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MICROBIAL BIOMASS IN FOREST SOILS OF NATURAL AND AGRICULTURAL ECOSYSTEMS

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Abstract

The profile of vertical distributions of microbial biomass and its correlation with organic carbon in the brown and gray forest soils of the Republic of Moldova have been investigated in natural and agricultural ecosystems. Sampling was carried out in 10 profiles per soil horizons to a depth of 170-200 cm. Microbial biomass constituted in brown forest natural soils 367.5-643.1 µg C g^{-1} soil and in gray forest natural soils 322.7-828.6 µg C g^{-1} soil in the top layer. The negative effects on soil microbial biomass were observed as a result of long-term land management practices. Microbial biomass decreased in brown forest arable soils to the level of 91.6-116.4 µg C g^{-1} of soil and in gray forest arable soils - to 117.1-283.0 µg C g^{-1} of soil in the arable layer. Microbial biomass was connected with the humus content. Correlation coefficients constituted 0.98-0.99 in brown forest soils and 0.82-0.91 in gray forest soils. The link effect between microbial biomass and humus content decreased from virgin to arable soils. A negative link has been established with profile depth.

Key words: *microbial biomass, forest soils, organic carbon, humus.*

INTRODUCTION

The soil matrix is the surface of soil particles with active centers, around which layers of adsorbed substances (organic, mineral substances, microorganisms, gases, ions, molecules) are formed in a certain way. The soil matrix is an active part of the soil, capable of reproducing a complex of cations, a film of sorbed water, an organic matrix on the surface of soil particles. It includes three matrices: mineral, organic, and organo-mineral. Organo-mineral matrix includes both mineral and organic matrix areas, as well as immobilized enzymes and microorganisms (Zubkova & Karpachevsky, 2001).

On the other hand, microbial materials are an important constituent of stable soil organic matter. Soil microbes produce chemically diverse, stable soil organic matter. It has been shown that soil organic matter accumulation is driven by distinct microbial communities more than clay mineralogy, where microbial-derived soil organic matter accumulation is greatest in soils with higher fungal abundances and more efficient microbial biomass production (Kallenbach et al., 2016).

On the whole, the soil microbial biomass represents both the living part of the total soil organic matter and the active part of the soil matrix, constantly synthesizing organic matter in the form of humic substances.

Many microbiological indicators in the matrix are related to organic matter and are linked to nutrient cycling and the biodiversity and productivity functions. Determination of the soil microbiological biomass content is one of the basic parameters for monitoring soil changes. Soil microbial biomass carbon is important in regulating soil organic carbon dynamics along soil profiles by mediating the decomposition and formation of soil organic carbon (Tingting Suna et al., 2020). The importance of studying the contribution of soil microorganisms to total organic carbon is determined by their exceptional role in the formation of soil quality, understood as "the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health" (Doran & Parkin, 1994; 1996; Doran & Safley, 1997; Anderson & Domsch, 1989). At the same time, it has been shown that increase in the share of microbial carbon in organic carbon by more than 20% in crop rotation plots and in mixed forests is an indicator of the growth of soil biodiversity (Anderson Traute-Heidi, 2003).

Soil management has a large impact on the size of the biomass pool of microorganisms (Von Lützow et al., 2002; Nima Tshering Lepcha & Bijayalaxmi Devi, 2020). Numerous studies have shown that microbial biomass and microbial turnover is much lower in deeper soil layers compared to surface layers (Eilers et al., 2012; Spohn et al., 2016; Young et al., 2019). However, the land management can influence this trend. One study showed that while in natural ecosystems (forests, grasslands) microbial biomass decreased with depth, in an arable field there was no significant change (Van Leeuwen et al., 2017). This was probably a consequence of the homogenizing influence of agricultural activities. Conversely, it had been shown that in soil environments that are mostly unfavorable in the surface layer biomass levels increase with depth, because subsoil communities are protected from surface stresses such as radiation or desiccation (Mueller et al., 2015). Despite this, the subsoil represents a significant reservoir of microbial biomass. Estimation the share of the total microbial biomass contained in the subsoil ranges from 30% (Fierer et al., 2003; Van Leeuwen et al., 2017) to 58% (Schütz et al, 2010) or more.

