatives to traditional ones, for growing energy crops. In addition, the cultivation of energy crops and biofuels serves as a very important compromise between the development of the energy sector and the "environmental friendliness" of industrial production.

It is this strategy for the development of "green energy" that allows solving the problem of balance between meeting the social, economic, and environmental issues arising in the bioenergy generation industry, which are considered by the concept of ecosystem services. The main advantages of energy crops from the point of view of soil science and the provision of ecosystem services are the suitability for growing on low-productive lands, the possibility of minimal application of fertilizers (or even abandonment of them), no need for weed control (except for one-time treatment in the first year of planting), and phytoremediation ability. This is especially noticeable when compared to permanent fertilization and pest control when growing traditional food and forage crops, which have significantly higher costs than those that cannot function normally and grow on non-agricultural land. Thus, the cultivation of energy crops invariably meets the social and economic needs of society, increasing the profits of entrepreneurs or farmers, meeting energy needs, and, in the long term, increasing the value of ecosystem services through effective management and potential restoration of soil quality. In this work, we draw attention to the fact that in the realities of Ukraine, the cultivation of energy crops with rational use is quite possible on agricultural land [27,28].

Therefore, the purpose of this publication is to detect and reveal the possibilities for optimization of ecosystem services of podzolized heavy loamy chernozem due to the cultivation of *Miscanthus x giganteus*.

2. Materials and Methods

The research was carried out during 2016–2021 aimed to optimize the ecosystem services of podzolized heavy loamy chernozem while growing the "Zvezdotsvetosenniy" *Miscanthus x giganteus* (referred to later on as *Mischanthus*) variety in the stationary field experiment of the National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky", enterprise "DG "Grakivske", the village of Novyi Korotychin the Kharkiv region of Ukraine (Figure 1).

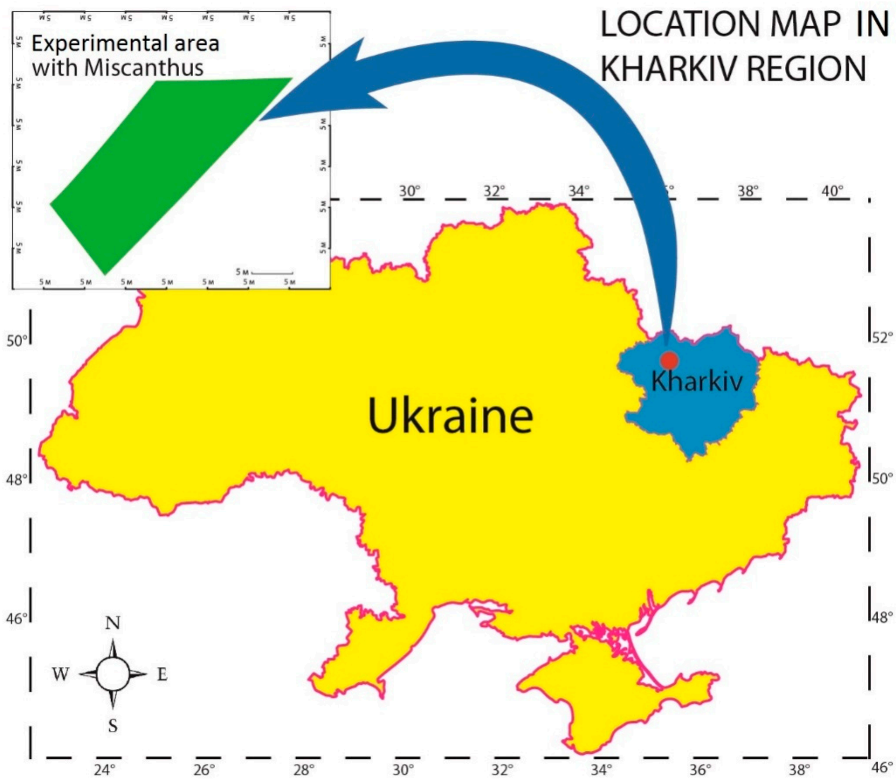


Figure 1. Experimental research area in Ukraine in Kharkiv region. Source: own elaboration.

