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# Impact of Organic Cultivation Technology of Fiber Hemp (*Cannabis Sativa* L.) on Soil Agrochemical and Bioecological Properties

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## ABSTRACT

Research into the correlations among components of soil biota is of significant importance for effective management of agroecosystems in organic agricultural production. Organic cultivation technologies contribute to increased nitrogen and phosphorus content in the soil, while reducing levels of $P_2O_5$ and $K_2O$ compared to inorganic methods. The influence of organic residue decomposers on macroelement composition in the soil has been examined, revealing a minimal impact on their levels. Organic technologies promote an augmentation of microorganisms, although there is a potential risk of heightened disease pathogens. It has been observed that under organic cultivation conditions, there is more intense tissue degradation, potentially attributed to higher microorganism activity. Transitional cultivation methods yield lower rates of degradation in comparison to organic techniques. The impact of organic technologies on the quantity of earthworms, nematodes, and springtails in the soil has been investigated. Organic practices have shown to increase their population, creating a favorable environment for soil biological indicators. Particular attention is given to correlation relationships between microorganisms responsible for nitrogen and phosphorus accumulation and the fungal component. High correlation values (r = 0.72–0.89) underscore the significance of comprehending these associations when employing organic cultivation methods. The study of correlations among soil biota components in organic production presents a promising task for the effective utilization of resources and the assurance of sustainable agroecosystem development.

**Keywords:** agroecosystem, hemp, biota components, microorganisms, correlations.

## INTRODUCTION

The influence of organic cultivation technology of industrial hemp on soil properties and the formation of quality indicators of hemp seeds in organic cultivation (Pylypchenko et al., 2023) plays a significant role in modern ecological agriculture. If the production of hemp products is properly managed it can be beneficial (Adesina et al., 2020). Hemp plants are capable of extracting toxic substances from the soil. Therefore, organic crops should be placed in areas free from toxic substances (Liang et al., 2013).

The presence of hemp in crop rotation is referred to as important due to its ability to slow down the growth of harmful organisms such as the fungus Verticillium dahliae, root nematodes Meloidogyne Chitwood and Meloidogyne hapla (Kok et al., 1994), or weeds (Lotz et al., 1991; van der Werf et al., 1995). This indicates the suitability of hemp for cultivation using organic techniques. The residues of hemp is an evidence of integration into the organic farming system as botanical insecticides, miticides, and repellents (van der Werf, 1994). Organic farms (which are trying to reach a minimisation of chemical agents use) incorporating hemp into crop rotation promotes the development of beneficial mycorrhizae which in turn stimulates plant competitiveness against weeds.

Mycorrhizal fungi play a crucial role in agroecosystems due to their ability to enhance nutrient and water uptake and aid in the suppression of weeds and pests (Soti et al., 2016). Similar roles are played by the allelopathic properties of hemp plants (Konstantinovic et al., 2021). The inclusion of hemp in crop rotations is important not only for improving soil fertility, disrupting pest and disease cycles but also for increasing organic content and organic carbon (Land et al., 2017; Fike et al., 2020).

Industrial hemp is suitable for cultivation across a wide range of environmental conditions. It thrives best under an average daily air temperature of 16–27°C, although it can tolerate both lower and higher temperatures. For instance, at temperatures of 8–10°C seeds can germinate within 8–10 days. Young plants with 8–10 leaves can withstand some frost impact, usually down to –5°C. In field conditions, a plant height achieved in 90 days can be attained in 40 days at 19°C under controlled conditions through regulation (Merfield, 1999). Excessive temperatures exceeding 30°C during the grain-filling phase will be a major factor affecting seed quality, limiting oil accumulation in the seeds (Baldini et al., 2020).

Hemp can be grown for several years in monoculture without decreasing yields. Hemp serves as a good predecessor for the key crop such as wheat (Gorchs et al., 2017). Hemp is one of the few crops that can be cultivated in monoculture, although this may lead to some deterioration in soil fertility (Chable et al.; Cherney and Small, 2016; Jalgaonwala and Mahajan, 2014).

An important aspect of organic cultivation of agricultural crops is soil biota. Its population significantly decreases under intensive technologies, reducing the intensity of its biological activity. Earthworms (Lumbricina), especially Lumbricus terrestris are central in this issue being one of the most crucial factors in soil formation and biological indicators of soil health (Guerra et al., 2021). It should be noted that the scientific literature includes more than sufficient publications on soil biota especially from the perspective of organic farming but information about the functioning of earthworms under hemp agroecosystems is scarce (Ilieva-Makulec et al., 2017).

Hemp plays important role in crop rotation due to its negative impact on harmful soil organisms (particularly - nematodes). These organisms are most sensitive to the emissions of hemp (Ilieva-Makulec et al., 2017) but some species also affect hemp: Caenorhabditis elegans, Meloidogyne incognita, Meloidogyne hapla, Meloidogyne javanica, and others (McPartland, 1996). Symptoms of infestation include developmental delay as wilting etc. These symptoms arise in locations with concentrated nematode populations but only in some of its parts. The stem nematode (Ditylenchus dipsaci) affects stems causing twisting, distortion and shortened internodes.