The importance of microbial carbon analysis of deeper soils in soil research is justified (Naylor et al., 2022) as an indicator of changes in the quality of soil organic matter.

Spatial patterning of soil microorganisms can occur both horizontally and vertically, through the soil profile. Most studies focus on processes occurring in the upper A horizons because so much of the short-term dynamics occurs there (Raubuch & Beese, 1995). Our research were focused on vertical distributions of microbial biomass densities in natural soils and those that exposedto to the long-term agricultural use.

Thus, the study of the microbial carbon gradient in soils of contrasting ecosystems is a necessary step for assessing the architectonics of the soil organoprofile and understanding carbon fluxes in soil layers at different depths.

MATERIALS AND METHODS

Our comparative study has been conducted in central and northern zones of the Republic of Moldova (Figures 1, 2). Five experimental sites have been tested. The content and profile distributions of microbial biomass of arable forest soils with the normal profile were investigated in comparison with the undisturbed forest soils in natural ecosystems. The research foresees the use of the profile method - "unplowed (natural) - plowed" pairs. Investigations were performed on the brown and gray forest soil. Sampling was carried out in 10 profiles per soil horizons to a depth of 150-240 cm.

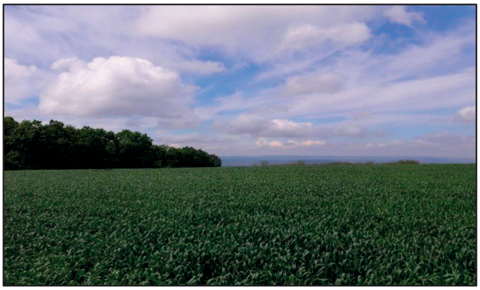

Figure 1. Fragments of natural and agricultural landscapes located in the central zone of the Republic of Moldova

Figure 2. Fragments of natural and agricultural landscapes located in the northern zone of the Republic of Moldova

Experimental sites with brown forest soils are located in the central zone of the Republic of Moldova, in the wooded steppe of the central - Moldovan forest province, in the district No. 8 of brown, gray forest soils and leached chernozems of the wooded steppe of hilly Kodru Forests.

The plot with *typical brown soil* (profile 1 under forest; profile 2 under arable) is situated in the Tuzara village and Gorodische com., Kalarash region (Figure 3).

The plot with *luvic brown forest soil* (profile 5 under forest; profile 6 under arable) is located in the Dolna com., Strasheni region (Figure 4).

Profile 1 Profile 2

Figure 3. Profiles of virgin typical brown forest soil (profile 1) and arable typical brown forest soil (profile 2)

Profile 5 Profile 6

Figure 4. Profiles of virgin luvic brown forest soil (profile 5) and arable luvic brown forest soil (profile 6)

Investigations were also conducted on the molic, albic and typical gray forest soils (classification of soils by Ursu A. (2001, 2016). The site with *molic gray forest soil* (profile 3 under forest; profile 4 under arable) is situated near the Grozeshti village, Nisporeni region (Figure 5). According to pedogeographic zoning, this site is located in the Central Plateau of Kodru Forests, in the region V of Kodru' Plateau, in the district No. 8 of brown, gray forest soils and leached chernozems.
The site with *albic gray forest soil* (profile 7 under forest; profile 8 under arable) falls within the hilly forest-steppe zone of the Northern Plain (I), in the forest-steppe of the Northern Plateau, in the district No. 1 of gray forest soils and clay-alluvial chernozems. Nearby is situating Terebna village, Edinets region (Figure 6).

