Scientific Papers. Series A. Agronomy, Vol. LXVI, No. 1, 2023
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

THE DEGREE OF DEPENDENCY OF SOIL ECOSYSTEM SERVICES ON THE SOIL MICROBIOTA ACTIVITY

Daniela RĂDUCU, Anca-Rovena LĂCĂTUȘU, Irina CALCIU, Alina GHERGHINA, Alexandrina MANEA, Olga VIZITIU

National Research and Development Institute for Soil Science, Agrochemistry and Environment (RISSA-Bucharest), 61 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: alinagherghina@yahoo.com

Abstract

To reveal the degree of dependency of soil ecosystem services on soil biota activity, the detailed investigations at macroscopic - microscopic level had been used. At macroscopic level, the physical data showed a low to medium bulk density and consequently a high to medium porosity. The poral space quantified by the image analysis at microscopic level showed the dominance of the pores in the size classes of 100-300 µm (equivalent pore diameter), the elongated pores being dominant. Among them the fine fissures delimitating the biological pedofeatures by the surrounding matrix were also included and represent the path for water and air circulation, creating thus hospitable conditions for the microorganisms developed on the biogenic pedofeatures surfaces. The micromorphological investigation showed textural differences in the macrofauna coprolites: many areas with skeleton grains concentrations depleted of plasmic material. But their further ingestion by the soil mezofauna resulted in the re-mixing of soil constituents, mezofauna proving to have an active role in the textural soil matrix restoration. Soil biota covered all the web food needs for the "factory fertility": the main soil ecosystem service.

Key words: *micromorphology, image analysis, soil fauna, Chernozem, porosity.*

INTRODUCTION

One of the most important functions of soil is that of habitat for soil biota. But when soil and its biota are studied, it is difficult to separate the habitat function of the soil from the food provider function, due to the complex activity of biota which „built" its habitat (by burrowing and create casts) and feeding on soil (ingesting it, modelling it, and then enriching it with mucilaginous secretions). Even if difficult, both functions/activities match together and evolve simultaneously. In this respect, soil biota is the best and most complete soil indicator of soil status.

The micromorphological method of study is a complex and complete technique to investigate soils, the main ecosystem services provider. The study of the soil at micromorphological scale could bring important information concerning the architectural structure of the soil as a complex edifice that provides ecosystem services which support all the above-ground biota.

Micromorphology has been for long a useful tool for characterizing the interaction between pedofauna and soil physical properties, thus, the study of soil thin sections provides the opportunity for investigating fauna-soil relationships since evidence of animal activities such as burrowing and deposition of excrement (fecal pellets) can be identified and quantified (Gargiulo et al., 2011). Micromorphological techniques are also commonly used to characterise void space and soil structure (Bruneau et al., 2004).

Most of the global environmental sustainability issues of today, such as food, water and energy security, climate change, and biodiversity protection require that the knowledge acquired in the last few decades by soil science is fully exploited and shared with all the other relevant disciplines (McBratney et al., 2014; Calzolari et al., 2016).

Considering only the inherent soil properties, it is likely that soils rich in organic matter and not compacted are potentially capable to host a relatively higher biodiversity pool (Gardi et al., 2013).

The assessment and monitoring of soil life and soil health can be used to encourage the development and adaptation by farmers of more sustainable and productive farming systems, especially were backed up by appropriate technical support and incentives (Bunning and Jimenez, 2003).

Soil organisms provide important ecosystem services (Jeffery et al., 2010). These include the storing and cycling of nutrients and pollutants, the decomposition and cycling of soil organic matter, the biocontrol of pests. Among soil organisms, soil microfauna has been used as indicator of soil quality; its role includes litter fragmentation, macropores formation, bioturbation (Calzolari et al., 2016).

Only by knowing soil in all its complexity, while maintaining its functionality and quality through actions aimed at protecting its properties, and acknowledging the importance it assumes in the quality of life worldwide, can we embark on a truly sustainable use of soil perceived as a resource and build a proper Man/Soil relationship to be left to future generations (Menta, 2012).

Soil fauna is an important reservoir of biodiversity and plays an essential role in several soil ecosystem functions; furthermore, it is often used to provide soil quality indicators (Menta, 2012).

A few large invertebrates (mainly earthworms) and social insects (ants and termites) can efficiently dig the soil and produce organo-mineral structures (casts and organo-mineral pellets that are resistant macro aggregates, mounds and nests) and a large variety of pores (galleries, chambers and voids resulting from an uncompleted backfilling of galleries) (Lavelle, 1996).