Cannabis sativa L. produces a wide range of secondary metabolites including steroids, flavonoids, lignans, alkaloids and others. However, cannabinoids and terpenes prevail among these compounds (ElSohly and Slade, 2005). Thus, hemp possesses the property of being used as an insecticide (Benelli et al., 2018; McPartland and Sheikh, 2018) an acaricide (Pavela et al., 2019) and a nematicide (Mukhtar et al., 2013).

According to he study by (Bernard et al., 2022), research on the interactions between hemp and nematodes is limited and lacks substantial data regarding pathogenicity or often lacks them entirely. Crop rotation and varietal characteristics play a crucial role in reducing hemp susceptibility to nematode infestations (Van Biljon, 2017; Zhang et al., 2013).

The analysis of literary sources indicates the necessity of studying various aspects of hemp cultivation when using organic technologies in production. Primarily, this pertains to ensuring crops are supplied with macro-nutrients and their influence on soil properties. Research outcomes addressing this issue in organic hemp cultivation are essentially absent despite of the significant number of scientific publications.

The purpose of the research was to determine the specific effects of organic hemp cultivation technologies on the content of macro-nutrients in the soil, its biologically active components, and to establish a system of interrelations among the biological components of the soil. This was done with the aim of developing effective management practices for the production processes of hemp agroecosystems in organic cultivation technologies.

## MATERIALS AND METHODS

The population of ammonifying microorganisms was determined by adding 1 ml of soil suspension to a nutrient medium (meat-peptone agar) in Petri dishes. Petri dishes were incubated in a thermostat at +28°C in the dark. Microorganism counting was performed after 48 hours of incubation (Bonde et al., 2001), spore-forming bacteria on the same medium after being heated to 75°C. 250 ml Erlenmeyer flasks containing 100 ml of nutrient medium were inoculated and incubated for 10-15 days at a temperature of 30°C. To induce and stimulate sporulation, bacteria were subsequently transferred to a sporulation medium (identical in composition but without glucose and with a lower concentration of ammonium chloride, only 1 g/l). Spores were collected by centrifugation, immediately frozen in liquid nitrogen, and then lyophilized. (Alef and Kleiner, 1987).

The quantity of streptomycetes was measured on starch-ammonium agar. The incubation period lasted for 2 weeks at a temperature of 22°C. Subsequently, Streptomycetes were counted following the method by Waksman (1959), and nitrogen-fixing bacteria were counted using a procedure that involved dilution to 10^-4 from a prepared bacterial suspension using a sterilized isotonic phosphate buffer solution. Then, 1 ml of this solution was inoculated onto Petri dishes containing 15 ml Jensen's medium and incubated in an N2 atmosphere. Petri dishes were observed at 12-hour intervals to count the increase in colony-forming units (Baldani et al., 2014).

The total biomass of microorganisms was determined using the rehydration method, which involves heating selected soil samples to temperatures up to 70°C, followed by preparing water and salt extracts from the dried soil. This process facilitates the rehydration of microbial cells and the release of intracellular components into the liquid medium. The results were compared with a control sample (Vance et al., 1987).

Carbon dioxide diffusion was assessed using the alkaline trap method, in which 50 g of air-dried soil was weighed, placed in a 0.5-liter container, and deionized water was added to bring the soil to 50% moisture capacity. For the alkaline trap method, 20 ml of 0.5 M NaOH was taken, poured into a bottle, and incubated for four days at 25°C. The NaOH solution was titrated with 0.5 M HCl to determine the $CO_2$ released during incubation (Anderson, 1982). The total content of humus and organic nitrogen was determined by a colorimetric method (Nelson and Sommers, 1982; Mehlich, 1984).

Data analysis was performed using descriptive statistics, regression, and analysis of variance (ANOVA) in the STATISTICA 10.0 software. Experimental data were evaluated using analysis of variance (ANOVA) to calculate the least significant difference ($LSD_{05}$) (Pylypchenko et al., 2023; Semenov et al., 2020).

## RESULTS

It's necessary to select a biocenosis for comparison the influence of hemp agroecosystems on soil agrochemical indicators in organic farming. The biocenosis should remain unaffected by agronomic operations for an extended period. In planning the research program a pasture variant which is located within the same area as the cultivated plots was chosen. This allows us for data comparison of agrobiochemical characteristics for each plot.

As indicated by the research results, the impact of the agroecosystem on nutrient content was statistically significant for all years of cultivation (Fig. 1). A clear trend of increased macroelements - NPK - was observed in the organic cultivation variants compared to the pasture and fallow variants (NIR05 was respectively 1.19, 1.71, and 1.28 mg/kg for each element). Favorable trend of phosphorus accumulation in organic plantations compared to nitrogen and potassium content was observed. Thus, organic cultivation technologies contribute to the development of improved agrochemical indicators in the soil compared to pasture or fallow land, providing convincing evidence of their potential for implementation.