The relief of the experimental field is leveled, has a gentle 2–3° slope of northern exposure. The field is bounded on all four sides by protective strips. Podzolized heavy loamy chernozem in the experimental area is characterized by the following parameters of the arable layer: pH aq. 5.9–6.0; the carbon content of organic matter is 1.89%; physical clay content is 43%. A one-factor experiment, which did not provide for the application of fertilizers and the use of plant protection products to assess the direct impact of growing *Mischanthus* on the studied soil, it was planted twice: in 2016 (*Mischanthus x giganteus* I) and 2019 (*Mischanthus x giganteus* II). Soil sampling was carried out from layers 0–20, 20–40, and 40–60 cm directly under the plants in triplicate according to Ukrainian state standards DSTU 4287: 2004 and DSTU ISO 11464: 2007. The number of ground invertebrates-microarthropods (the method of eclectation according to Berlese in Tullgren's modification). Counting the yield of *Miscanthus* was carried out by the method of test plots (sheaves) in triplicate followed by weighing. The carbon content in organic matter was determined by the oxidometric method–DSTU 4289:2004.

The number of microarthropods was determined by the selective Tullgren method, which is based on the use of a trait common to all soil inhabitants-the desire to penetrate deep into the soil when the upper layers of the soil dry out. Brief description of the measurement method: soil samples (from a layer of 0–20 cm) of a fixed volume (150 cm^3) were placed in a sieve inserted into a funnel of a slightly larger diameter, under which a vessel with a fixing solution (70% alcohol) was placed. Natural light was used to dry the surface of the soil sample. The number of microartopods that moved down and, sliding along the walls of the funnel, moved into the fixative liquid was counted after distillation using a magnifying glass, previously filtered on filter paper. The results were statistically processed using Microsoft Excel.

3. Results

The idea of the study is based on obtaining new scientific knowledge about the influence of constant (for five years) cultivation of a perennial energy crop of *Miscanthus* on the optimization of ecosystem services in podzolized heavy loamy chernozem. It is especially important to receive up-to-date scientific information on improving the provision of ecosystem services by soil, which contributes to the solution of the tasks under the UN Sustainable Development Goals (UN SDGs) related to food security, water scarcity, climate change, loss of biodiversity, and threats to public health [29].

The spread of degradation processes due to irrational use of land—excessive plowing, short crop rotations, and rapid climatic changes—forces the scientific community and specialists to intensively search for fundamentally new ways to restore soil fertility, which are used in agricultural production. In this context, it is important to understand that the guarantee of agroecological stability of soils, the promotion of the development of self-reproduction of their fertility, and buffering capacity is the preservation of biological diversity [30,31].

Based on the positive phytoremediation experience of growing energy crops [32,33], we have established a positive effect of growing *Miscanthus* on podzolized heavy loamy chernozem in relation to the optimization of ecosystem services.

3.1. Weather Conditions at the Research Site

The climatic changes observed in recent years [34] are confirmed by the fact that on the experimental site during the research period from 2016 to 2021, there was an increase in average monthly temperatures (Figure 2) as well as a noticeable decrease in the amount of precipitation (Figure 3).

Assessing the weather data, we note that in the Kharkiv region, even before the beginning of the second decade of the 21st century, the average monthly rainfall was at the level of 43 mm, which means, about 520 mm came to the earth's surface annually, and about 260 mm per year during the growing season. Since 2011, almost every year the amount of precipitation has dropped significantly, and the average value of the air temperature has increased.

Aridization, or signs of desertification, is especially noticeable in September, which is the very month in Ukraine when agricultural enterprises plant winter crops. However, now the realities of the weather conditions in September are as follows: The air temperatures are quite high, and there is practically no natural moisture in the soil (see Figure 2), which means the problems of agricultural production caused by climatic changes are clearly observed.