In what concerning the soil mesofauna, an index for assessing the biological quality of soil, is based on the number of microarthropod groups adapted to the soil habitat (Parisi et al., 2005), thus, the underlying concept is that the higher the soil quality, the higher the number of microarthropod groups adapted to the soil habitat (Parisi et al., 2005).

The sum of structures produced by a population or community of invertebrate engineers creates a specific environment“ defined by Lavelle (2002) as a functional domain which is characterized by (i) the nature and spatial array of the biogenic structures, solid aggregates, mounds or constructs and pores of different shapes or sizes; (ii) the specific communities of smaller organisms from the meso- and microfauna and microorganisms that they host; and (iii) the spatial and temporal scales at which soil processes operate.

Despite the formation of casts, earthworms generally change the soil structure by the formation of macropores when penetrating the soil; the burrowing activity leads to complex burrow systems (Emmerling et al., 2002).

The soil biological communities are characterized by a higher diversity, by several orders of magnitude, compared to aboveground biomass, and therefore, this environmental compartment has become one of the last great frontiers in the study of biodiversity (Gargiulo et al., 2011).

The shape and size of voids are expected to be influenced by faunal activities (Bruneau et al., 2004). The role of structures created by these organisms may be highly significant in the ecosystem functions since the often are privileged sites for all basic soil processes (Lavelle, 1996).

The image analysis techniques allow direct investigations of the soil pore system and provide valid tools to quantitatively analyse both shape and size distribution of pores (Gargiulo et al., 2011).

The soil invertebrates communities can be used as assessment and prediction tools of ecosystem services; many species of invertebrates being important in soil fertility and playing a vital role in the production and maintenance of healthy soils (Chiriac & Murariu, 2021).

The paper goal was to emphasize the dependency degree of a soil ecosystem services on the soil microbiota activity, studying the pedofeatures generated by the biota activity (coprolites) as well as the bio-poral space, by the aim of the physical data, the micromorphological investigation and the image analysis quantification on soil thin sections.

MATERIALS AND METHODS

The researches had been performed in a site located in the Eastern part of the Romanian Plain, in Southern Bărăgan Plain, with a temperate continental climate and a steppe bioclimate. The soil is Typic Chernozem

(according to SRTS-2012 and Vermic Chernozem according to WRB-SR-2014).
The average annual temperature is 10.8°C, and the average annual rainfall is 480 mm, while the evapotranspiration reaches 700 mm. The global drainage is good. The water table is at > 10 m.
The soil was sampled both undisturbed (in metal cylinders for physical analysis and in micromorphological boxes for image analysis and micromorphological investigations) and disturbed (for physical and chemical analysis) from each pedogenetic soil horizon. The soil sampled and data interpretations were made according to ICPA- Methodology (1987).
The granulometry was determined by the aim of the pipette method while for the bulk density (g cm^{-3}) the cylindrical core method has been used, and the aeration porosity has been calculated.
For the micromorphological investigation, the undisturbed soil blocks (after air dried and impregnated with epoxy-resins) were used to prepare oriented thin section (having 25-30 μm thick). Each thin section has been studied with the Documator (20 X) and the optical microscope (50-100 X) in PPL (plain polarized light) and XPL (crossed polarized light). The terminology used for the micromorphological description was according to Bullock et al. (1985).
The porosity was quantified by the aim of image analysis, in order to characterize, at micromorphological level, the pore space. The image analysis has been performed on soil thin sections with the help of an image-analyzing computer (PC-IMAGE software produced by Foster Findlay Associates - London). The instrument was adjusted to measure pores greater than 50 μm. The pores have been measured by their shape, which is expressed by the shape factor (perimeter^2/4π*aria).

RESULTS AND DISCUSSIONS

At macroscopic level, the physical analyses pointed out the presence of a relatively uniform medium (medium loam) texture in the soil profile, which emphasized a balanced distribution of the granulometric fractions in all the pedogenetic horizons of the soil profile.

On this general background, of a soil with loamy texture, the bulk density has been low (1.28 g/cm^{-3}) in the top horizon, and increasing to medium (1.37–1.45 g/cm^{-3}) in the underlying horizons, while the total porosity values were, consequently, high in the upper horizons (51.9 %v/v) and slowly decreased to medium (ranging between 45.5-48.3% v/v) in the deeper horizons.
At microscopic level, the image analysis quantification of the pores (according to their shape and size) showed that the total porosity (<100 - >1000 μm) was 0.27 m^2m^{-2} (Figure 1).
According to the micromorphometric method, a soil is considered compact when the total macroporosity is less than 0.10 m^2m^{-2}, moderately porous when the porosity ranges from 0.10 to 0.25 m^2m^{-2}, porous when the porosity ranges from 0.25 m^2m^{-2} to 0.40 m^2m^{-2}, and extremely porous over 0.40 m^2m^{-2} (Pagliai, 1988).
In this respect the obtained data emphasised that studied soil was porous. Further, the image analysis data of the pores (according to their size) showed the dominance of the pores in the size classes of 100-300 μm equivalent pore diameter (Figure 1).