Organic technologies significantly affect soil biochemical activity (Fig. 2). The highest tissue degradation intensity was observed in organic cultivation. The lowest values of 26.6–27.4 were recorded in the pasture variant. The highest value of 34.5% was observed in variants using organic residue decomposers. Additionally, there was greater carbon dioxide gas diffusion intensity and an increased soil nitrification capacity. The conditions of cultivation years only affected $CO_2$ diffusion (NIR05 = 0.87). The agroecosystem composition influenced all the investigated indicators – NIR05. For tissue degradation intensity – 0.62%, $CO_2$ diffusion – 1.43 $m^2 \cdot min^{-1}$, and nitrification capacity – 0.22 $mg \cdot kg^{-1}$ of soil.

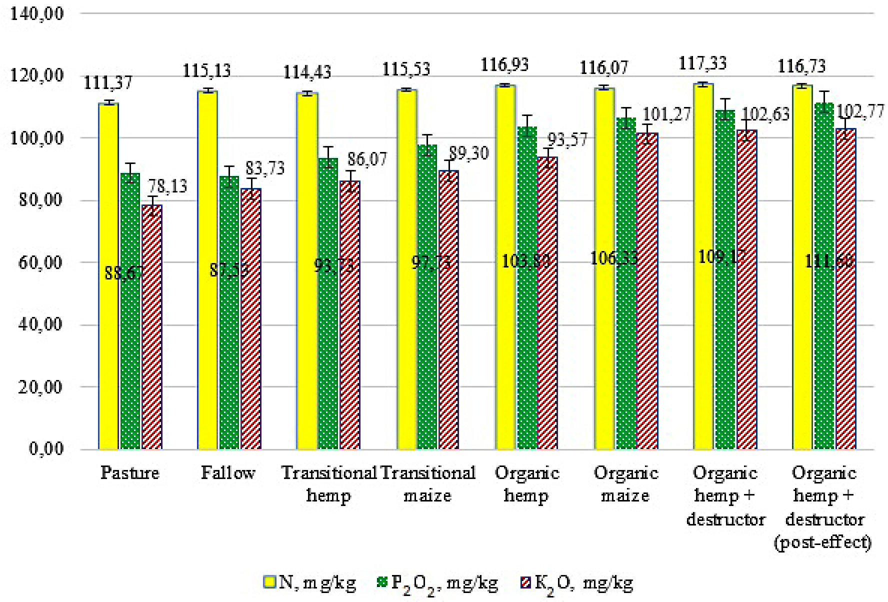


**Figure 1.** Macronutrient content in the soil depending on the agroecosystem composition (2019–2021)

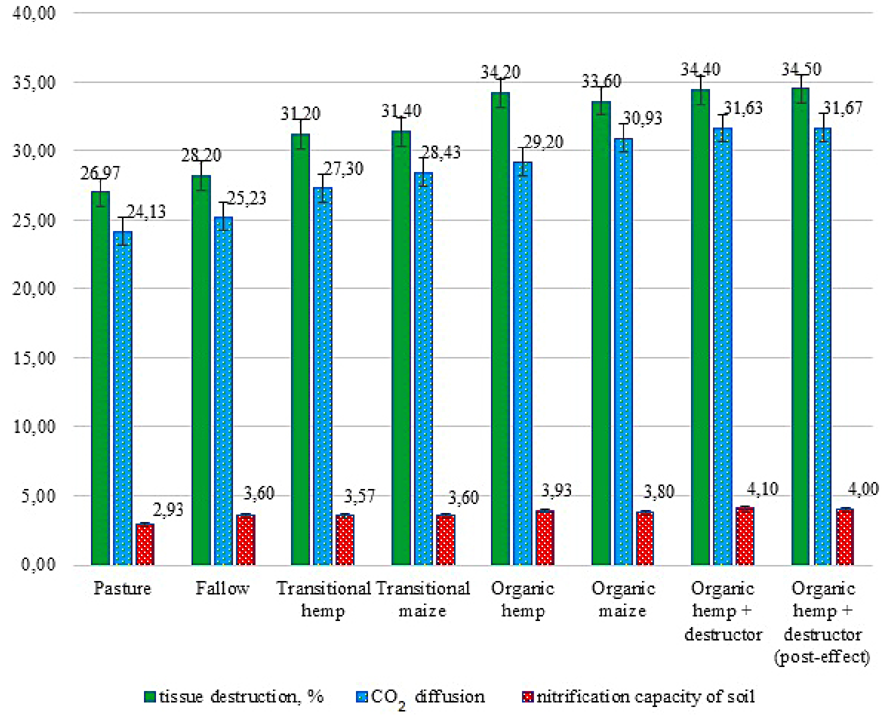


**Figure 2**. Soil biochemical properties depending on the agroecosystem composition (2019–2021)

Soil microorganisms is an extremely important characteristic of its condition and suitability for use. The results of the conducted research revealed that the quantitative and qualitative composition of soil microbiota were influenced by the conditions of cultivation and the composition of agroecosystems which were observed in years. Organic hemp and corn crops have contributed to an increase in soil biological activity. The use of a biodegrader has also led to some improvement in this indicator. Overall, organic technologies have had a positive impact on soil biological activity.

