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Impact of tropho-metabolic activity of earthworms (Lumbricidae) on distribution of soil algae within *Acer platanoides* L. plantation in recultivated territories of Western Donbass (Ukraine)

O. Didur[1*], Y. Kulbachko[1], Y. Maltsev[2]

[1]*Oles Honchar Dnipro National University, Gagarin ave., 72, Dnipro, 49010, Ukraine, E-mail: didur@ua.fm*
[2]*Bogdan Khmelnitsky Melitopol State Pedagogical University, Getmanskaya st., 20, Melitopol, 72312, Ukraine*
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Rational use of natural resources in conditions of modern environmental management is an ongoing challenge to maintain sufficient level of wellbeing – natural resources and healthy environment in the contest of biodiversity preservation, formation of soil fertility, esthetic properties of landscapes and other ecologically important services. One way to optimize technogenic landscapes is forest recultivation – creation of stable forest ecosystems on disturbed territories, which can be powerful environmentcreation tool. The pertinent activity of animals – ecological engineers has great importance for improvement of ecological state of forest ecosystems on the recultivated territories. Soil engineers, such as earthworms, are the key organisms in functioning of soil – most important component of terrestrial ecosystem. They participate in various ecological processes and play key role in numerous ecosystem services: biogeochemical cycles support, forming of sustainable hydrological regime of territory and soil productivity, protection from the erosion. Additional natural soil biotic factor, multiplying these effects – algae, which reflect biogenic grade of soil and their naturalization in conditions of forest recultivation. Although, soil algae and earthworms are important components, supporting soil fertility, biogenic relationship of these groups of organisms, especially in the conditions of forest recultivation, remains largely unstudied The aim of the research is to evaluate the impact of pedotrubation and tropho-metabolic activity of earthworms (*Oligochaeta*: *Lumbricidae*) on resettlement of soil algaflora representatives within maple (*Acer platanoides* L.) plantation on the soil recultivation plot in Western Donbass in the Steppe zone of Ukraine. In fresh coprolites of earthworms *Aporrectodea caliginosa* on the studied plot, five species of soil algae (*Chlorella vulgaris* Beijerinck, *Botrydiopsis eriensis* Snow, *Phormidium retzii* (Agardn) Gomont, *Bracteococcus sp*., *Chlorococcum pulchrum* Archibald et Bold) were found. They belong to divisions *Chlorophyta*, *Cyanophyta*, *Xantophyta* and represented by *Ch*- and *P*-living forms, which can dwell in artificial forest ecosystem with severehydrothermal conditions. Such representatives as *Phormidium retzii*, *Chlorococcum pulchrum*, *Botrydiopsis eriensis* were present only in soil and coprolites on the soil surface. This indicates their rise to the soil surface in result of tropho-metabolic and pedotrubation activity of worms. This allows considering that, earthworms in the studied plot of soil recultivation contribute to redistributions and resettlement of soil algae, their exploration to new territories, and ultimately – naturalization of artificial edaphotopes of forest plantations in recultivated lands.
Key words: ecosystem services; ecological engineers; forest recultivation; biogenicity of soil; coprolites of earthworms; soil algae

Introduction

The problem of rational natural resources management is becoming increasingly important due to the intensification of anthropogenic impacts on the environment. One of the most pertinent issuesofmodern ecology – development of approaches to the conservation and rational use of biological diversity and the productivity of ecosystems in conditions of anthropogenic impact, in particular in the technological process of coal mining, leading to a radical change of a landscape, its hydrological regime, soil and vegetation disturbance, reduction of species diversity of flora and fauna, deterioration of soil fertility (Chakravarty, 2012; Brygadyrenko, 2015; Faly et al., 2017; Klymenko et al., 2017), which can be caused by mining tails, continuously exposed to wind and water erosion.During this process toxic compounds contained in mining tails penetrate into water ecosystems, soil and atmosphere, negatively affecting biota and human living environment (Benbrahim et al., 2004) and,

