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Structure of soil micromycete communities in grey forest soil under long-term energy crop cultivation

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ABSTRACT

The relevance of the study is driven by the growing interest in energy crops not only as a source of biomass, but also as a factor influencing the biological and phytosanitary status of soil. This paper presents the results of a study of the genus-level structure of soil micromycete communities in grey forest soil under long-term cultivation of perennial energy crops in the western region of Ukraine. The object of the study was the effect of long-term cultivation of *Silphium perfoliatum* L., *Sida hermaphrodita* (L.) Rusby, and *Miscanthus* × *giganteus* on the genus-level structure of soil micromycetes in grey forest soil; soil under a traditional field crop rotation was used as the control. Soil analysis was carried out on the basis of phytopathological laboratory examinations, including the determination of the abundance of fungi belonging to the genera *Fusarium, Penicillium, Trichoderma, Aureobasidium,* and *Gliocladium*. It was established that the composition of soil micromycetes depended on the cultivated crop species. The highest abundance of *Fusarium* was detected in soil under *Silphium perfoliatum*, whereas under *Miscanthus* × *giganteus* it was close to the control level. The highest abundance of *Penicillium* was recorded under *Sida hermaphrodita* and *Silphium perfoliatum*. The greatest development of *Trichoderma* was observed under *Miscanthus* × *giganteus*, whereas fungi of this genus were not detected in soil under *Silphium perfoliatum*. *Aureobasidium* was detected only in the control and under *Sida hermaphrodita*, while the highest abundance of *Gliocladium* was found under *Sida hermaphrodita*. The results indicate that long-term cultivation of perennial energy crops causes species-specific changes in the structure of soil micromycetes. Among the studied energy crops, *Miscanthus* × *giganteus* had the most favorable effect on the formation of soil micromycete communities, since soil under this crop combined a low abundance of *Fusarium* with a very high abundance of *Trichoderma*. In contrast, *Silphium perfoliatum* proved to be the least favorable variant, as soil under this crop showed a high abundance of *Fusarium* and the absence of *Trichoderma*.

Keywords: energy crops, soil micromycetes, *Sida hermaphrodita, Silphium perfoliatum, Miscanthus × giganteus, Fusarium, Penicillium, Trichoderma*.

INTRODUCTION

Under current bioenergy development trends, perennial energy crops are regarded as an important source of renewable plant biomass and as a tool for the environmentally balanced use of land resources (Kaletnik et al., 2021; Ivanenko et al., 2026). Their cultivation is associated not only with the production of stable biomass for solid biofuels, biogas, bioethanol, and other bioproducts, but also with the possibility of reducing anthropogenic pressure on the environment, increasing energy independence, diversifying energy sources, and bringing marginal and degraded lands into economic use (Schuck, 2006; Kharytonov et al., 2022). In addition, perennial energy crops are increasingly considered a nature-based solution that makes it possible to combine biofuel production with additional environmental benefits, including carbon sequestration and a reduction in the overall environmental impact (Agostini et al., 2021; Romanchuk et al., 2025). In this context, energy crops are increasingly regarded not only as a feedstock source for bioenergy, but also as a factor contributing to the long-term improvement of the ecological condition of agricultural landscapes and as an important component of sustainable natural resource use (Honcharuk et al., 2024; Kaletnik et al., 2025). This approach is consistent with the current view that perennial energy crops should be evaluated not only in terms of the amount of biomass they produce, but also in terms of their environmental impact, ecological functions, and suitability for sustainable land use, especially in areas exposed to elevated environmental risk (Králík et al., 2023).

For Ukraine, the cultivation of energy crops is becoming particularly relevant due to growing energy risks, the deterioration of part of the agricultural land, and the need to find new ways of using areas with limited suitability for conventional farming (Shebanina et al., 2023). According to Kaletnik et al. (2025), perennial energy crops are an adaptive source of biomass for marginal lands, and their cultivation on disturbed and degraded areas is regarded as one of the promising ways to combine economic feasibility with environmental restoration. The authors also note that the productivity of such crops depends largely on natural and climatic conditions. In particular, aboveground biomass yield was higher in the steppe zone than in the forest-steppe, which indicates the need to consider zonal features when assessing their adaptability and cultivation efficiency. Thus, energy crops are important not only as a source of bioenergy feedstock, but also as a means of the environmentally sound use of lands with different levels of fertility.