The quantity of nitrogen-fixing organisms was significantly lower in the pasture variants. In the corn and hemp variants grown under organic technology its quantity was almost the same as in the fallow variant (Table 1). Organic technologies provided a nearly consistent amount of these organisms within the range of 5.0–5.2 million/g. Transition cultivation technologies resulted in approximately 10% of the higher content of this

**Table 1.** Microorganism count in the soil depending on the agroecosystem (2019–2021)

| Variant | Nitrogen-fixing, million/g | Phosphorus-mobilizing, million/g | Micromycetes, thousand/g | Streptomycetes, thousand/g | Spore-forming bacteria, thousand/g |
|---|---|---|---|---|---|
| Pasture | 4.2 | 5.1 | 67.6 | 0.4 | 105.5 |
| Fallow | 5.0 | 5.0 | 65.4 | 0.5 | 104.5 |
| Transitional hemp | 4.6 | 5.3 | 67.2 | 0.6 | 107.8 |
| Transitional maize | 4.6 | 5.3 | 66.8 | 0.6 | 105.6 |
| Organic hemp | 5.0 | 5.7 | 71.2 | 0.7 | 108.6 |
| Organic maize | 5.0 | 5.5 | 68.3 | 0.6 | 108.7 |
| Organic hemp + destructor | 5.1 | 5.7 | 71.6 | 0.7 | 109.6 |
| Organic hemp + destructor (post-effect) | 5.2 | 5.7 | 76.6 | 0.7 | 109.2 |
| HIP05 (factor A - year) | 0.037 | 0.036 | 0.366 | 0.023 | - |
| HIP05 (factor B - technology) | 0.061 | 0.058 | 0.596 | 0.038 | 0.67 |
| HIP05 (AB) | 0.111 | - | - | - | - |

microorganism group compared to the pasture. This indicator was increased by 23.8% in organic technologies use. The highest result was recorded in the variant of organic hemp with a decomposer.

Unlike nitrogen-fixing bacteria, the quantity of phosphorus-solubilizing microorganisms depended on the conditions of the year and cultivation technologies. These factors independently affected this microbiota component without any shared influence. The lowest quantity of these microorganisms was observed in the fallow variant – 5.0 million/ha. Transitional maize and hemp crops exhibited the same value for this indicator while the highest quantity was found in variants with organic hemp and the use of a decomposer. The difference between cultivation technology variants and agroecosystems reached up to 14%.

The quantity of microfungi in the soil is greatly influenced by its moisture content and temperature regime. In the conducted research this group of fungi depended on the conditions of the year and technology. In agroecosystems with organic hemp its quantity was the highest, by reaching its maximum in the variant of organic hemp with subsequent decomposer use. The smallest quantity of these organisms was recorded in the fallow variant. If in organic agroecosystems the quantity of microfungi reached 71.9 thousand/ha. For instance, in other research variants it was only 66.7 thousand/ha which is eight percent less. Thus, the ecological evaluation of organic technologies was higher. Considering that this group of fungi includes agents of root rot tits indicator should be taken into account during the organic farming technologies planning.

The quantity of microfungi and actinomycetes increases in soils under unfavorable conditions for ammonifiers. In an organic cultivation system this may indicate a threat of soil toxicity. In our research the quantity of actinomycetes was also greater in organic variants. Moreover, their quantity increased by 75% compared to the pasture variant. This quantity of organisms was not critical or hazardous for organic hemp cultivation. Existing trends must be taken into account in production management.

Under organic production the quantity of spore-forming bacteria can increase including many pathogenic ones. Their quantity is also higher in variants with organic technologies. Overall, the variation in average quantities of these organisms had a small range – 104.5–109.6 thousand/ha. This difference between variants was statistically significant indicating minor differences between cultivation technologies in absolute indicators. Thus, organic farming technologies contribute to the growth of soil microbiota compared to transitional technologies. Thus, organic hemp cultivation technology promoted the better development of soil microbiota, with the quantity of pathogenic organisms not reaching dangerous levels for the crops.

Earthworms, certain nematode species and woodlice are considered reliable biological indicators. They determine the soil's suitability for agricultural crop cultivation. Additionally, they assess the suitability of the environment for supporting life, which plays a significant role in soil formation.

The annual conditions did not statistically affect the quantity of earthworms, woodlice and nematodes in the soil. The main influence on these organisms was exerted by the composition of the agroecosystem. There was no observed interaction between these factors. In the pasture variant number of Lumbricus terrestris individuals was 64–66 individuals per square meter (Table 2) (which is practically the same as in the plot with fallow).