ultimately, decrease health potential (Lykholat et al., 2016). Therefore, in mining regions the problem of optimization of ecological situation is one of the top priorities (Mbaya, 2013; Kuzmishyna et al., 2015).
To reduce negative impact of technogenesis on the environment, a series of measures for soil conservation and vegetative cover restoration is required. One of the solutions for this problem is forest recultivation – a series of measures comprising forest cultivation on mine rock dumps and other lands, disturbed during extraction of mineral resources from deposits (Ibarra and de las Heras, 2005; Chibrik et al., 2016).
Soil algae as representatives of autotrophic organisms are important components of ecosystems and participate in various biological processes, as initial link for numerous microbiological chains, supporting normal functioning of all biota in general (Maltseva, 2007; Maltsev, 2013; Scherbina et al., 2014; Maltsev et al., 2017a, 2017b, 2017c; Shcherbyna et al., 2017 et al.). They participate in natural overgrowth of various technogenic substrates – ashes, tails, sands, disturbed by high levels of contamination (Baranova, 2012), influencing physico-chemical properties of soils, entering transbiotical relationship with soil inhabitants and higher plants, improving biogenicity of soil itself or soil substrate (Maltseva, 2007). Furthermore, soil algae emit into environment a spectrum of biologically active substances, vitamins, slimes, improving segregations of particular mineral particles of substrate and creation of future soil structure (Gollerbah and Shtina, 1969; Sirenko and Kondrateva, 1999; Shekhovtseva and Maltseva, 2015; Maltsev and Konovalenko, 2017), and also serve as a barrier against erosion (Dubovik, 1995).
Along with other green plants, algae participate in creation of primary production for the first order consumers, in particular soil saprophagues, such as millipedes, louses, earth worms, collembolas, oribatid mites. They cause redistribution of algae groups due to their selective consumption (Shtina and Gollerbah, 1976). The fact of appearance of algae along with other representatives of zoomicrobiological complex in the substrate of mine tails indicates initial stage of owergrowth with further accumulation of organic matter. Specialties of formation of pioneer algae communities on disturbed soils are presented in the series of works (Maltseva et al., 2009; Maltseva and Chayka, 2011; Maltseva and Posrednikova, 2011; Maltseva and Baranova, 2014 et al.).
Earthworms – typical representatives of functional group of ecosystem engineers (Bhadauria and Saxena, 2010; Eisenhauer, 2010; Cameron et al., 2013; Cunha et al., 2016). They have one of the leading roles in the soil processes (Albrecht et al., 1998; Kavdir and İlay, 2011), transformation of vegetable leaf litter, formation and stabilization of soil fertility are the most important in steppe and forest ecosystems. They modify physic-chemical conditions in soil by mixing and reducing vegetation leftovers, creating new habitats, earthworms have their impact on activity and composition of soil microbiota (Striganova, 1980; Li et al., 2002; Ferlian et al., 2018 et al.).
In their presence decomposition of organic matter improves significantly, directly due to their activity and indirectly through the stimulation of microbiological activity by their excrete (Satchell, 1983; Eisenhauer, 2011). Soils, enriched by coprolites of earthworms, demonstrate higher resistance to the negative impact of technogenesis (Kulbachko et al., 2010; Kul'bachko et al., 2011, 2015; Blouin et al., 2013; Jouquet et al., 2014; Amossé et al., 2015).
Thus, vital activity of soil algae, as well as earthwormsis connected mainly with provision of such important ecosystem services as increase of soil fertility and nutrients turnover. Benefits for such forest ecosystem define the importance of this group of organisms, which value substantially increases in modern conditions of climate change to the arid side and temperature rise especially in semiarid climatic zones (Lykholat et al., 2017). As results of study show, soil animals (Shtina et al., 1981) consume general mass of algae. Algophagous are found in various systematical groups of invertebrate dwelling in soil. Such representatives, as mites, collembolas, chironomid larvae eat away only algae while worms and enchytreides swallow it along with particles of soil (Striganova, 1980; Shtina et al., 1981). These studies have established that algae are not simply swallowed by worms in the process of feeding, but are also digested in the intestinal tract, and their nitrogen is included in the metabolic processes of the invertebrate organism. At the same time, the preservation of a significant part of the labeled nitrogen in the soil indicates an unequal digestion of algae by earthworms, which causes redistribution of the composition of algal groups in the soil.
For its part, coprolites of earthworms have a dual effect on algae. Thus, soil algae do not inhabit fresh coprolites of earthworms. Certain suppression is caused by fresh coprolites due to high concentration of various compounds that prevent inhabiting of coprolites by algae from surrounding environment, which subsequently decreases. Therefore, algae, found in fresh coprolites of earthworms, can be distinguished as representatives of soil algal flora, which passed through the digestive system of earthworms, were not assimilated and thus were rides to soil surface. Other passive ways of propagation and redistribution in the biogeocoenosis of algae is their penetration deep into soil through soil cracks, cavities left from the roots of plants, due to animal movements, with water, and also,while attached to the growing roots of plants.
Despite the fact that soil algae and earthworms are important components that support soil fertility, the biogenic relationship of these groups of organisms, especially in conditions of forest recultivation has not been practically studied.
The aim of the study was to evaluate the effects of the pedoturbation and tropho-metabolic activity of earthworms (*Oligochaeta: Lumbricidae*) on the distribution of soil algal flora within the plantation of the (*Acer platanoides* L.) in the forest reclamation site of the Western Donbass (Ukraine).