In the broader context of bioenergy development, the findings of Kaletnik et al. (2021) further expand the understanding of the potential of energy crops in Ukraine, showing that the country has considerable capacity for cultivating *Miscanthus*, switchgrass, energy willow, and poplar without threatening food security. At the same time, the authors emphasize that individual energy crops differ substantially in their ability to adapt to environmental conditions. In particular, *Miscanthus* is reported to grow within a relatively wide temperature range and to have moderate to high moisture demand, but to be inferior to some other perennial energy crops in frost and drought tolerance. Such differences in species adaptability are important not only for predicting biomass yield, but also for understanding that different energy crops may affect the physical, chemical, and biological condition of soil in different ways. Therefore, species-specific characteristics of energy crops should be regarded as one of the key factors determining the nature of their interaction with the soil environment.

Among perennial energy crops, *Miscanthus × giganteus*, *Silphium perfoliatum* L., and *Sida hermaphrodita* (L.) Rusby are of particular interest (Peni et al., 2020). These species attract attention because of their high biomass productivity, long plantation lifespan, and the possibility of cultivation on soils with low fertility and on marginal lands (Nabel et al., 2016; Nahm and Morhart, 2018). *Miscanthus × giganteus* is currently regarded as one of the most promising crops for cultivation on low-fertility soils in Ukraine, as it is characterized by high energy efficiency, substantial energy yield per unit area, a long productive lifespan, and the ability to produce stable biomass yields for solid biofuel production (Lohosha et al., 2025). According to these authors, *Miscanthus* can be grown in one place for more than 20 years and, when the main cultivation requirements are met, ensures high rhizome establishment and stable biomass production. Of particular importance is the fact that long-term *Miscanthus* cultivation is accompanied by the accumulation of substantial belowground biomass and has a positive effect on the soil humus balance, which directly links this crop to possible changes in the biological environment of soil.

Technological studies are also important for understanding the effect of *Miscanthus* × *giganteus* on soil. Adamchuk et al. (2024) note that under Ukrainian conditions *Miscanthus* does not produce fully viable seed; therefore, it is propagated vegetatively by rhizomes. The authors also emphasize that this crop can be used for more than 20 years, requires lower nitrogen inputs than many annual and perennial grasses, and after several years of cultivation accumulates 15–20 t/ha of belowground biomass, thereby contributing to a positive humus balance. At the same time, Palamarchuk et al. (2026) showed that *Miscanthus* productivity depends substantially on planting time, plant density, and plantation establishment method. Thus, biomass formation and the potential effect of this crop on soil are determined not only by its biological traits, but also by agronomic factors.

Silphium perfoliatum and *Sida hermaphrodita* are no less promising, as they are regarded as crops suitable for the environmentally sound use of marginal lands. These perennial species can affect the soil environment through their well-developed root systems, the accumulation of organic matter, changes in soil water and nutrient regimes, and long-term cultivation without annual disturbance of the plough layer. It has also been shown that agronomic practices, especially nitrogen fertilization level, can substantially alter functionally important soil microbial communities associated with nitrification, denitrification, and nitrogen fixation (Kim et al., 2022). The long period of use of energy crops, the specific features of root system development, and the continuous input of plant residues into the soil create conditions for a gradual transformation of its biological status. It has also been established that the ability of perennial energy crops to accumulate organic carbon in soil and retain it over a long period depends largely on the characteristics of their root systems, which further emphasizes the importance of studying their influence on the soil environment (Xu et al., 2024). Therefore, *Miscanthus* × *giganteus*, *Silphium perfoliatum*, and *Sida hermaphrodita* are important not only as sources of energy biomass, but also as crops capable of exerting a long-term influence on soil condition, including its microbiological and mycological properties.