The site with *typical gray forest soil* (profile 9 under forest; profile 10 under arable) is also located in the hilly forest steppe zone of the Northern Plain (I), the forest-steppe hill of Rezina district No. 5 of gray forest soils and argillaceous chernozems near the Raspopeni village, Sholdaneshti region (Figure 7).

Profile 3 Profile 4

Figure 5. Profiles of virgin molic gray forest soil (profile 3) and arable molic gray forest soil (profile 4)

Profile 7 Profile 8

Figure 6. Profiles of virgin albic gray forest soil (profile 7) and arable albic gray forest soil (profile 8)

Profile 9 Profile 10

Figure 7. Profiles of virgin typical gray forest soil (profile 9) and arable typical gray forest soil (profile 10)

The microbial biomass C was measured by the rehydratation method based on the difference between C extracted with 0.5 M K_2SO_4 from dried soil at 65-70°C within 24 h and fresh soil samples with K_c coefficient of 0.25 (Blagodatsky, Blagodatskaya et al., 1987). K_2SO_4 - extractable organic C concentrations in the dried and fresh soil samples were simultaneously measured by dichromate oxidation. The ratio between microbial and organic carbon was determined according to Kennedy & Papendick (1995). The quantity of K_2SO_4 - extractable C was determined at 590 nm with spectrophotometer.

Organic C was analyzed by the dichromate oxidation method (Arinushkina, 1970). The humus content was calculated using the coefficient of 1.724. The microbial biomass index and humus content was evaluated statistically by the correlation analysis.

RESULTS AND DISCUSSIONS

Soil microbial biomass decreases with soil depth in all land-use types of forest soils. Maximum content of microbial biomass in topsoil in natural forest soils is obesrved due to the availability of a larger amount of organic matter from trees. The presence of trees continuously adds litter to the top layer and increases root turnover. Organic matter in the litter layer in tree-based forest systems increases the amount of organic carbon in the soil profile, thereby helping in the restoration of better soil quality. As a result, microorganisms of natural soils exist in conditions of high supply of the organic matter and its conservation within the limits of the ecosystem.

The distribution of microbial biomass on the genetic horizons in soils of natural and anthropogenic ecosystems is sharply different. The highest level of the microbial biomass in natural brown forest soils have been determined in the layer 0-19 cm (A_1 genetic horizon), these constituting 367.5 µg C g^{-1} soil in the typical brown forest soil and 643.1 µg C g^{-1} soil in the luvic brown forest soil (Figure 8).

The quantity of the microbial biomass reaches in the natural molic gray forest soil 322.7 µg C g^{-1} soil in the layer 0-19 cm (Ad genetic horizon), in the albic gray forest soil – 802.5 µg C g^{-1} soil (Ao genetic horizon, layer 0-7 cm), in the typical gray forest soil - 828.6 µg C g^{-1} sol in A_1d genetic horizon in layer 0-30 cm (Figure 9).

The biomass index decreases in the soil profile of natural brown forest soils to a depth of 65-175 cm, in the soil profile of natural gray forest soils - to a depth of 122-190 cm.

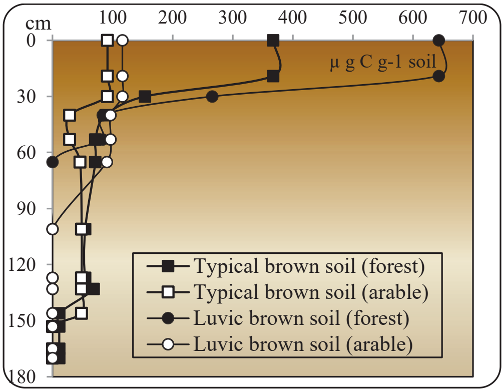

Figure 8. The profile distribution of microbial biomass in natural and arable brown forest soils

Thus, microbial biomass in natural soils is concentrated in the A genetic horizon, in brown forest soils - in the amount of 44.4-56.9%, in gray forest soils - in the amount of 45.0-64.7% from the profile total biomass. The profile distribution of microbial biomass in natural soils is associated with the concentration of leaf litter and the deposition of soil organic carbon in the upper layers.

