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THE PUBLIC GOODS AND THE MULTI-ANNUAL VARIATION OF BIODIVERSITY ASSOCIATED TO SOYBEAN CROP

Alexandrina Manea[1], Iulian Bogdan Mușat[2], Alina Eftene[1]*, Marian Mușat[2], Daniela Răducu[1]

[1]National Research and Development Institute for Soil Science, Agro-Chemistry and Environment (ICPA Bucharest), 61 Mărăşti Blvd., 011464 Bucharest, Sector 1, Romania

[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăşti Blvd., 011464 Bucharest, Sector 1, Romania

*Corresponding author. E-mail: alinagherghina@yahoo.com

ABSTRACT

The objectives of the study were: to emphasize the public goods associated to soybean crop; and to qualitatively appreciate the multi-annual variation of soil biodiversity cohabitating with the soybean roots and the *Rhizobium* bacteria. The researchers were performed in the Eastern part of the Romanian Plain, in Southern Bărăgan Plain, Perișoru region. The soil is Vermic Chernozem (according to SRTS-2012 and WRB-SR-2014) formed in carbonate loess like deposits. The climate is temperate continental with the average annual temperature of 10.8°C, and the average annual precipitation of 480 mm. The main environmental public goods associated with the soybean crop and analyzed in this paper were: 1) soil quality and land capability; 2) water quality and availability; 3) biodiversity of agricultural land. Soil quality was analyzed based on the analytical data of physical, hydro-physical and chemical parameters of the soil. The land capability was quantified based on the values of the ecopedological indicators used for the land evaluation, both for land favourability and land quality. In this respect, for soybean, 72 points were obtained, which included the land from the studied site in the third class of favourability. The quality and the availability of water resources are also public goods associated with soybean crop, thus the water from the wells (located in the studied plot) was analyzed, the data showing normal limits for all analyzed water parameters. Regarding the multi-annual variation of the biodiversity, under intensive/irrigated soybean crop, the soil biodiversity did not change, while the upper-ground biodiversity was closely related to the plant changes into the crop rotation and consequently, many species being specialized accompany each crop within the crop rotation.

Keywords: soybean, biodiversity, irrigation, public goods, ecopedological indicators.

INTRODUCTION

Cooper et al. (2009) underlined that there is a wide range of public goods associated with agriculture, many of which are highly valued by society. The most significant of these are environmental, such as agricultural landscapes, farmland biodiversity, water quality, water availability, soil functionality, climate stability etc.

According to Fitter et al. (2005), soils are one of the last great frontiers for biodiversity research and are home to an extraordinary range of microbial and animal groups. Biological activities in soils drive many of the key ecosystem processes that govern the global system, especially in the cycling of elements such as carbon, nitrogen and phosphorus.

Microorganisms have been named „key stewards of the biosphere" (Jansson and Fredrickson, 2010), and perhaps nowhere else on the planet is this title more fitting than in soil (Tecon and Or, 2017). Their roles range from maintenance of human, animal and plant health to driving biogeochemical cycles at the global scale (Jansson and Fredrickson, 2010).

Several biotic and abiotic processes act to redistribute organic C within the soil profile: roots extension, transport by fungal hyphae, bioturbation by soil macrofauna (e.g. earthworms) and transport by water flow in soil pores (Lavelle, 2012).

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At the scale of plant roots and macrofauna (centimetres to millimetres), soil is best described as a highly complex assemblage of pore spaces (more or less water saturated) and soil aggregates (Orgiazzi et al., 2016; Tecon and Or, 2017).

Soil resistance, as showed by Hossne et al. (2015), is an inverse function of the moisture, and had no influence when applied irrigation frequencies that produced the greatest soil moisture. The root volume, root fresh weight and soil rooted volume conserved the tendency of higher values for treatments with daily and inter-day irrigation frequencies.

According to Ponder (2004), the mechanism by which compacted soil supported better growth than not compacted is not completely understood. Much of the better growth is likely due to better soil physical changes that caused better soil moisture conditions for growth. Severely compacted layer below the depth of tillage is a special problem of soil compaction in many farmlands. This severely compacted layer restricts root growth and water available for plant roots.

The soybean root system is characterized as diffuse, but has three distinct morphologically defined components: the primary root, commonly called the taproot that originates as the radicule from a germinating seed, the lateral roots, often referred to as secondary roots that emerge from the taproot, and the tertiary roots that originate from lateral roots (Lersten and Carlson, 2004).