Soil micromycetes are an important component of soil biota, as they participate in the decomposition of plant residues, the transformation of organic matter, the formation of humic compounds, nutrient cycling, and the maintenance of the phytosanitary status of agroecosystems (Irfan et al., 2026). In the broader context of sustainable agriculture, rhizosphere microorganisms are regarded as an important factor in improving soil condition, increasing plant tolerance to stress, and optimizing the functioning of agroecosystems (Xing et al., 2026). Soil organic matter, in turn, is one of the key indicators of soil quality and biological activity, as it determines the intensity of microbiological processes, nutrient availability, soil structure, and ecological stability. It has been shown that changes in land use and agrotechnological pressure can significantly affect humus content, soil organic matter, microbial carbon, and the activity of microorganisms involved in the transformation of plant-derived substrates (Symochko et al., 2024). At the same time, it has been established that in soils with lower organic matter content and a more acidic reaction, particularly grey forest soils, the role of micromycetes in the structure of the soil microbiome increases (Demyanyuk et al., 2020). This confirms that biological soil indicators are sensitive markers of soil condition and can be used to assess the effects of long-term agricultural use. Micromycete communities also respond sensitively to environmental conditions, plant cover type, and crop cultivation practices. Depending on their ecological function, individual genera may act as saprotrophs, pathogen antagonists, or potentially phytopathogenic forms. For this reason, the structure of soil micromycete communities is an informative indicator of the biological condition of soil under the long-term cultivation of different perennial crops.

Recent studies show that micromycetes are well adapted to different environmental conditions and respond sensitively to cultivation practices. In particular, studies in cereal crops have shown that the abundance of micromycetes, the frequency of occurrence of individual species, and the level of sporulation depend significantly on the cultivation technology, while under sufficient moisture conditions representatives of the genus *Fusarium* may become dominant (Havryliuk et al., 2023). At the same time, plant root exudates may influence the phytopathogenic background, as they are capable of altering the composition and abundance of the mycobiota, suppressing pathogenic fungi, and inhibiting their sporulation (Beznosko et al., 2023). This suggests that species-specific traits of energy crops and the products of their root exudation may be important factors shaping the structure of the soil mycobiota.

Particular attention in the analysis of soil mycobiota is drawn to the genera *Fusarium, Penicillium, Trichoderma, Aureobasidium,* and *Gliocladium* (Ma et al., 2013; Luo et al., 2026). Representatives of the genus *Fusarium* are among the most widespread soil phytopathogens; *Penicillium* is a typical saprotrophic component of soil mycobiota, whereas *Trichoderma* and *Gliocladium* are regarded as important antagonistic fungi (Park et al., 2020; Adedayo and Babalola, 2023). Korniłłowicz-Kowalska et al. (2025) showed that in agricultural soils *Penicillium, Trichoderma,* and *Gliocladium* are associated with a more favorable soil condition, whereas *Fusarium* belongs to undesirable phytopathogens. Therefore, the ratio of these genera can be used to assess the ecological and phytosanitary condition of soil.

Although most studies of micromycetes focus on soil and plant agrocenoses, findings obtained in other environments also indicate the high adaptive capacity of fungi to diverse conditions. Hasanova et al. (2025) found that the abundance and species composition of micromycetes vary depending on temperature, pH, dissolved oxygen content, and substrate availability, while *Trichoderma viride* actively degrades cellulose (Li et al., 2025). This once again demonstrates that the structure of micromycete communities depends not only on plant traits, but also on environmental conditions and the availability of organic matter. At the same time, modern fungal studies are increasingly complemented by molecular methods, which allow more accurate identification of fungi (Meskini et al., 2026).

In our previous studies, we found that long-term cultivation of energy crops on grey forest soil in the western forest-steppe of Ukraine is accompanied by noticeable changes in its ecological, biochemical, and microbiological characteristics. In particular, it was established that under the long-term cultivation of *Miscanthus* × *giganteus*, *Silphium perfoliatum*, and *Sida hermaphrodita*, the mineral composition of the soil changes, the abundance of the main physiological groups of microorganisms increases, and the overall biological activity of the soil rises (Razanov et al., 2025; Razanov et al., 2026). At the same time, the structural features of soil micromycete communities, in particular the ratio between phytopathogenic, saprotrophic, and antagonistic genera, remained insufficiently studied under these conditions.