In 2020 and 2021 the quantity of earthworms in the fallow variant was slightly lower – 60 and 61 individuals. The highest quantity of these organisms was recorded in the organic variants although the deviations were within the range of statistical error. In 2019 the lowest quantity of Lumbricus terrestris was observed in the variants with transitional cultivation technology, which indicates an adverse impact on these organisms from mineral fertilizers and pesticides. Organic cultivation plots had 5–14 more earthworms.

In 2020 and 2021, the lowest quantity of earthworms was also observed in the fallow variant and in the transitional variants. In the pasture and organic technology variants the difference amounted to 6–8 and 7–12 individuals respectively. There was not observed any statistically significant impact of the destructor on the formation of earthworm populations.

On average, over the years of the study, the quantity of earthworms in pasture and non-organic cultivation variants ranged from 58 to 65 individuals/m$^2$, while in organic hemp cultivation variants it ranged from 64 to 68 individuals/m$^2$. The difference in woodlice populations was 90–91 and 94–95 individuals/m$^2$ and the difference in nematode populations was 112–124 and 132–133 individuals. The provided data indicate a certain positive trend in the influence of organic cultivation technologies on organisms that serve as biological indicators of the soil.

**Table 2.** Impact of agroecosystem composition on soil bioindicators (individuals/m$^2$)

| Year (Factor A) | Experimental Variants (Agroecosystem, Factor B) | Earthworms | Beetles | Nematodes |
|---|---|---|---|---|
| 2019 | Pasture | 64 | 91 | 113 |
| | Fallow | 63 | 91 | 112 |
| | Transitional hemp | 56 | 89 | 120 |
| | Transitional maize | 58 | 91 | 126 |
| | Organic hemp | 63 | 93 | 130 |
| | Organic maize | 61 | 94 | 130 |
| | Organic hemp + destructor | 67 | 96 | 132 |
| | Organic hemp + destructor (post-effect) | 69 | 95 | 133 |
| 2020 | Pasture | 66 | 90 | 112 |
| | Fallow | 60 | 91 | 114 |
| | Transitional hemp | 60 | 90 | 119 |
| | Transitional maize | 60 | 91 | 125 |
| | Organic hemp | 66 | 95 | 131 |
| | Organic maize | 61 | 93 | 129 |
| | Organic hemp + destructor | 66 | 95 | 131 |
| | Organic hemp + destructor (post-effect) | 68 | 96 | 132 |
| 2021 | Pasture | 65 | 91 | 112 |
| | Fallow | 61 | 92 | 113 |
| | Transitional hemp | 58 | 91 | 121 |
| | Transitional maize | 59 | 92 | 122 |
| | Organic hemp | 63 | 95 | 135 |
| | Organic maize | 60 | 95 | 132 |
| | Organic hemp + destructor | 70 | 96 | 133 |
| | Organic hemp + destructor (post-effect) | 68 | 94 | 135 |
| HIP05 (factor A) | | 4.2 | 3.5 | 4.1 |

## DISCUSSION

In comparison with the results of other authors (Ilieva-Makulec et al., 2017) it can be concluded that organic cultivation technologies for hemp crops have a positive influence on the formation of a larger earthworm population.

The effect of the variants on the woodlice population in the soil was not as pronounced but statistically significant. Their quantity was practically the same, with a slight difference observed in the variants with organic technologies. The highest quantity of woodlice was recorded in all variants where organic hemp was planted while the lowest was on the variants with transitional cultivation technologies.

There was significantly greater differentiation among the research variants for nematodes. In terms of this indicator the difference between organic and inorganic technologies was 20–23 individuals. Organic maize plantations did not statistically differ from hemp plantations in terms of nematode populations. The nematode population was statistically higher in organic plantations. Under conditions of inconsistent moisture there was no nematocidal or protective effect. The obtained results contradict the findings (Benelli et al., 2018; McPartland and Sheikh, 2018; Pavela et al., 2019) which indicates the inconsistency of results under different agroecological conditions (Mukhtar et al., 2013).

The presented results suggest that hemp is a favorable crop for increasing the populations of earthworms, woodlice, and certain nematode species. As demonstrated by the correlation analysis soil community components exist in a complex system of interrelationships and a distinct characteristic of these relationships is solely positive dependence. This dependence can vary in strength, however no inverse correlations were observed. Since the quantity of living organisms was greater in variants with organic technologies it can be concluded that there was an increase in the population of harmful organisms.

The average number of earthworms over the study years exhibited strong positive correlations only with the quantity of microfungi (Figure 3) and woodlice, with r = 0.70. However, in certain years the interrelationships within the biological components of the soil system may differ. For instance, correlations between the number of earthworms and woodlice, as well as nematodes, were characterised by weak positive associations (r = 0.27).

The quantity of earthworms showed the closest correlation with the quantity of microfungi (r = 0.56) while the highest correlation coefficients was observed between the nematode environment and the quantity of sporulating bacteria (r = 0.75), streptomycetes (r = 0.78), and phosphorus-mobilizing microorganisms (r = 0.85). Slightly lower correlation relationships existed between the quantity of nematodes and the quantity of nitrogen-fixing bacteria and streptomycetes with values of 0.61 and 0.66 respectively. This distribution of correlations might be associated with the feeding peculiarities of the organisms (Figure 4).