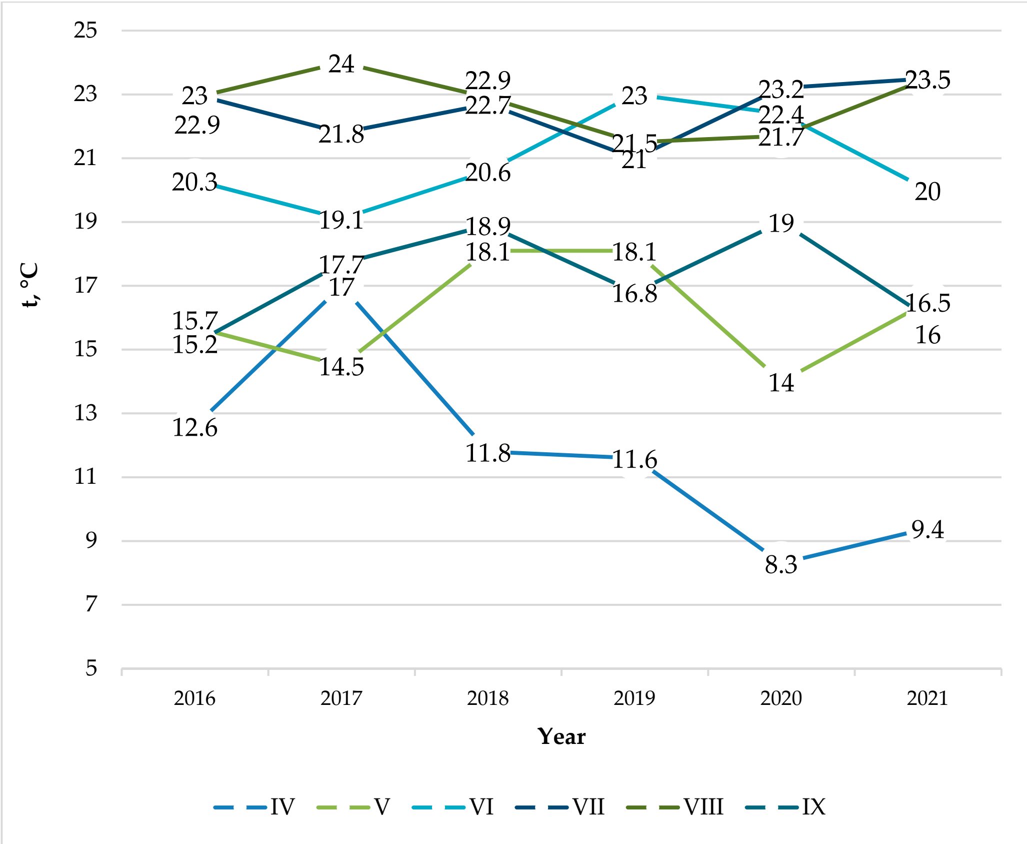


Figure 2. Average monthly temperature within the periods April–September in 2016–2021. Source: own elaboration.

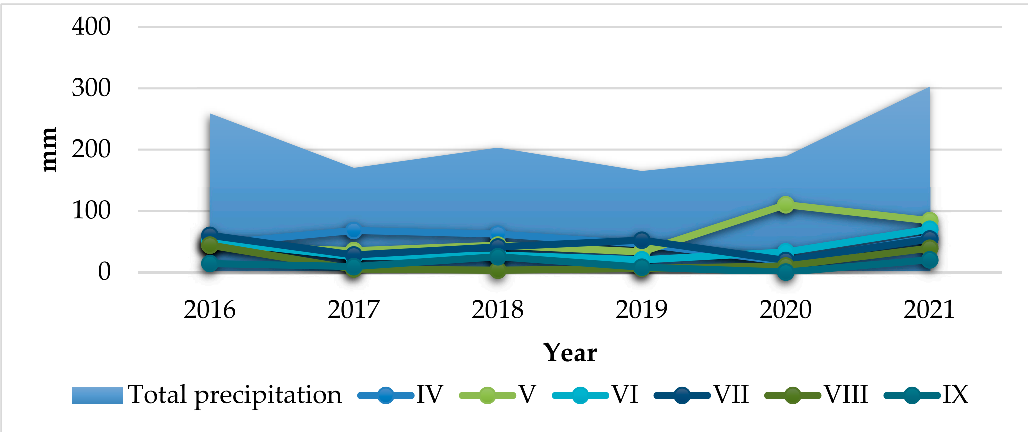


Figure 3. The amount of precipitation within the periods of April–September in 2016–2021. Source: own research results.

However, growing *Miscanthus* on black soil, even in such challenging weather conditions, has not prevented the soil from improving ecosystem services, as evidenced by the gradual increase in yields of this energy crop.

3.2. Harvest of Miscanthus x giganteus

The world practice of growing *Miscanthus* involves accounting for the harvest in the third year after planting, so we have provided data on the harvest since 2018 (Table 1).

Table 1. Yield of *Miscanthus x giganteus* on black soil in 2018–2021, dry weight t/ha.

Energy Culture	2018	2019	2020	2021
Miscanthus x giganteus	14.3	18.6	21.7	24.5

Source: own research results.