The aim of the study was to determine the effect of long-term cultivation of energy crops on the structure of soil micromycete communities in grey forest soil of the western forest-steppe of Ukraine by assessing the abundance and relative proportions of individual fungal genera under the cultivation of *Silphium perfoliatum*, *Sida hermaphrodita*, and *Miscanthus* × *giganteus* in comparison with soil under field crop rotation.

MATERIALS AND METHODS

The study was conducted in the western forest-steppe of Ukraine at permanent experimental plots with grey forest light loam soil characterized by a low humus content. The climate of the study area is moderately continental, with a mean annual air temperature of 8.5–8.8 °C and annual precipitation of 700–850 mm. The highest precipitation occurs in summer, whereas the lowest occurs in winter.

The object of the study was the communities of soil micromycetes in grey forest soil under the long-term cultivation of energy crops and under traditional field crop rotation. The experiment included four variants: soil under field crop rotation as the control and soil under perennial energy crops (*Silphium perfoliatum* L., *Sida hermaphrodita* (L.) Rusby, and *Miscanthus* × *giganteus*). The energy crops had been grown continuously for more than 20 years.

Soil samples were collected from the 0–20 cm layer in accordance with DSTU 4287:2004, "Soil Quality. Sampling". For each treatment, a composite sample was prepared from at least five individual point samples. The mycobiota of the soil samples was analysed at the laboratory of the Institute of Applied Biotechnology LLC (Kyiv, Ukraine) in accordance with DSTU 7847:2015, "Determination of the Number of Microorganisms in Soil by Plating on a Solid (Agar) Nutrient Medium".

The mycological status of the soil was assessed on the basis of laboratory analysis, which included determining the total abundance of mycobiota, the proportion of phytopathogenic and other saprotrophic fungi, as well as the percentage contribution of individual micromycete genera to the fungal complex. Within the framework of the study, the genera *Fusarium, Penicillium, Trichoderma, Aureobasidium,* and *Gliocladium* were analyzed as representative components of the soil mycobiota with different functional roles. The genus *Fusarium* was regarded as a predominantly phytopathogenic component, *Penicillium* as a saprotrophic component involved in organic matter decomposition, *Trichoderma* and *Gliocladium* as predominantly antagonistic genera, and *Aureobasidium* as one of the components of the soil mycobiota.

The abundance of individual micromycete genera, expressed as thousand CFU per 1 g of soil, was determined by calculation based on the total abundance of mycobiota and the percentage share of the respective genus reported in the laboratory test protocols. The calculation was performed using the following formula: Ag = (Ta × P) / 100, where Ag is the abundance of an individual micromycete genus, thousand CFU/g soil; Ta is the total abundance of mycobiota, thousand CFU/g soil; P is the share of the respective genus, %.

Using this approach, the abundance of *Fusarium, Penicillium, Trichoderma, Aureobasidium,* and *Gliocladium* was determined in the soils of the different experimental variants. The obtained values were used for a comparative assessment of the genus composition of soil micromycetes under the long-term cultivation of energy crops and under field crop rotation. Particular attention was paid to the ratio between phytopathogenic, saprotrophic, and antagonistic genera, as well as to the nature of changes in the fungal complex depending on the cultivated crop species. The results were summarized and interpreted through comparative analysis among the experimental variants. For data presentation, calculated values of the abundance of individual micromycete genera and their proportions in the structure of the soil fungal complex were used. It should be noted that in some variants the calculated abundance values of different micromycete genera (or their percentage increase relative to the control) coincided; this does not indicate a calculation error, but reflects the identical percentage share of the respective genera reported in the original laboratory test protocols for those variants.

RESULTS

The long-term cultivation of perennial energy crops in grey forest soil of the western forest-steppe of Ukraine was accompanied by pronounced changes in the structure of soil micromycete communities. It was established that different crop species formed different ratios between phytopathogenic, saprotrophic, and antagonistic fungal genera, indicating a different effect of plant cover on the mycological status of the soil.