The components of the microbiological community also exhibit a complex system of direct correlations among each other. The coefficient values in this aspect are significantly higher with a greater number of strong correlations (Table 3).

The results of statistical analysis reveal that streptomycetes play a significant role among the soil microbiota components. It holds the highest

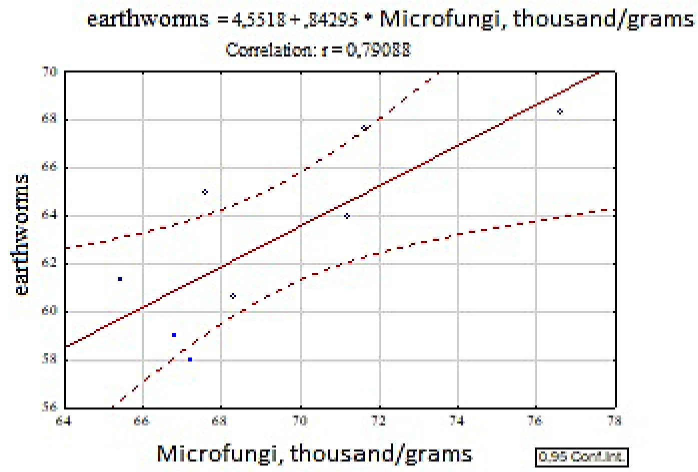


**Figure 3.** Dependency graph of the quantity of earthworms on the content of microfungi in the soil

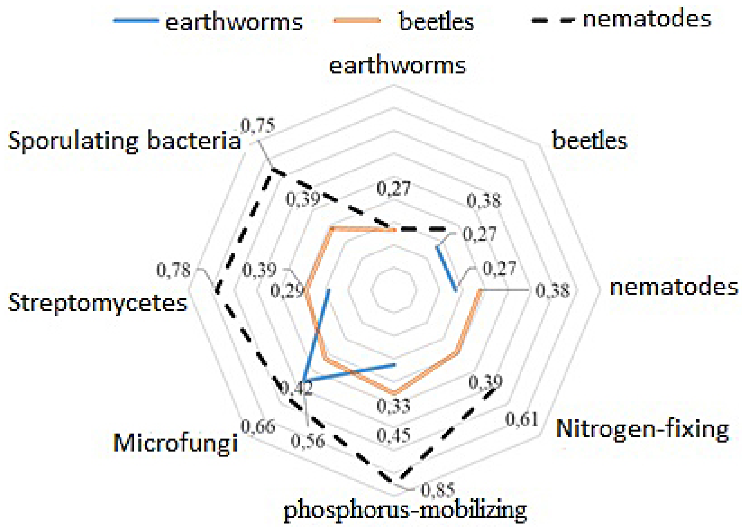


**Figure 4.** Correlation plots among soil biota components

**Table 3**. Correlation coefficients among soil microbiota components

| Components | Nitrogen-fixing | Phosphorus-mobilizing | Microfungi |
|---|---|---|---|
| Nitrogen-fixing | | 0.65 | 0.57 |
| Phosphorus-mobilizing | 0.65 | | 0.78 |
| Microfungi | 0.57 | 0.78 | |
| Streptomycetes | 0.76 | 0.89 | 0.72 |
| Sporulating bacteria | 0.60 | 0.86 | 0.70 |

correlation coefficient values with agronomic characteristics – the quantities of nitrogen-fixing and phosphorus-mobilizing organisms – r = 0.72–0.86. Among the other components the correlation between the quantity of nitrogen-fixing bacteria was weaker. On the contrary phosphorus-mobilizing bacteria showed a strong correlation with all investigated soil microbiota components – r = 0.78–0.89. Thus, soil microorganisms may exist within a complex system of interactions, which evidently can be altered by other cultivation factors. However, it's worth noting the absence of reverse correlations, which can have both positive and negative consequences, as the number of harmful microorganisms may also increase in organic cultivation technologies.

## CONCLUSIONS

Organic cultivation technologies contributed to an increase in the content of alkaline-hydrolyzed nitrogen by almost 3 mg/kg. The content of $P_2O_5$ in variants with pastures, fallow and transitional maize and hemp cultivation was 16.6 mg/kg lower compared to variants cultivated with organic technologies. The average content of $K_2O$ in inorganic variants was 83.6 mg/kg, while in organic variants it was 100.1 mg/kg. The application of organic residue decomposers did not affect the content of macroelements in the soil. Thus, in organic technologies, the macroelement composition of nutrients is formed more effectively.

Organic cultivation technologies promote the development of improved soil biological activity. The highest tissue degradation intensity was observed in variants cultivated with organic technologies – by 30.5%. In contrast, transitional cultivation methods were provided only by 28%. Higher intensity of $CO_2$ diffusion and nitrification capacity were also observed in organic variants. Organic farming technologies contribute to an increase in the quantity of microorganisms in the soil. It should be considered that alongside the increase in the quantity of beneficial organisms the number of pathogenic agents also grows.