Methods

Studied material was collected in conditions of steppe zone of Ukraine (Dnipropetrovsk region) within the forest recultivation area planted with maple (*Acer platanoides* L.) located in the Western Donbass. Studied experimental-production site of recultivation is located in the zone of "Pavlogradskaya" colliery fields (48°33'32"N, 35°59'13"E) and represented by five stratigraphic types of bulk edaphotos with different thickness of recultivation layers (Fig. 1).

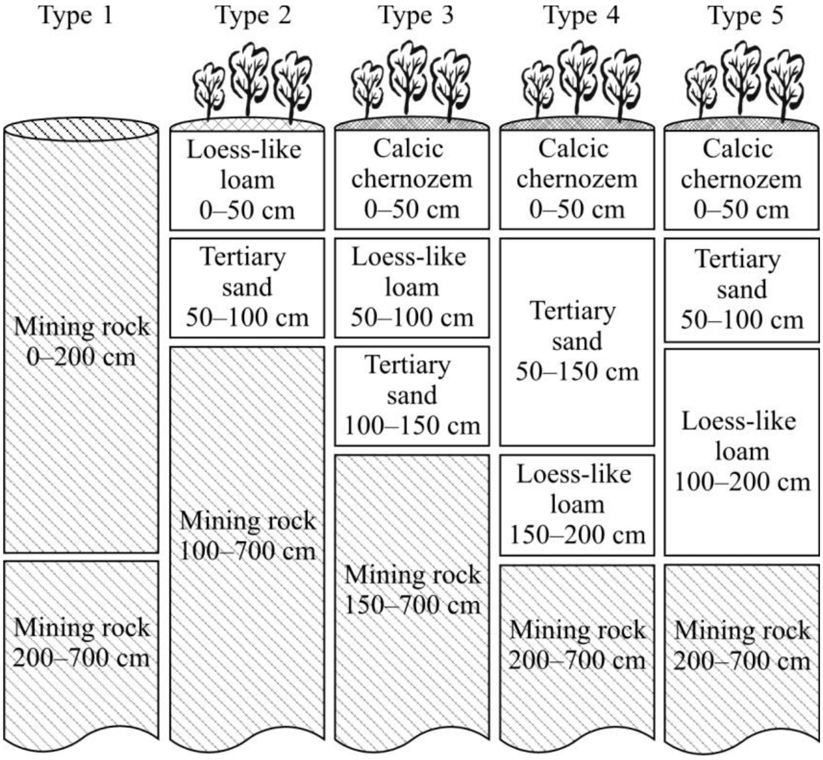

Fig. 1. Stratigraphic pattern of bulk soils on the forest recultivation plots

To improve productivity of planted forest, fertile soil layer was put within the studied territory. Loess-like loam and humificated calcic chernozem – potentially fertile substrates without signs of salinity were used to form such layers.Trees and bushes, in particular maple (*Acer platanoides* L., 1753) – deciduous tree plant of the family *Sapindaceae*, were planted at the stage of biological recultivation of the area. This popular ornamental plant is often used for recreational areas, as well as for agromelioration and forestry. Maple is frost resistant, withstands temperatures up to minus 40 degrees Celsius, in conditions of a moderate geographical area is not damaged by late spring and early autumn frosts. In the steppe conditions, it is rather heat-resistant and drought-resistant. Within maple tree plantations on studied stratigraphic types of forest recultivation, one species of the earthworm *Aporrectodea caliginosa* (Savigny, 1826) was found. It is saprophage, secondary destructor, nitrogen liberator, humifier, which belongs to endogenous soil worms (Zhukov et al., 2007). Its coprolites were collected from the soil surface.