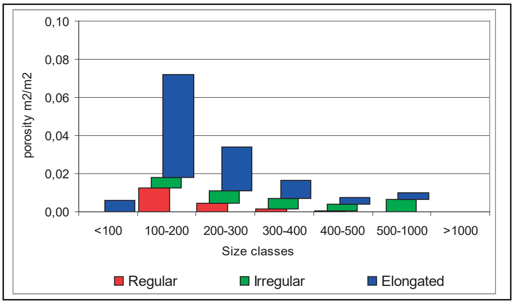

Figure 1. The pore size distribution according to their shapes

Regarding the pore distribution, characterized by their shape, there have been defined three categories: regular pores (more or less rounded); irregular pores (with irregular shape); elongated pores (mainly fissure). The pore size distribution is expressed as equivalent pore diameter, for regular pores and as width for elongated pores.
The regular pores (in the studied soil) are better represented in the classes of 100-200 μm equivalent pore diameter, decreasing slowly in

the classes of 200 to 400 µm equivalent pore diameter. This type of porosity is generated mainly by the biological activity (fauna and plant roots).
The irregular pores are more frequent and became dominant in the class of 100-200 µm equivalent pore diameter, decreasing in the higher value classes.
The irregular pores are most common in the soil, being mainly generated by the physico-mechanical processes, the pores opening along the less resistant directions. This type of porosity included also the pores generated by the collapse of the biogenic channels and/or chambers.
The elongated pores were the most frequent, being also dominant in the classes ranging between 100 to 400 µm (equivalent pore diameter).
Among the elongated pores there are also included the fine fissures that delimitated the rounded or ellipsoidal biological pedofeatures by the surrounding soil matrix. These fine fissures are the path for the water drainage as well as for the air, creating vital conditions for the microorganisms which populated the coprolite and pedotubules surfaces.
In the case of the size class of 100-200 µm (equivalent pore diameter), the proportion of the different type of pores (regular, irregular, and elongated) are best represented.
The poral space constantly renewed under both biological activity and physico-mechanical processes (due to the soil wetting - drying events).
At microscopic level, the micromorphological investigation on soil thin sections showed a complex structure with mainly granular and crumby structural aggregates while local the structure is spongy.
The structural aggregates are mainly biogenic (Figures 2 and 3) as a result of the high biological activity.
The porosity is represented by the fine cracks, biogenic channels, packing and interconnected voids, and is relatively high. Packing voids also appear inside the structural elements.
The soil matrix shows a certain non-uniformity due to the presence of a high number of zoo-aggregates (coprolites) and pedotubules with different compositions (with soil material brought by the fauna from different horizons of the soil profile) generated by a high pedoturbation process.

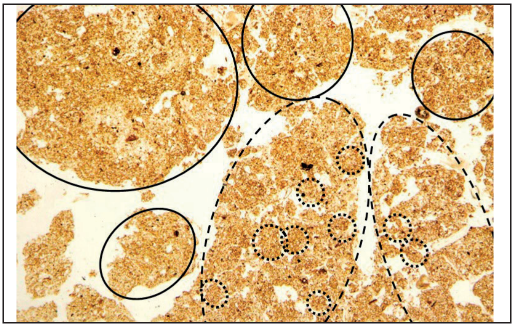

Figure 2. Biogenic pedofeatures: macrofauna coprolites ; and pedotubules ; macrofauna coprolites .

Many lumbric pedotubules are rich in small plant fragments (Figure 3).