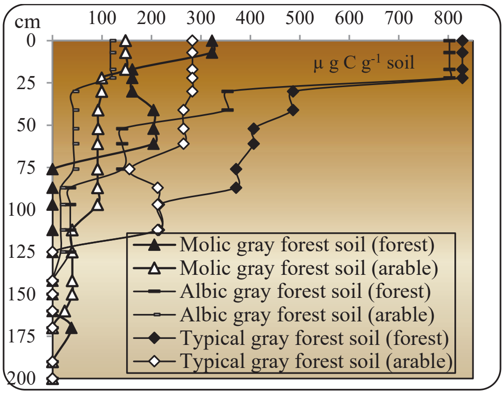

Figure 9. The profile distribution of microbial biomass in natural and arable gray forest soils

A similar trend has been noticed in the distribution of organic carbon content in natural soils, the value of which in the upper layers (Ad genetic horizon, layer 0-19 cm) in the typical brown forest soil constitutes 1.67%, in the luvic brown forest soil - 2.08% (Table 1). The organic carbon content in natural molic gray forest soil constitutes 3.16% (Ad genetic horizon, layer 0-17 cm), albic gray forest soil - 1.70% (Ao genetic horizon, layer 0-7 cm) and typical gray forest soil - 2.20% in the A1d genetic horizon, layer 0-30 cm (Table 2).

The share of microbial carbon from the organic carbon content (C_{MB}/C_{org}) in the A genetic horizon of natural brown forest soils constitutes 1.74-2.20% and natural luvic brown forest soil - 3.09-3.10%. The share of microbial carbon from the organic carbon content in gray forest soils under the forest constitutes in the molic gray forest soil - 1.02% in the soil layer 0-17 cm (genetic horizon Ad), in the albic gray forest soil - 4.72% and 3.05% in the soil layer 0-7 cm and 7-30 cm (genetic horizon Ao and A1), in the typical gray forest soil - 3.77% in the soil layer 0-30 cm (genetic horizon A1d).

Increasing the contribution of microbial carbon to the content of organic matter in the lower layers of horizon B is associated with growth of the abundance of anaerobic microorganisms in these layers.

The long-term use of arable management leads to the decrease of the content of microbial biomass in arable chernozems both in the upper horizons, and in the soil profile in general. The low content of microorganisms in the upper layers is characteristic of arable forest soils. The long-term use of forest soils leads to the reduction of the microbial biomass in the arable layer by several times.

Table 1. The profile distribution of the organic carbon content and share of microbial carbon on genetic horizons in brown forest soils of natural and agricultural ecosystems

Soil, profile	Horizon index	Depth, cm	C_{org}, %	C_{MB} / C_{org}, %
Typical brown forest soil (forest), P1	Ad	0-19	1.67	2.20
	A1	19-37	0.85	1.81
	A2	37-53	0.51	1.74
	B1	53-101	0.33	2.17
	B2	101-133	0.24	2.28
	BC	133-146	0.20	3.45
	C	146-175	0.13	0.87
Typical brown forest soil (arable), P2	A ar	0-34	0.45	2.04
	A1A2	34-62	0.27	1.06
	B1	62-83	0.19	2.41
	BC	83-153	0.14	3.47
	C	153-175	0.14	0
Luvic brown forest soil (forest), P5	Ad	0-19	2.08	3.09
	A1	19-30	0.86	3.10
	B1	30-65	1.00	0.84
	B2	65-105	0.21	0
	BC	105-128	0.16	0
	C	128-170	0.12	0
Luvic brown forest soil (arable), P6	A ar	0-40	0.46	2.53
	B1	40-65	0.34	2.85
	B2	65-102	0.20	4.54
	BC	102-127	0.18	0
	C	127-165	0.10	0