Soil quality is closely related to the concept of „ecological status“ and to the ecosystem services provided by the soil, thus including a wide range of species and soil functions.

Fitter et al. (2005) showed that establishing the linkage between ecosystem function and ecosystem biodiversity is a substantial scientific challenge.

The objectives of the study were: to emphasize the public goods associated to soybean crop; and to qualitatively appreciate the multi-annual variation of soil biodiversity cohabitating with the soybean roots and the *Rhizobium* bacteria.

MATERIAL AND METHODS

The studied area is located (Figure 1) in the central part of the Southern Bărăgan Plain (the Eastern part of the Romanian Plain), in Perişoru region (5.5 km south-west Perişoru village).

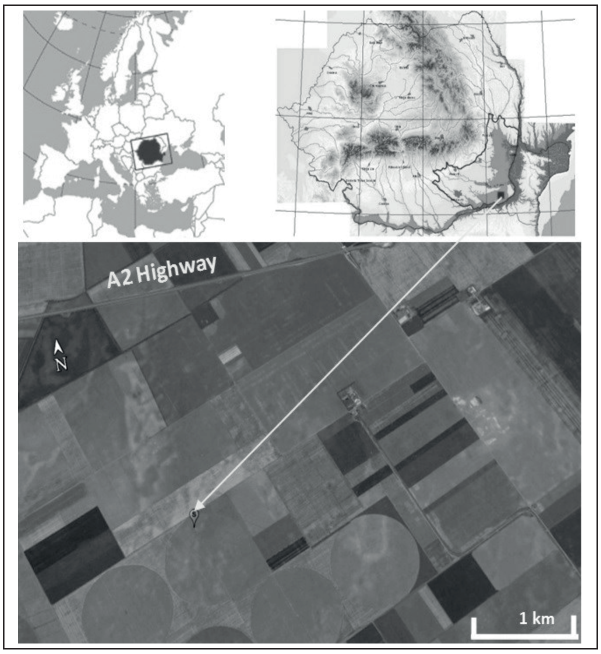

Figure 1. Location of the studied area and the soil profile

The climate is temperate continental, with long and warm summers and droughty periods in late summer and early fall. The average annual temperature is 10.6°C and the average annual precipitation is 480 mm, while the evapotranspiration reaches 700 mm. De Martonne aridity index is 23. The water table is at >10 m depth, the moisture regime of the soil is ustic, while the soil temperature regime is mesic.

The soil is Vermic Chernozem (according to SRTS-2012 and WRB-SR-2014) formed in carbonate loess like deposits.

The studied site is located in the steppe bioclimatic zone (Danubian stepe subzone).

In the whole area, the natural vegetation was replaced by crops. The weeds are specific for the steppe bioclimatic zone: *Echinochloa crus-galli, Cynodon dactylon, Agropyron cristatum, Agropyron repens, Bromus arvensis, Cirsium arvense, Solanum nigrum, Matricaria chamomilla.*

The soil profile (Figure 2a), was dug in a soybean plot (Figure 2b), and from each pedogenetic horizon soil was sampled as: a) disturbed samples - for particle size distribution, and chemical characteristics; and b) undisturbed soil sampled in cylinder (Figure 2c) for both physical and hydrophysical analysis and in micromorphological boxes (Figure 2c), according to RISSA Methodology, 1987.

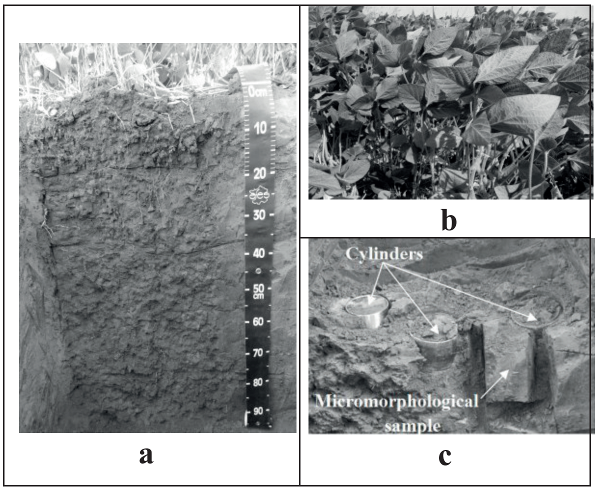

Figure 2. Soil profile (a); soybean crop in the studied site (b); undisturbed soil samples for physical and micromorphological analysis (c)

In order to characterize soil physical and chemical status of the soil, the following indicators and indices were analyzed:

- granulometry; bulk density (*BD*, g/cm^3);
- indicators for soil structural hydrostability characterization: structural macro-hydrostability (*AH*, % g/g); soil dispersion (*D*, % g/g); structural instability index (*IS*);
- hydrophysical indices: wilting point (*CO,* % g/g); field capacity (*CC*, % g/g); and the available moisture holding capacity (*CU,* % g/g), calculated as difference between CC and CO;
- chemical parameter: pH; sum of the exchangeable bases (*SB*, me/100 g soil); base saturation degree ($V_{8.3}$%); humus content.