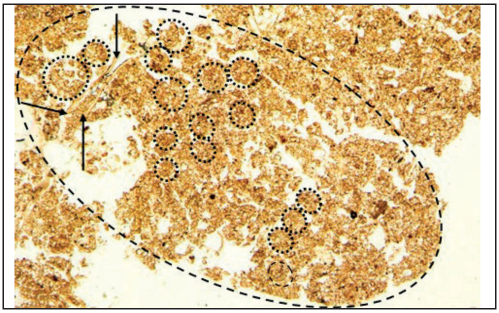

Figure 3. Pedotubul consumed by the mesofauna and replaced by the small coprolites ; vegetal fragment →

Locally, it has been observed many areas (reduced as surfaces), in which the skeleton grains (of the fine sand and loam sizes) appear concentrated and depleted of the plasmic material.
The soil matrix plasma is clayey-humico-Fe, dark brown due to the strong pigmentation with humons. The coarse fraction (soil skeleton) is composed of subangular–subrounded mineral grains predominantly of fine sand and loam size of: plagioclase feldspar, K-feldspars, muscovite, biotite, chlorite, green hornblende, calcite, glauconite, garnet, epidote, rutile, sphene, and opaque mineral. The chloritization process affected some feldspars grains and mica flakes.
The organic matter is represented mainly by the humified constituents and less by the plant

residues, located both in bio-voids and in soil matrix. The pedofeatures were mainly biogenic, being represented mostly by coprolites and podotubules, as well as depleted small areas. The big coprolites and pedotubules had been partially consumed by coprophagous mesofauna and replaced by the small coprolites (Figure 2).
The soil texture is one of the most stabile soil characteristics, its changing could appear under drastic threats as flooding, erosion, landslides, etc.
The detailed micromorphological investigation located the area with depleted skeleton grains into the lumbric biogenic pedofeatures (Figures 2-4). In these areas the skeleton grains were partially or totally depleted of plasmic material (Figure 4), and from their more or less lax spatial distribution, a porous micro-space had been resulted, which further favours the soil solution circulation, and consequently creates furthermore leaching conditions for soil plasma.

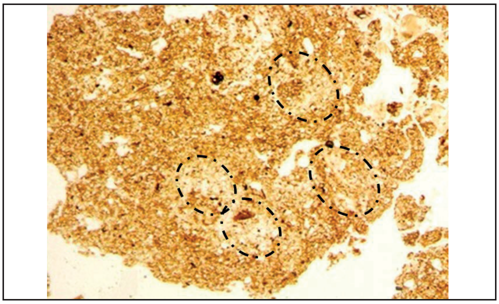

Figure 4. Many areas in the lumbric biogenic pedofeature (coprolite) with depleted skeleton grains concentrations

Thus, the secondary enrichment in the depleted skeleton grains (which appear in many areas of the coprolites) could be considered textural changes. These textural changes had been generated at a microscopic scale and only locally.
But the further evolution of the coprolites is their ingestion by mesofauna.
In this respect, in the lumbric biogenic pedofeatures consumed by the soil mezofauna, the soil matrix is again reorganized: the plasmic material and the skeleton grains being mixed again (Figures 2 and 3).

It seems that mesofauna had an active role of restoring the soil matrix composition (at textural level), by mixing the soil constituents and strengthening the structural edifice of the soil.
The soil biota covered all the web food (it doesn't matter how harsh the environmental conditions are), covering all the needs of the "factory fertility" and driving the soil organic matter transformation from fresh vegetal remains (Figure 3) to the humified organic matter and accomplish the main soil ecosystem service: soil fertility. Consequently, the soil is the mirror of its biodiversity.
Besides the organic substances transformations by both macrofauna, the higher „soil architects", and mesofauna, the biota restored the soil conditions (also the textural organization).
The combination of the macroscopic (physical data) - microscopic investigations (image analysis quantification and micromorphological observations on soil thin sections) allowed to emphasizing the high degree of dependency of the soil ecosystem services on the soil biota activity: from the micro-textural fabric of the soil to the 3D architectural organization of the soil aggregates and adjacent poral system.

CONCLUSIONS

At macroscopic level, the physical analyzes pointed out that on the general background of a soil with loamy texture, the bulk density has been low to medium, and consequently the porosity values were high to medium.
At microscopic level, the image analysis quantification of the pores (according to their shape and size) showed that studied soil was porous, and pores prevail in the size classes of 100-300 μm (equivalent pore diameter).
Concerning the pore distribution (characterized by their shape), the elongated pores were dominant, followed by the irregular and regular pores respectively.
Among the elongated pores the fine fissures delineating the biological pedofeatures by the surrounding soil matrix were also included, and represent the path for water and air, creating thus vital conditions for the microorganisms that developed on the biogenic pedofeatures surfaces.

At microscopic level, the micromorphological investigation on soil thin sections showed a high activity of the soil fauna, emphasized by the high number of zoo-aggregates (coprolites) and pedotubules.

In many lumbric coprolites skeleton grains concentrations (depleted of plasmic material) appeared, but mezofauna consuming these pedofeatures mix again the soil constituents, having thus an active role in the soil matrix composition restoration (at textural level).