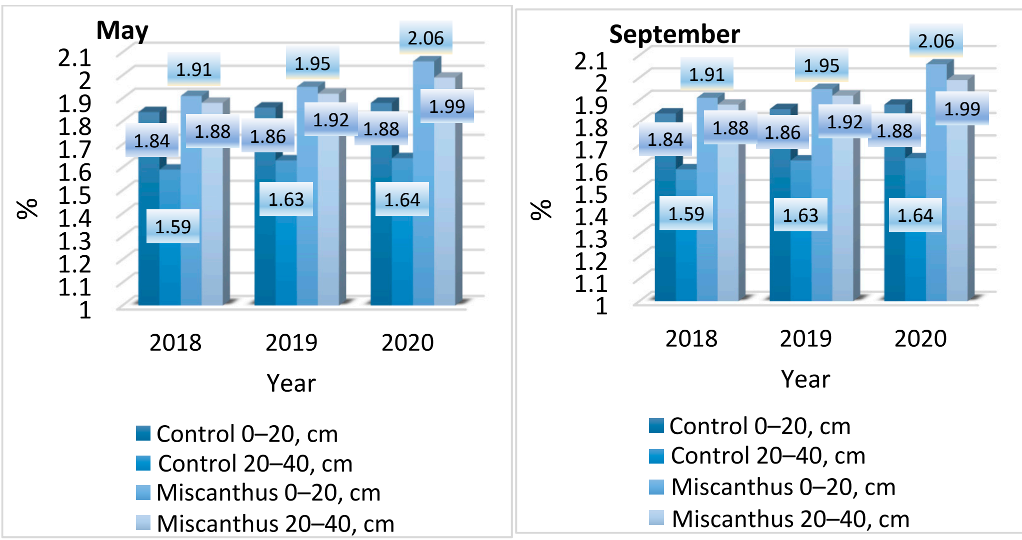
The peculiarities of *Miscanthus* cultivation are that the harvest is usually not taken into account for the first two years, and the harvest is recorded from the third year. It was found that even in relatively dry conditions, *Miscanthus* plants produce significant volumes of biomass without reducing soil productivity, even without fertilization. So, in the third year of cultivation in 2018, the yield of dry biomass of *Miscanthus* was 14.3 t/ha, in 2019–18.6 t/ha, in 2020–21.7 t/ha, and already in September 2021, it was 24.5 t/ha. The harvest for the last year is equivalent to 15.9 tons of coal, 9.8 tons of crude oil, 41.7 tons of timber, or 12,618 m^3 of natural gas [35].

Due to the fact that in our studies, podzolized chernozem during the cultivation of *Miscanthus* was not subjected to agrotechnological processing, starting from the second year of cultivation, and the complete rejection of any fertilizers and plant protection products, we received a significant amount of biomass of *Miscanthus*, which indicates a high ecological value and the profitability of growing it. According to scientists [36], starting from the third year, the profitability of *Miscanthus* cultivation is 726% and can remain almost at this level for many years until its complete elimination.

Energy raw materials are referred to as an ecosystem supply service that is the easiest to understand and quantify. At the same time, the resulting harvest is a material benefit that has a specific price in monetary terms and a guaranteed energy supply. On the Ukrainian market, the cost of 1 ton of *Miscanthus* pellets is about UAH 4500, and the cost of 1 ton of straw briquettes is only UAH 2700.

3.3. Carbon Content in Soil Organic Matter

Studies have shown that under the influence of growing *Miscanthus* on podzolized heavy loamy chernozem, the amount of organic matter carbon in the arable and subsoil layers increases (Figure 4).



(**a**) (**b**)

Figure 4. Carbon content in organic matter of chernozem, May (**a**)–September (**b**) 2018–2020, in %. Source: own research results.

It was found that over three years in the 0–20 cm layer in May, the organic carbon content increased from 1.91% in 2018 to 2.06% in 2020, while in September this indicator changed over the same years, respectively, from 1.92% to 2.11%.