In particular, the abundance of fungi of the genus *Fusarium* in grey forest soil depended markedly on the cultivated crop species (Figure 1). In the control treatment, this value was 7.95 thousand CFU/g soil. Under the long-term cultivation of energy crops, the abundance of *Fusarium* increased, although the extent of this increase varied among the crops. The highest value was recorded in soil under *Silphium perfoliatum* – 15.45 thousand CFU/g soil, which was 94.3% higher than in the control. In soil under *Sida hermaphrodita*, the abundance of *Fusarium* was 11.73 thousand CFU/g soil, exceeding the control by 47.5%. The lowest accumulation among the energy crops was found under *Miscanthus* × *giganteus* – 8.24 thousand CFU/g soil, which was only 3.6% higher than in the control treatment. Thus, according to their effect on *Fusarium* development, the studied crops can be arranged in the following order: *Silphium perfoliatum* > *Sida hermaphrodita* > *Miscanthus* × *giganteus* > control. The obtained results indicate that the most favorable conditions for *Fusarium* accumulation were formed under the long-term cultivation of *Silphium perfoliatum*, whereas *Miscanthus* × *giganteus* was characterized by the lowest accumulation of this phytopathogenic genus among the energy crops.

The analysis showed that the abundance of fungi of the genus *Penicillium* in grey forest soil also varied depending on the cultivated crop species (Figure 2). In the control treatment, this value was 7.95 thousand CFU/g soil. Under the long-term cultivation of energy crops, the abundance of *Penicillium* changed unevenly. The highest value was recorded in soil under *Sida hermaphrodita* (47.05 thousand CFU/g soil), which was 5.92 times higher than in the control. A very similar value was found in soil under *Silphium perfoliatum* (46.46 thousand CFU/g soil), which was 5.84 times higher than in the control. In soil under *Miscanthus* ×

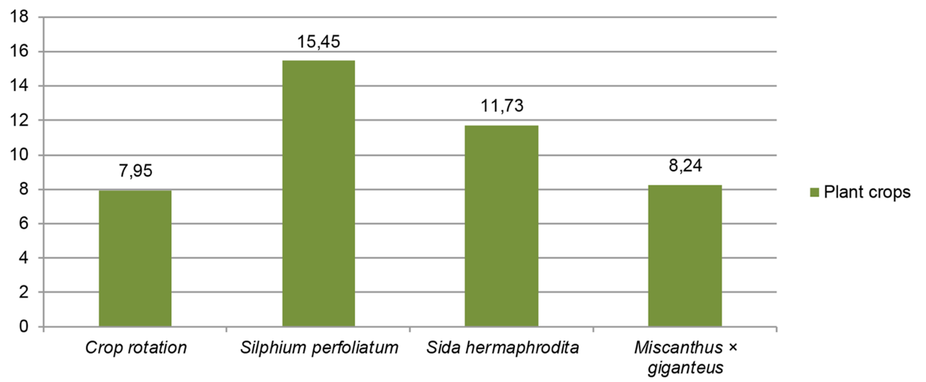

Figure 1. Abundance of fungi of the genus *Fusarium* in grey forest soil under long-term cultivation of energy crops, thousand CFU/g soil

giganteus, the abundance of *Penicillium* was 8.24 thousand CFU/g soil and exceeded the control only slightly, by 3.6%. Thus, according to their effect on *Penicillium* accumulation, the studied crops can be arranged in the following order: *Sida hermaphrodita* > *Silphium perfoliatum* > *Miscanthus* × *giganteus* > control. The obtained results indicate that the most favorable conditions for the development of fungi of the genus *Penicillium* were formed under the long-term cultivation of *Sida hermaphrodita* and *Silphium perfoliatum*, whereas under *Miscanthus* × *giganteus* their abundance remained close to the control level.

It was established that the abundance of fungi of the genus *Trichoderma* in grey forest soil differed among the experimental variants (Figure 3). In the control treatment, this value was 19.91 thousand CFU/g soil. Under the long-term cultivation of energy crops, changes in the abundance of *Trichoderma* were observed. In particular, fungi of this genus were not detected in soil under *Silphium perfoliatum*. In soil under *Sida hermaphrodita*, the abundance of *Trichoderma* was 15.73 thousand CFU/g soil, which was 21.0% lower than in the control. The highest value was recorded in soil under *Miscanthus* × *giganteus*, where it was 3.10 times higher than in the control treatment. Thus, according to their effect on *Trichoderma* development, the studied crops can be arranged in the following order: *Miscanthus* × *giganteus* > control > *Sida hermaphrodita* > *Silphium perfoliatum*. The obtained results indicate that the most favorable conditions for the development of fungi of the genus *Trichoderma* were formed under the long-term cultivation of *Miscanthus* × *giganteus*, whereas representatives of this genus were not detected in soil under *Silphium perfoliatum*.