To distinguish representatives of algoflora samples were taken from the soil layers 0–5 cm, 5–10 cm, 10–15 cm in three repeats. In laboratory soilsamples were transferred to Petri dishes and were kept moisturized for 12 hours with changing light-dark phases. Sterile glasses were put on surface of samples to allow algae to develop on the glass down side. Cultures were evaluated within 2–3 weeks (Kuzyahmetov and Dubovik, 2001). Systematical structure was established according to the system developed by I. Kostikov and co-authors (Kostikov et al., 2001). Classification of living forms was performed according to Shtina and Gollerbah (1976). Mathematical processing of obtained data was performed with MS Excel Office program tool.

Results and discussion

The composition of soil algae in the upper soil layer of various stratigraphic types of bulk edaphotopes and coprolites of earthworm's *A. caliginosa* within maple plantation in the forest recultivation plot is presented hereafter.

In the second* (*non-chernozem*) *type (the upper half-meter layer of loess-like loam), soil algae (8 species) were distributed non-uniformly: *Bracteococcus* sp., *Chlorella vulgaris* Beijerinck, *Phormidium borianum* Kützing, *Stichococcus minor* Nägeli were found in the litter. In the soil layers – *Botrydiopsis eriensis* Snow (0–5 cm), *Stichococcus minor* (0–5 cm), *Chlorella vulgaris* (5–10 cm), *Hantzschia amphioxys* ((Ehrenberg) Grunow in Cleve et Grunow (0–5 cm and 5–10 cm), *Nostoc paludosum* Kützing (0–5 cm and 10–15 cm), *Phormidium borianum* (0–5 cm and 10–15 cm), *Eustigmatos magnus* (B. Petersen) Hibberd (10–15 cm), in coprolites – *Botrydiopsis eriensis* and *Chlorella vulgaris* were identified. The largest species richness was found in the litter (4 species) and 0–5 cm soil layer (5 species).

The presence of two species of algae (*Botrydiopsis eriensis* and *Chlorella vulgaris*) in fresh coprolites of earthworms and in deeper soil layers indicates that earthworms, due to their tropho-metabolic activity, contribute to their rise to the surface of bulk soils and provide possibility for their further resettlement. On the bulk loess like loam in coprolites of worms, soil algae were presented by two divisions – green and yellow-green algae, found species were distinguished as Ch-life forms.

In the third* (*calcic chernozem*) *type of bulk soil (the upper half-meter layer of calcic chernozem with loess-like loam interlayer) 10 species of algae were identified.Following were identified in the litter: *Eustigmatos magnus* and *Hantzschia amphioxys.* In the soil layers – *Nostoc microscopicum* Carmichael sensu Elenkin (0–5 cm), *Nostoc paludosum* (0–5 cm and 10–15 cm), *Bracteococcus sp.* (5–10 cm and 10–15 cm), *Crucigenia sp.* (5–10 cm), *Phormidium retzii* (Agardh) Gomont (5–10 cm), *Chlorella vulgaris* (10–15 cm), *Nostoc linckia* (Roth) Bornet et Flahault (10–15 cm), *Phormidium* (*Leptolyngbya*) *molle* (Kützing) Gomont (10–15 cm).

The litter of this type was the least inhabited with algae, the greatest algae species richness of algae was found for the soil layers 5–10 cm and 10–15 cm – 5 species for each.

In fresh coprolites of earthworms, only one species of algae – *Phormidium retzii*, which representative of the *P*-life form, was identified, in soil it was found only at a depth of 5–10 cm. It's rise to the surface of the calcic chernozem layer due to the trophy-metabolic activity of earthworms can contribute to its resettlement and the explorationto a new territory.