In the subsurface layer (20–40 cm) of the studied chernozem, a similar tendency is observed with respect to a gradual increase in the carbon content of organic matter. The established pattern is extremely important for the development of measures to reduce greenhouse gas emissions into the atmosphere, which is a powerful argument for fulfilling Ukraine's obligations, which are reflected in a number of state documents, in particular: "Concept for the implementation of state policy in the field of climate change for the period up to 2030" (Order of the Cabinet of Ministers of Ukraine dated 6 December 2016 No. 932-r); "National Action Plan to Combat Land Degradation and Desertification" (Order of the Cabinet of Ministers of Ukraine dated 30 March 30 2016 No. 271-r). A gradual increase in the organic carbon content in the studied chernozem under the *Miscanthus* indicates an improvement in the supporting ecosystem service, which, together with a regulatory service (habitat formation, soil formation), provides a significant improvement in the ecological state of this chernozem. The ability of energy crops to store carbon in soil can be attributed to several ecosystem services. Firstly, this is a regulation service—that is, improving soil quality by increasing carbon as the main humus-forming element and improving air quality due to a decrease in carbon dioxide near plantations with energy crops; secondly, the service of maintaining ecosystems, because the content of this element in the soil is part of the process of the biogeochemical carbon cycle, and, consequently, a decrease in the release into the atmosphere, and therefore, counteraction to global warming.

3.4. The Number of Microarthropods in the Experiment

The biodiversity of soil microfauna, numerous representatives of which are microarthropods–invertebrate oribatids (Oribatida, Acarina carapace mites) and colembola (Springtail Collembola), plays an important role in the destruction and transformation of organic matter. It should also be noted that these soil microorganisms are extremely sensitive and are often used as bioindicators of environmental changes. Since their number clearly reacts to air temperature, moisture, and soil chemical composition, our results vary somewhat depending on the month and year of the study. The number of oribatids on the studied soil under the *Miscanthus* is shown in Figure 5.

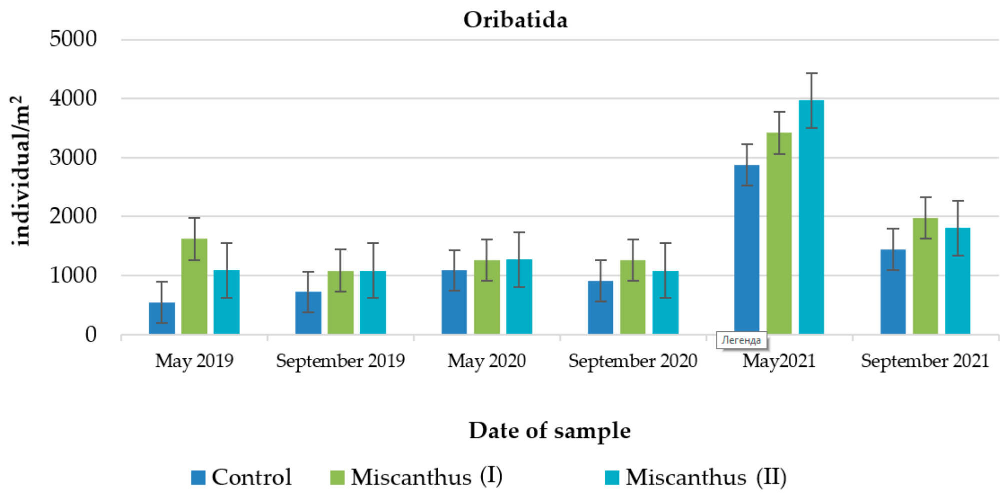


Figure 5. The number of oribatids on the studied soil under the *Miscanthus*: May 2019–HIP05 = 225; September 2019–HIP05 = 146; May 2020–HIP05 = 130; September 2020–HIP05 = 192; May 2021–HIP05 = 354; September 2021–HIP05 = 142. Source: own research results.

The figure clearly shows that in 2020 the number of oribatids in May and September was 1086 and 908 specimens/m^2, respectively, and 1260 and 1264 specimens/m^2 under *Miscanthus*. However, in 2021, the number of oribatids almost tripled compared to previous years because May 2021 was characterized by moderate temperatures and relatively high rainfall of 84 mm.

Our studies, carried out on podzolized heavy loamy chernozem in 2020, found that in the control, the number of colemboles (Figure 6) in May was 1622, and in September, 1986 ind./m^2, and under *Miscanthus* plants, respectively, 1628 and 3240 ind./m^2.