On average over the years of the study the quantity of earthworms in variants with pastures and inorganic cultivation methods were by 6–10 individuals/m$^2$ lower compared to organic technologies. The difference for springtails and nematodes was by 4–5 and by 20–21 individuals. Thus, in hemp agroecosystems cultivated using organic technologies, a favorable environment is created for the existence of soil biological indicators, which has a positive impact on preserving soil fertility properties.

Soil biota components are interrelated within a complex system of correlation connections. For instance, microorganisms accumulating nitrogen and phosphorus strongly correlate with the fungal component (r = 0.72–0.89). This characteristic needs to be considered and studied by employing organic cultivation methods. The absence of reverse correlations between the quantity of beneficial and pathogenic microorganisms needs to be taken into account when implementing organic cultivation technologies.

## REFERENCES

1. Pylypchenko A., Marenych M., Hanhur V., Semenov A., Sakhno T., Ponomarenko S., Karpuk L., Rozhkov A. 2023. Formation of the quality indicators of hemp (*Cannabis sativa* L.) seeds sown under organic growing technology. Journal of Ecological Engineering, 24(8), 218–227.
2. Adesina I., Bhowmik A., Sharma H., Shahbazi A. 2020. A review on the current state of knowledge of growing conditions, agronomic soil health practices and utilities of hemp in the United States. Agriculture, 10(4), 129.
3. Liang S., Xu Y., Chen Y., Yang M., Guo H. 2013. Advances and the effects of industrial hemp for the cleanup of heavy metal pollution. Acta Ecologica Sinica, 33(5), 1347–1356.
4. Kok C.J., Coenen G.C.M., A de Heij A. 1994. The effect of fibre hemp (*Cannabis sativa* L.) on selected soil-borne pathogens. Journal of the International Hemp Association, 1, 6–9.
5. Lotz L.A.P., Groeneveld R.M.W., Habekotte B., H. van Oene. 1991. Reduction of growth and reproduction of *Cyperus esculentus* by specific crops. Weed Research, 31(3), 153–160.
6. Van der Werf H.M.G., van Geel W.C.A., Wijlhuizen M. 1995. Agronomic research on hemp (*Cannabis sativa* L.) in the Netherlands, 1987-1993. Journal of the International Hemp Association, 2(1), 14–17.
7. Van der Werf H. 1994. Crop physiology of fibre hemp (*Cannabis sativa* L.). Doctoral thesis, Wageningen Agricultural University, Wageningen, the Netherland, 152.
8. Soti P., Rugg S., Racelis A. 2016. Potential of cover crops in promoting mycorrhizal diversity and soil quality in organic farms. Journal of Agricultural Science, 8(8), 42–47.
9. Konstantinovic B., Koren A., Kojić M., Samardzic N. 2021. Allelopathic properties of hemp. Contemporary Agriculture, 70(3-4), 101–107.
10. Land M., Haddaway N.R., Hedlund K., Jorgensen H.B., Katterer T., Isberg P.E. 2017. How do selected crop rotations affect soil organic carbon in boreo-temperate systems? A systematic review protocol. Environmental Evidence, 6(9), 1–8.
11. Fike J.H., Darby H., Johnson B.L., Smart L., Williams D.W. (2020). Industrial hemp in the USA: a brief synopsis. In: Crini G., Lichtfouse E. (eds). Sustainable Agriculture Reviews 42, 111.
12. Merfield C.N. Industrial hemp and its potential for New Zealand. 1999. A Report for the 1999 Kellogg Rural Leadership Course, 33.
13. Baldini M., Ferfuia C., Zuliani F., Danuso F. 2020. Suitability assessment of different hemp (*Cannabis sativa* L.) varieties to the cultivation environment. Industrial Crops and Products, 143, 111860.
14. Gorchs G., Lloveras J., Serrano L., Cela S. 2017. Hemp yields and its rotation effects on wheat under rainfed Mediterranean conditions. Agronomy Journal, 109(4), 1551–1560.
15. Chable V., Dawson J., Bocci R., Goldringer I. 2014. Seeds for organic agriculture: development of participatory plant breeding and farmers' networks in France. In organic farming, prototype for sustainable agricultures: prototype for sustainable agricultures. In: Bellon S., Penvern S. (eds). Springer: Dordrecht, the Netherlands, 383–400.
16. Cherney J.H., Small E. 2016. Industrial hemp in North America: production, politics and potential. Agronomy, 6(4), 58.
17. Jalgaonwala R., Mahajan R. 2014. A review on microbial endophytes from plants: A treasure search for biologically active metabolites. Global Journal of Research on Medicinal Plants & Indigenous Medicine, 3(6), 263–277.
18. Guerra C.A., Bardgett R.D., Caon L., Crowther T.W., Delgado-Baquerizo M., Montanarella L., Navarro L.M., Orgiazzi A., Singh B.K., Tedersoo L., Vargas-Rojas R., Briones M.J.I., Buscot F., Cameron E.K., Cesarz S., Chatzinotas A., Cowan D.A., Djukic I., van den Hoogen J., Lehmann A., Maestre F.T., Marín C., Reitz T., Rillig M.C., Smith L. C., de Vries F.T., Weigelt A., Wall D.H., Eisenhauer N. 2021. Tracking, targeting, and conserving soil biodiversity. Science, 371(6526), 239–241.
19. Ilieva-Makulec K., Bielecki M., Makulec G. 2017. Plants with known antagonistic properties against pests: how they influence non-target free-living soil fauna? Studia Ecologiae et Bioethicae, 15(4), 41–53.
20. McPartland J.M. 1996. A review of *Cannabis* diseases. Journal of the International Hemp Association, 3(1), 19–23.