Microbial biomass index gradually decreases in the profile of arable soil. In arable brown forest soils, some species can be detected at a depth of 102-153 cm, in arable gray forest soils – at the depth of 115-240 cm. The profile distribution of microbial carbon in arable forest soils corresponds to the distribution of organic carbon. The share of microbial carbon in the organic carbon content constitutes 2.04% in the arable typical brown forest soil (layer 0-34 cm) and 2.53 % in the arable luvic brown forest soil (layer 0-40 cm). The share of microbial carbon in the organic carbon content constitutes 0.70% in the soil layer 0-22 cm (genetic horizon A1ar) of the molic gray forest soil, 1.14% in the soil layer 0-30 cm (genetic horizon A1ar) of the albic gray forest soil and 2.26% in the soil layer 0-32 cm (genetic horizon A1B1ar) of the typical gray forest soil.

Thus, the share of microbial carbon in its organic content in arable forest soils is lower than in natural ones.

Because of the long-term use of arable land, homogenization of the arable layer and decrease in the reserves of microbial carbon and humus, the natural stability of chernozems reduces.

The vertical distribution of microorganisms in forest soils is inextricably linked with the distribution of organic matter along the soil profile and, accordingly, with its depth. The analysis of the interdependence between the microbial biomass indicator, on the one hand, and the humus content, on the other hand, demonstrated their close positive connection (Tables 3, 4). The correlation coefficient (R^2) between the biomass of microorganisms and humus content in the typical brown soil constitutes R^2 = 0.98 (n=12) and in the luvic brown soil - R^2 = 0.99 (n=11). The correlation coefficient (R^2) between the biomass of microorganisms and humus content in the molic gray forest soil R^2 = 0.82 (n=12), in the albic gray forest soil - R^2 = 0.91 (n=12) and in the typical gray forest soil - R^2 = 0.82 (n=11).

Table 2. The profile distribution of the organic carbon content and share of microbial carbon on genetic horizons in gray forest soils of natural and agricultural ecosystems

Soil, profile	Horizon index	Depth, cm	C_{org}, %	C_{MB} / C_{org}, %
Molic gray forest soil (forest), P3	Ad	0-17	3.16	1.02
	A1	17-41	1.87	0.86
	B1	41-75	0.82	2.49
	B2	75-125	0.69	0
	BCk	125-170	0.49	0
	Ck	170-190	0.39	0.98
Molic gray forest soil (arable), P4	A1 ar	0-22	2.11	0.70
	A1	22-33	1.91	0.52
	B1	33-61	0.96	0.96
	B2	61-112	0.62	1.47
	BCk	112-158	0.35	1.15
	Ck	158-170	0.22	1.13
Albic gray forest soil (forest), P7	Ao	0-7	1.70	4.72
	A1	7-30	1.16	3.05
	A2	30-52	0.51	2.77
	Bt1	52-87	0.41	1.88
	Bt2	87-142	0.34	1.06
	BC	142-211	0.64	0
	C	211-240	0.60	0
Albic gray forest soil (arable), P8	A1ar	0-30	1.03	1.14
	B1	30-87	0.41	1.02
	Bt2	87-142	0.48	0.35
	BC	142-211	0.52	0
	C	211-240	0.49	0.66
Typical gray forest soil (forest), P9	A1d	0-30	2.20	3.77
	B1	30-43	0.85	5.72
	Bt2	43-76	0.50	8.14
	Bt3	76-97	0.44	8.43
	BC	97-122	0.41	5.25
	C	122-160	0.31	0
Typical gray forest soil (arable), P10	A1B1ar	0-32	1.25	2.26
	Bt2	32-66	0.37	7.16
	Bt3	66-77	0.37	4.21
	BC	77-115	0.33	6.44
	C	115-150	0.26	0