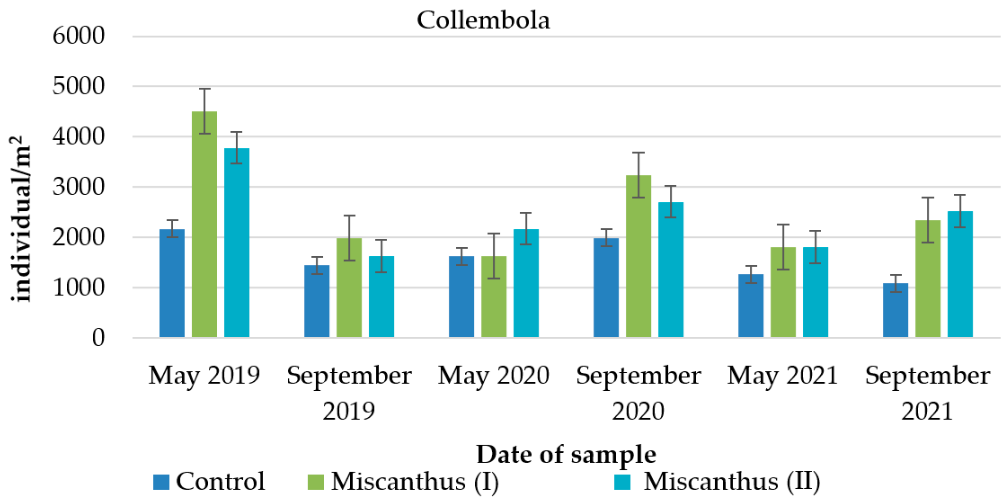


Figure 6. The number of colemboles on chernozem under *Miscanthus*: May 2019–HIP05 = 362; September 2019–HIP05 = 232; May 2020–HIP05 = 284; September 2020–HIP05 = 188; May 2021–HIP05 = 204; September 2019–HIP05 = 192. Source: own research results.

The number of colembol specimens differs from oribatids in variants and decreases somewhat over time, although it remains much higher than in the control. This indicator is due, to a large extent, to the increase in the number of ticks (oribatids) because some of them are predators that feed on colemboles. Thus, microarthropods sensitively react not only to weather conditions but also to the species composition of plants in the ecosystem and to the species composition of soil microorganisms.

In general, the number of microarthropods indicates that under the plants of the *Miscanthus* there are more favorable conditions for their habitation and development and, consequently, for the biodiversity of the ecosystem as a whole, which refers to a supporting ecosystem service. Under such conditions, the activation of the biological factor (microarthropods) enhances the course of the soil-forming process towards self-adaptation and self-reproduction, which will certainly lead to an improvement in soil fertility.

4. Discussion

Based on the achieved results, it is assumed that this research has obtained positive evidence regarding the impact of the cultivation of *Miscanthus* on the optimization of ecosystem services in podzolized loamy chernozem, which is usually used for growing traditional crops of wheat, corn, sunflower, and beet.

The results are consistent with the findings of other researchers on the cultivation of individual bioenergy crops on marginal lands [37,38]. The results of the study are of great practical importance in the context of achieving climate neutrality by 2050, in particular, by increasing the area of cultivation of bioenergy crops, including those on marginal lands [39]. It should be noted that the use of biomass for energy crops in combination with other alternative energy sources [40,41] is one of the priority areas for ensuring low-carbon development of the agricultural sector and the economy as a whole.

Integration of energy crops into agricultural landscapes can foster permanence and maintain sustainability if they are placed in such a way as to stimulate multiple ecosystem services and mitigate harmful ecosystem effects from existing crops [42], as well as promote balanced land use [43].

For example, energy crops in the coastal regions of the midwest United States have a positive effect on ecosystem services while the benefits-costs ratio has fluctuated significantly. At the same time, the overall monetary value of the improved ecosystem services associated with the introduction of perennial energy crops was much lower than the opportunity cost. The mismatch between recoverable costs and social value is a fundamental challenge for the expansion of perennial energy crops and sustainable agricultural landscapes [42] and the potential for biomass supply [44]. Analyzing the dynamics and uncertainty of land-use transformation for the production of perennial energy crops, [45] examined the effects of payment for ecosystem services policies. It has been found that the current expected profit from growing perennial energy crops (including switchgrass) is insufficient for these crops to be widely adopted by American farmers due to relatively unstable yields, volatile incomes, and high costs of growing crops. At the same time, switchgrass has the potential to provide energy while reducing greenhouse gas emissions [46].