On the fourth* (*calcic chernozem*) *stratigraphic type of bulk soil (the upper half-meter layer of calcic chernozem with one-meter sand interlayer) 11 species of algae were found. Following were identified in the litter (4 species): *Bracteococcus sp*., *Chlorella vulgaris*, *Crucigenia* sp., *Psendococcomyxa simplex* (Mainx) Fott. In soil layers 9 species were identified – *Chlorella sp.* (0–5 cm and 5–10 cm), *Crucigenia sp.* (0–5 cm), *Gloeotila protogenita* Kützing (0–5 cm), *Stichococcus bacillaris* Nägeli (0–5 cm), *Nostoc linckia* (0–5 cm and 5–10 cm), *Calothrix brevissima* G.S.West (5–10 cm), *Nostoc paludosum* (5–10 cm), *Phormidium boryanum* (5–10 cm), *Chlorella vulgaris* (10–15 cm). *Bracteococcus sp.* was found in coprolites. In contrast to the third bulk type, this type could be characterized by high species richness of algae in the litter (4 species) and soil layers 0–5 cm and 5–10 cm – 5 species of algae. In coprolites of worms, one species of algae was found – *Bracteococcus sp.* – a representative of green algae, belonging to the *Ch*-life form. This species on the given type was identified only in the litter.

***On the fifth* (*calcic chernozem*)** type of bulk soil (the upper half-meter layer of calcic chernozem with a half-meter sand interlayer), in contrast to all the previous ones, the maximal species richness of algae (15 species) was established. The greatest number (8 species) was found for litter and soil bulk layer 10–15 cm (5 species). *Chlorella vulgaris*, *Bracteococcus* sp., *Eustigmatos magnus*, *Klebsormidium dissectum* (Gay) Ettl et Gärtner, *Klebsormidium subtilissimum* (Rabenhoert) Pickett-Heaps, *Pseudococcomyxa simplex*, *Scotiellopsis rubescens* Vinatzer, *Stichococcus bacillaris* were identified in the litter. In soil layers – *Nostoc paludosum* (0–5 cm), *Stichococcus bacillaris* (0–5 cm), *Chlorella vulgaris* (5–10 cm), *Chlorococcum pulchrum* Archibald et Bold (5–10 cm), *Eustigmatos magnus* (5–10 cm), *Botrydiopsis eriensis* (10–15 cm), *Hantzchia amphioxys* (10–15 cm), *Nostoc* sp. (10–15 cm), *Phormidium boryanum* (10–15 cm), *Xanthonema stichococcoides* (Pascher) Silva (10–15 cm). In coprolites of earthworms two species were identified – *Chlorococcum pulchrum* and *Bracteococcus eriensis*.

Representative of green microalgae *Chlorococcum pulchrum* was found in earthworms' coprolites within 5–10 cm layer, yellow-green *Bracteococcus eriensis* – within 10–15 cm layer. This indicates that the tropho-metabolic activity of worms contributes to their rise to the surface of the bulk soil and exploration to a new territory. It should be noted that both representatives belong to the *Ch*-life form. The presence of these species in fresh coprolites of earthworms and their absence in the litter can serve as a reliable confirmation of the involvement of earthworms through their trophic activity in dispersing algae along the soil layers. Thus, the environment-creation role of earthworms (on the example of *Aporrectodea caliginosa* (Savigny, 1826) in the formation of algogroups within the areas of forest recultivation is carried out through their burrowing and trophic-metabolic activities.

The trophic connection of saprophages and algae is manifested in the ingestion of algae by earthworms together with soil and plant remains. The trophic-metabolic function of earthworms contributes to a redistribution of the taxonomic composition of algae by transferring their individual representatives to the surface of reclaimed substrates.

Conclusion

The results of the study showed thatfive species of soil algae (*Chlorella vulgaris*, *Botrydiopsis eriensis, Phormidium retzii*, *Bracteococcus sp.*, *Chlorococcum pulchrum*) belonging to divisions *Chlorophyta*, *Cyanophyta*, *Xantophyta* were found in fresh coprolites of earthworms *Aporrectodea caliginosa* within the recultivated territory within maple plantations on various stratigraphic types of bulk edaphotopes. They were represented by *Ch*- and *P*-life forms that can live in an artificial forest ecosystem with severe hydrothermal conditionsin the coprolites of earthworms in the plantations of maple.

Representatives such as *Phormidium retzii* (Agardn) Gomont, *Chlorococcum pulchrum* Archibald et Bold, *Botrydiopsis eriensis* Snow were present only in soil and coprolites on the soil surface. This indicates their rise due to tropho-metabolic and pedoturbation activity of worms to the soil surface. As a result, earthworms in the areas of forest recultivation contribute to the redistribution and dispersion of soil algae, their exploration to new territories, and ultimately the naturalization of artificial edaphotopes of forest plantations on recultivated lands.

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