Table 3. Correlation between microbial biomass and humus content in forest soils

Soil	Land use	Correlation coefficient (R^2)
Typical brown forest soil	forest	0.98
	arable	
Luvic brown forest soil	forest	0.99
	arable	
Molic gray forest soil	forest	0.82
	arable	
Albic gray forest soil	forest	0.91
	arable	
Typical gray forest soil	forest	0.82
	arable	

Table 4. Correlation between microbial biomass and humus content in forest soils

Soil	Land use	Correlation coefficient (R^2)
Brown forest soil	forest	0.97
	arable	0.79
Gray forest soil	forest	0.56
	arable	0.29

The correlation coefficient between the microbial biomass and humus content in brown forest soils under natural vegetation is R^2 = 0.97 (n=13); in arable soils - R^2 = 0.79 (n=10). The correlation coefficient between the microbial biomass and humus content in natural gray forest soils constitutes R^2 = 0.56 (n=19); in arable soils - R^2 = 0.29 (n=16).
Since the abundance of microorganisms decreases with the depth of the soil profile, the correlation between these values is negative. The correlation coefficient (R^2) between the biomass of microorganisms and soil profile depth in brown forest soils constitutes R^2 = -0.66 (n=23) and in gray forest soils - R2 = -0.64 (n=35). The correlation coefficient between the microbial biomass and soil profile depth in brown forest soils under natural vegetation constitutes R^2 = -0.74 (n=13); in arable soils - R^2 = -0.76 (n=10). The correlation coefficient between the microbial biomass and soil profile depth in natural gray forest soils amounts R^2 = -0.74 (n=19); in arable soils - R^2 = -0.65 (n=16).

CONCLUSIONS

Soil microbial biomass represents both the living part of the total soil organic matter and the active part of the soil matrix. The results of the study demonstrated that land use affect have a significant impact on the microbial biomass carbon. In its turn, the profile distribution of organic carbon of the soil also affects this indicator. The content of organic and microbial carbon depends on the depth of the soil profile.
Evaluation of microbial biomass resources in forest soils in conditions of natural and agricultural ecosystems showed significant differences between these soils.
Undisturbed forest soils in conditions of the natural ecosystems are characterized by a higher biomass of soil microorganisms in comparison with arable soils and concentrated in the A genetic horizon. Microbial biomass constituted 367.5-643.1 μg C g^{-1} soil in brown forest natural soils and in 322.7-828.6 μg C g^{-1} soil gray forest natural soils in the top layer. The differences between brown and gray natural forest soils are manifested in a higher specific concentration of microbial biomass in the A genetic horizon of gray forest soils (45.0-64.7% of the total biomass in gray soils versus 44.4-56.9% in brown soils) and in a greater depth of microbial distribution along the soil profile (up to depths of 122-190 cm) in gray forest soils, while in brown forest soils microorganisms were found to a depth of 65-175 cm.
The long-term arable use of forest soils led to the reduction of microbial potential and contributed to the degradation and decrease of soil stability. In the conditions of arable land microbial biomass was reduced to the level of 91.6-116.4 in brown forest soils and to 117.1-283.0 μg C g^{-1} of soil in gray forest soils in the arable layer. The share of microbial carbon in its organic composition in arable forest soils is reduced compared with those under natural vegetation. At the same time profiles of the arable forest soils are covered by the degradation process in general. The negative effects on soil microorganisms were observed as a result of enhanced mineralization process, the content of organic carbon in arable soils has been significantly reduced.
The microbial biomass, being a part of the labile organic matter, was connected with the soil organic carbon content. The vertical distribution of microorganisms in forest soils is closely related with the distribution of organic matter and with its depth. The interaction

between microbial components and humus status is closer in soils of natural ecosystems. Correlation coefficients constituted 0.98-0.99 in brown forest soils and 0.82-0.91 in gray forest soils. The link effect between microbial biomass and humus content decreased from natural to arable soils. A negative link has been established with the profile depth.

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