In this context, the results of a survey of farmers and non-experts on the perception of energy crop production in Germany turned out to be interesting. In particular, it was found that many farmers consider themselves responsible for the provision of many ecosystem services while they prefer the regional scale of growing energy crops based on conventional crops. Most of the non-specialists interviewed noted the ambiguity of energy crops as a source of energy without side effects. In layman's opinion, the use of biomass for renewable energy production is not an important ecosystem service. Biomass production should be limited to fields that do not require food production and the use of crop residues or materials for landscape management [46].

Global scientists and practitioners are mainly exploring the possibilities and cultivation of energy crops on marginal lands. For example, [37] notes in the article that: (i) ecosystem services differ depending on the type of marginal land; (ii) special bioenergy crops can improve ecosystem services on marginal lands; (iii) there is a need to intensify research in this direction, as there is currently a lack of field data on the productivity of energy crops on marginal lands, and ecosystem services are hardly discussed in the literature. This was among the reasons why the current research was conducted, aiming to fill in the existing gap in experimental data, which would be beneficial for further substantiation of strategies to expand the cultivation of *Miscanthus* in particular soil conditions, as well as to take these findings into account in the policies being implemented towards the protection of the environment, achieving climate-neutrality and improving biodiversity, as well as supplying clean energy from a renewable source.

Another direction to increase the impact of the cultivation of specialized energy crops is to do this on marginal lands, which can provide, in particular, such ecosystem services as biomass production, control of water and wind erosion of soil, sequestration of carbon in the soil, absorption or content of pollutants or metals, stabilization or reclamation of disturbed soils, and improvement of properties. It is summarized in [37] that growing energy crops on marginal lands can increase soil carbon sequestration, restore contaminated or compacted soils, and improve biodiversity. Fertilizing or adding organic improvers increases biomass yield and carbon sequestration on marginal lands [37].

Growing energy crops on marginal lands is considered a useful opportunity for farmers against the progressive risk of underutilization or non-use of these lands. Scenario modeling results indicate the positive impact of energy crops on ecosystem services in terms of environmental quality and biodiversity value [38]. At the same time, other studies show that increased production of bioenergy crops leads to increased soil-use and land-use conflicts and also decreases the supply of several ecosystem services, such as regulation of soil erosion, carbon sequestration, environmental value, and landscape aesthetic value [38]. Therefore, this indicates the need to continue experimental research to answer the question of the impact of energy crops on soil ecosystem services. Among the new and promising areas of research is also the evaluation of the efficiency of growing bioenergy crops using alternative fertilizer systems, including green manure [47].

A substantiated approach needs to be taken with each agricultural practice, as particular ones are especially influential on sustainable development and its goals (SDGs). The authors argue [48], in this context, that such ecosystem service as soil conservation service can be among those, as it contributes simultaneously to SDG 15 (Life on land), SDG 13 (Climate action), and SDG 6 (Clean water and sanitation), as well as several others to a lesser extent. In our opinion, the cultivation of *Miscanthus* on black soils under the conditions verified within the experimental research proves that such an approach is highly beneficial for the soil conservation service and thus is of high importance in light of ensuring sustainable development.

5. Conclusions

Based on experimental studies conducted in 2016–2021 on the optimization of ecosystem services of podzolic heavy loamy chernozem by growing *Miscanthus*, its positive impact on the analyzed soil ecosystem services—supply and regulation—was established. The cultivation of *Miscanthus* on chernozem even in relatively dry conditions over the years of research has not prevented the improvement of ecosystem services provided by this soil, as evidenced by the gradual annual increase in the yield of this energy crop.

It is established that under the influence of the growth of *Miscanthus* on chernozem, the amount of carbon organic matter in the soil increases both in the arable and in the underlying layer. The gradual increase in the organic carbon content of chernozem under *Miscanthus* indicates improved support for ecosystem services, which together with regulatory services (habitat formation, soil formation), provides a significant improvement in the agro-ecological condition of the soil and environment. Growing perennial energy crops on agricultural soils provides a significant amount of biomass and a positive phytoremediation effect on the soil by reducing erosion, conserving biodiversity, carbon sequestration and improving the agri-environmental situation.

Further research on the impacts of *Miscanthus* cultivation on chernozem ecosystem services should focus on (i) the economic valuation of possible ecosystem services and an analysis of the cost-benefit ratio of growing energy crops; (ii) strategies for sustainable management of energy crops in specific areas, climatic and socio-economic criteria; (iii) the development of innovative bioenergy projects for the cultivation of energy crops and an assessment of their economic efficiency and investment attractiveness.

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