The combination of the macroscopic – microscopic investigations throughout image analysis quantification and micromorphological observations on soil thin sections, allowed to emphasizing the high degree of dependency of the soil ecosystem services on the soil biota activity.

ACKNOWLEDGEMENTS

This work was supported by the Romanian Ministry of Research, Innovation and Digitization, through the Project number PN 23 29 05 01; and the Project number PN 23 29 06 01. Financial support for the publication of this study was jointly provided by the Romanian Ministry of Research, Innovation and Digitization, trough the Project number 44 PFE/2021, Program 1 - "Development of national research-development system, Subprogramme 1.2 - Institutional performance - RDI Excellence Financing Projects".

REFERENCES

Bruneau, P.M.C., Davidsona, D.A., Grievea, I.C. (2004). An evaluation of image analysis for measuring changes in void space and excremental features on soil thin sections in an upland grassland soil. *Geoderma, 120*. 165–175.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., Tursina, T., Babel, U. (1985). *Handbook for soil thin sections description*. Wine Research Publication.

Bunning, S., Jiménez, J.J. (2003). Indicators and Assessment of Soil Biodiversity/Soil Ecosystem Functioning for Farmers and Governments. *OECD Expert Meeting on indicators of Soil Erosion and Soil Biodiversity 25 – 28 March 2003*, Rome, Italy.

Calzolari, C., Ungaroa, F., Filippi, N., Guermandi, M., Malucelli, F., Marchi, N., Staffilani, F., Tarocco, P. (2016). A methodological framework to assess the multiple contributions of soils to ecosystem services delivery at regional scale. *Geoderma*, *216*. 190–203.

Chiriac, L.S., Murariu, D. (2021). Plant-soil fauna interaction – bioindicators of soil properties in agroecosystems. *Scientific Papers. Series A, Agronomy*, *LXIV*(1), 39–49.

Emmerling, Ch., Schloter, M., Hartmann, A., Kandeler, E. (2002). Functional diversity of soil organisms – a review of recent research activities in Germany. *J. Plant. Nutr. Soil Sci.*, *165*. 408–420.

Gardi, C., Jeffery, S., Saltelli, A. (2013). An estimate of potential threats levels to soil biodiversity in EU. *Glob. Chang. Biol.*, *19*. 1538–1548.

Gargiulo, L., Mele, G., Terribile, F. (2011). Soil fauna activity and soil porosity: characterization by micromorphological image analysis. *Geophysical Research Abstracts*, *Vol. 13*, EGU2011-EGU General Assembly: 2082.

Jeffery, S., Gardi, C., Jones, A., Montanarella, L., Marmo, L., Miko, L., Ritz, K., Peres, G., Rombke, J., Van Der Putten, W.H. (Eds.) (2010). *European Aatlas of Soil Biodiversity*. European Commission, publications Office of the European union, Luxemburg.

Lavelle, P. (1996). Diversity of soil fauna and ecosystem function. *Biology international, 33*. 3–16.

Lavelle, P. (2002). Functional domains in soils. *Ecological Research, 17*. 441–450.

Menta, C., (2012). *Soil fauna diversity – Function, soil degradation, biological indices, soil restoration. Chapter 3*. In: Gbolagade Akeem Lameed (Ed.) Biodiversity Conservation and Utilization in a Diverse World. INTECH-open science/open mind, 59–94.

McBratney, A., Field, D.J., Koch, A. (2014). The dimensions of soil security. *Geoderma*, *213*. 203–213.

Pagliai, M. (1988). Soil porosity aspects. *International Agrpphysics*, *4*. 215–232.

Parisi, V., Menta, C., Gardi, C., Jacomini, C., Mozzanica, E. (2005). Microarthropod communities as a tool to assess soil quality and biodiversity: a new approach in Italy. *Agriculture, Ecosystems & Environ*ment, *105*. 323–333.

ICPA Methodology-1987, (1987). *Methodology for elaborating pedological studies*. *Vol. I–III*. Bucharest, RO: The Agricultural Technical Propaganda Office.

SRTS-2012 - Florea, N., Munteanu, I., (2012). *Sistemul român de taxonomia solurilor. (Romanian Soil Taxonomy System)*. Bucharest, RO: Editura Estfalia.

WRB-SR-2014 (2014). *World reference base for soil resources International soil classification system for namig soils and creating legends for soil maps*. World Soil Resources Reports 106, Food and Agriculture Organization of the United Nations, Rome.