Fungi of the genus *Aureobasidium* were detected only in selected experimental variants. In particular, this value was 3.94 thousand CFU/g soil in the control soil and 3.87 thousand CFU/g soil in the soil under *Sida hermaphrodita*, that is, it remained at nearly the same level. In the protocols for soils under *Silphium perfoliatum* and *Miscanthus* × *giganteus*, representatives

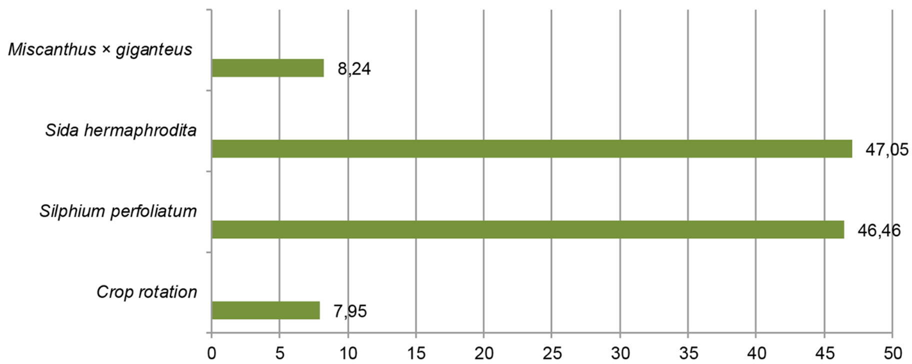

Figure 2. Abundance of fungi of the genus *Penicillium* in grey forest soil under long-term cultivation of energy crops, thousand CFU/g soil

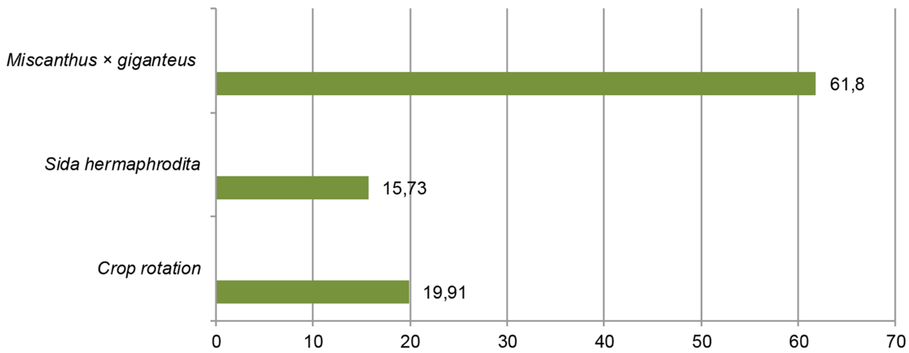

Figure 3. Abundance of fungi of the genus *Trichoderma* in grey forest soil under long-term cultivation of energy crops, thousand CFU/g soil

of the genus *Aureobasidium* were not reported; therefore, their abundance was not calculated for these variants. The obtained results indicate that, based on the available data, no significant differences in the abundance of *Aureobasidium* were found between the control and the soil under *Sida hermaphrodita*.

The study showed that the abundance of fungi of the genus *Gliocladium* in the control treatment was 7.95 thousand CFU/g soil. In soil under *Silphium perfoliatum*, the abundance of *Gliocladium* decreased to 3.86 thousand CFU/g soil, which was 51.4% lower than in the control. In contrast, in soil under *Sida hermaphrodita*, the abundance of fungi of this genus increased to 11.73 thousand CFU/g soil, which was 47.5% higher than in the control treatment (Figure 4). The obtained results indicate that the most favorable conditions for the development of *Gliocladium* were formed under the long-term cultivation of *Sida hermaphrodita*, whereas in soil under *Silphium perfoliatum* the abundance of this genus was the lowest among the variants for which calculated data were available.