21. ElSohly M.A., Slade D. 2005. Chemical constituents of marijuana: the complex mixture of natural cannabinoids. Life Sciences, 78(5), 539–548.
22. Benelli G., Pavela R., Petrelli R., Cappellacci L., Santini G., Fiorini D., Sut S., Dall'Acqua S., Canale A., Maggi F. 2018. The essential oil from industrial hemp (*Cannabis sativa* L.) by-products as an effective tool for insect pest management in organic crops. Industrial Crops and Products, 122, 308–315.
23. McPartland J. M., Sheikh Z. 2018. A review of *Cannabis sativa*-based insecticides, miticides, and repellents. Journal of Entomology and Zoology Studies, 6(6), 1288–1299.
24. Pavela R., Maggi F., Iannarelli R., Benelli G. 2019. Plant extracts for developing mosquito larvicides: from laboratory to the field, with insights on the modes of action. Acta Tropica, 193, 236–271.
25. Mukhtar T., Kayani M.Z., Hussain M.A. 2013. Nematicidal activities of *Cannabis sativa* L. and Zanthoxylum alatum Roxb. against Meloidogyne incognita. Industrial Crops and Products, 42, 447–453.
26. Bernard E.C., Chaffin A.G., Gwinn K.D. 2022. Review of nematode interactions with hemp (*Cannabis sativa*). Journal of Nematology, 54(1), 20220002.
27. Van Biljon E.R. (2017). Nematode pests of tobacco and fibre crops. In: Fourie H., Spaull V., Jones R., Daneel M., De Waele D. (eds). Nematology in South Africa: a view from the 21st century. Springer, Cham, 285-310.
28. Zhang Q.Y., Li Z.L., Han B.J. 2013. Immediate responses of cyst nematode, soil-borne pathogens and soybean yield to one-season crop disturbance after continuous soybean in northeast China. International Journal of Plant Production, 7(2), 341–353.
29. Bonde T.A., Nielsen T.H., Miller M., Sørensen J. 2001. Arginine ammonification assay as a rapid index of gross N mineralization in agricultural soils. Biology and Fertility of Soils, 34, 179–184.
30. Alef K., Kleiner D. 1987. Applicability of arginine ammonification as indicator of microbial activity in different soils. Biology and Fertility of Soils, 5, 148–151.
31. Waksman S.A. 1959. Strain specificity and production of antibiotic substances. X. Characterization and classification of species within the *Streptomyces griseus* group. Proceedings of the National Academy of Sciences of the United States of America, 45(7), 1043–1047.
32. Baldani J.I., Reis V.M., Videira S.S., Boddey L.H., Baldani V.L.D. 2014. The art of isolating nitrogen-fixing bacteria from non-leguminous plants using N-free semi-solid media: a practical guide for microbiologists. Plant and Soil, 384(1), 413–431.
33. Vance E.D., Brookes P.C., Jenkinson D.S. 1987. An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry, 19(6), 703–707.
34. Anderson J. P. E. 1982. Soil respiration. In: Page A. L., Miller R. H., Keeney D. R. (eds.). Methods of Soil Analysis. Agronomy monograph, 9(2). Chemical and biological properties, 2nd ed. SSSA and ASA. Madison, WI, 831–871.
35. Nelson D.W., Sommers L.E. 1982. Total carbon, organic carbon, and organic matter. In: Page A.L., Miller R.H., Keeney D.R. (Eds.). Methods of Soil Analysis. Agronomy Series, 9(2). Chemical and Microbiological Properties, 2nd ed. SSSA and ASA. Madison, WI, 539–579.
36. Mehlich A. 1984. Photometric determination of humic matter in soils, a proposed method. Communications in Soil Science and Plant Analysis, 15(12), 1417–1422.
37. Semenov A., Korotkova I., Sakhno T., Marenych M., Hanhur V., Liashenko V., Kaminsky V. 2020. Effect of UV-C radiation on basic indices of growth process of winter wheat (*Triticum aestivum* L.) seeds in pre-sowing treatment. Acta Agriculturae Slovenica, 116(1), 49–58.