DISCUSSION

The obtained results showed that the long-term cultivation of energy crops affected soil micromycete communities in grey forest soil in different ways. This is consistent with the findings of other researchers, who have shown that the composition of soil mycobiota depends on plant species, soil environmental conditions, and the input of organic matter into the soil. In particular, Korniłłowicz-Kowalska et al. (2025) demonstrated that the plant factor has a significant effect on the structure of the soil fungal complex, and that *Fusarium, Penicillium, Trichoderma, Gliocladium,* and *Aureobasidium* play the greatest role in its variability.

In our study, the highest abundance of *Fusarium* was found in soil under *Silphium perfoliatum* and *Sida hermaphrodita*, whereas under *Miscanthus* × *giganteus* it remained close to the control level. This indicates that soil under *Silphium perfoliatum* and *Sida hermaphrodita* provided more favorable conditions for the development of the phytopathogenic component

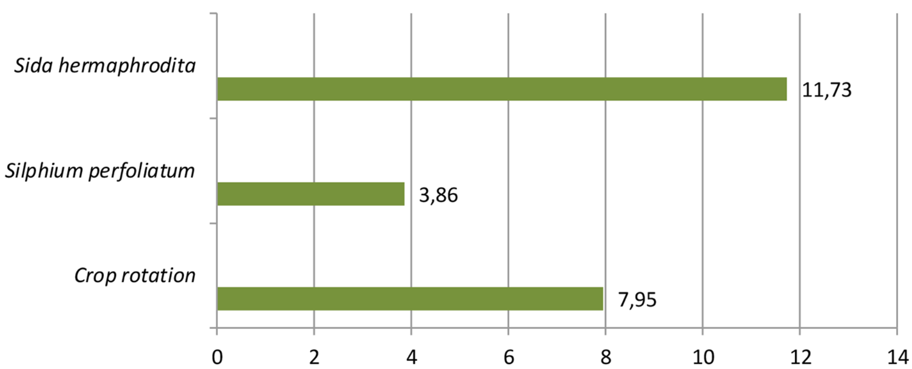

Figure 4. Abundance of fungi of the genus *Gliocladium* in grey forest soil under long-term cultivation of energy crops, thousand CFU/g soil

than soil under *Miscanthus* × *giganteus*. This interpretation is consistent with literature data in which *Fusarium* is regarded as an important group of soil phytopathogens.

A different pattern was observed for *Penicillium*. Its abundance was highest in soil under *Sida hermaphrodita* and *Silphium perfoliatum*, whereas in the control and under *Miscanthus* × *giganteus* it remained low. These results are in good agreement with the findings of Korniłłowicz-Kowalska et al. (2025), who showed that *Penicillium* often belongs to the dominant genera in agricultural soils, is associated with the decomposition of plant residues, and is characterized by pronounced antagonistic properties. The authors also noted that *Penicillium*, together with *Gliocladium*, actively colonizes old and dead roots and participates in the decomposition of plant residues, including cellulose and lignocellulose.

This is important for interpreting our results, since in soil under *Sida hermaphrodita* and *Silphium perfoliatum*, where the abundance of *Penicillium* was the highest, plant residues were likely incorporated more rapidly into the processes of organic matter transformation. This conclusion is also consistent with the broader context of soil microbiological research. Symochko et al. (2024) showed that changes in the composition or amount of organic matter entering the soil directly affect enzymatic activity, microbial biomass, and the structure of microbial communities. In addition, soil organic matter determines nutrient regime, soil structure, and biological activity, while its decline in agroecosystems is accompanied by changes in the microbial complex.

The most informative results were obtained for *Trichoderma*. In soil under *Miscanthus* × *giganteus*, the abundance of this genus was the highest and exceeded the control by more than threefold, whereas it was not detected in soil under *Silphium perfoliatum* and was lower than the control under *Sida hermaphrodita*. This difference is one of the most important findings of the study, since *Trichoderma* is generally regarded as one of the most valuable antagonistic genera of soil fungi. In particular, Adedayo and Babalola (2023) considered plant growth-promoting fungi in the rhizosphere as an important component of beneficial mycobiota capable of improving plant condition and the soil environment. Therefore, the sharp increase in the abundance of *Trichoderma* in soil under *Miscanthus* × *giganteus* may be interpreted as an indication of a more favorable phytosanitary condition of the soil in this variant.

At the same time, the absence of *Trichoderma* in soil under *Silphium perfoliatum* against the background of a high abundance of *Fusarium* makes this variant the least balanced. Such a contrast between the two genera is consistent with the approach proposed by Korniłłowicz-Kowalska et al. (2025), according to which the ratio between phytopathogenic and antagonistic genera can be used as an informative indicator of the ecological and phytosanitary condition of soil. Thus, *Miscanthus* × *giganteus* formed the most favorable composition of soil micromycetes, whereas *Silphium perfoliatum* appeared to be the least favorable.

A clear tendency was also found for *Gliocladium*: the highest abundance of this genus was recorded in soil under *Sida hermaphrodita*, a lower abundance in the control, and the lowest abundance in soil under *Silphium perfoliatum*. This is consistent with the findings of Korniłłowicz-Kowalska et al. (2025), who associated *Gliocladium*, together with *Penicillium*, with the decomposition of root residues and antagonistic activity against other fungi. Therefore, the simultaneous increase in *Penicillium* and *Gliocladium* in soil under *Sida hermaphrodita* may be regarded as an indication of the strengthening of the saprotrophic–antagonistic block of the soil mycobiota.

As for *Aureobasidium*, it was detected only in the control and in soil under *Sida hermaphrodita*, and in nearly the same amounts. Unlike the previous genera, this parameter did not show clear differences among the variants. At the same time, the presence of *Aureobasidium* in the mycobiota indicates that even less abundant genera may be part of the overall restructuring of the soil fungal complex. In the study by Korniłłowicz-Kowalska et al. (2025), *Aureobasidium* also belonged to the genera sensitive to plant type and cultivation conditions, although its role was less pronounced than that of *Fusarium, Penicillium, Trichoderma,* or *Gliocladium*.

An important explanation for the observed differences may be the root exudates of plants. Beznosko et al. showed that they are capable of influencing the composition and abundance of the mycobiota, suppressing pathogens, reducing the effects of toxins, and inhibiting fungal sporulation. This suggests that species-specific traits of energy crops and the products of their root exudation may have been one of the key mechanisms shaping the different composition of soil micromycetes in soils under *Silphium perfoliatum*, *Sida hermaphrodita*, and *Miscanthus* × *giganteus*.

Additional support for this interpretation is provided by our previous results on the biological activity of soil under energy crops. In particular, it was shown that the long-term cultivation of energy crops, especially *Sida hermaphrodita*, increases the biological fertility of grey forest soil, promotes the formation of stable microbial communities, and may be regarded as an environmentally sound way of using low-productivity land (Razanov et al., 2026).

CONCLUSIONS

The long-term cultivation of perennial energy crops in grey forest soil was accompanied by changes in the genus composition of soil micromycetes, and the nature of these changes depended on the crop species. The highest abundance of *Fusarium* was detected in soil under *Silphium perfoliatum*, whereas under *Miscanthus* × *giganteus* it was close to the control level.

The highest abundance of *Penicillium* was recorded in soil under *Sida hermaphrodita* and *Silphium perfoliatum*, whereas the greatest development of *Trichoderma* was observed under *Miscanthus* × *giganteus*. This indicates that energy crops differed in their effects on the saprotrophic, antagonistic, and phytopathogenic components of soil mycobiota.

Miscanthus × *giganteus* formed the most favorable composition of soil micromycetes, characterized by a low abundance of *Fusarium* and a very high abundance of *Trichoderma*. The least favorable variant was *Silphium perfoliatum* because of the high abundance of *Fusarium* and the absence of *Trichoderma*, whereas *Sida hermaphrodita* occupied an intermediate position and was characterized by a high abundance of *Penicillium* and *Gliocladium*. The obtained results indicate that perennial energy crops should be evaluated not only in terms of biomass productivity or overall biological activity of the soil, but also in terms of their long-term influence on the composition of soil micromycetes.

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