For the micromorphological study, undisturbed soil samples were air drayed in the laboratory and impregnated with epoxidic resins and after hardening, oriented thin sections (25-30 μm) were made. The oriented thin sections were studied with the optical microscope in PPL (plane polarized light).

The terminology used for micromorphological description was according to Bullock et al. (1985).

RESULTS AND DISCUSSION

The multiannual variation in environmental public goods and the quality of these goods depend to a large extent on the type of farming practices and the availability of farmers to manage crops, in order to improve their environmental impact and to develop a sustainable and competitive agriculture.

The main environmental public goods associated with the soybean crop and analyzed in this paper were: 1) soil quality and land capability; 2) water quality and availability; 3) biodiversity of agricultural land.

1) Soil quality and land capability

Soil quality was analyzed based on the analytical data of physical, hydro-physical and chemical parameter of the soil.

The granulometry data showed a medium loam texture of the soil in all the pedogenetic horizons, due to a higher content of the fine sand (0.2-0.02 mm) ranging between 43.0-45.6% and a lower content of colloidal clay (<0.002 mm) ranging between 25.5-27.7%.

The behavior of different soil structural elements in relation to the water impact is one of the most used indicators for highlighting the soil stability (Dumitru et al., 2005).

The values of the structural instability index (IS - Figure 3) ranging from extremely high (3.20) to very high (1.28), showed great instability of the soil structure, and a high risk to soil structure degradation.

It also showed a high risk of pore space to collapse under water impact and/or compaction processes.

Consequently, the values of the structural macro-hydrostability (AH, % g/g - Figure 3) were small, ranging between very small (2% g/g) and small (6% g/g).

Dispersion (D, % g/g) showed high values (9% g/g), except the Apt horizon, where the dispersion decreased to medium (6% g/g). Dispersion could be caused in many cases by tillage, when relatively wet soil is tilled. However, it is a very slow process due to the presence of a moderate amount of colloidal clay and high amount of calcium humates that represent the bricks of the structural aggregates.

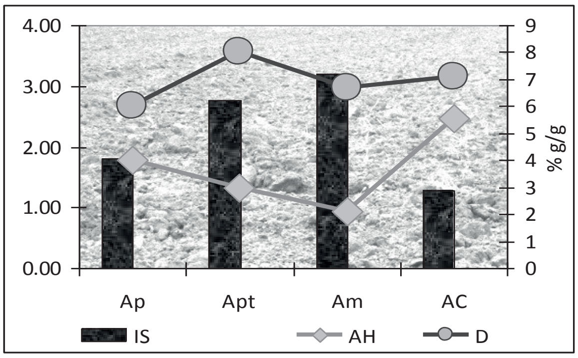

Figure 3. The indicators for the hydrostability characterization

After one year of soybean cultivation, the technological factors specific to soybean crop usually have a little remnant influence on the macro-aggregates hydro-stability.

The extremely high values of the structural instability index showed a low resistance to tillage and a high vulnerability to destructuration.

Although it is well known that Chernozem is an exceptional soil for most agricultural crops due to its natural characteristics (mainly a self-restoration of the structure), we recommend technological variants with the lowest soil traffic to minimize the negative impact on soil structure and biodiversity („soil structure engineers"), as well as the controlled irrigation.

The analytical data also reflects the susceptibility to negative agro-pedological processes, such as crusting, which can affect soybean emergence.

Soil water content is of particular importance for soil-plant relationships, as well as for the design and exploitation of irrigation facilities.

The characterization of the physical status of the studied soil was also achieved through the water balance of the soil, respectively through the relation between the soil and the storage and supply of water to soybean plants, emphasized by the most important hydrophysical indices.

The wilting point (CO, % g/g - Figure 4) values are medium (maintaining to the lower limit of the class). The wilting point, which is the soil water content under which the crop wilt irreversibly (showing the lower limit of plant available water content), showed relatively low values.

The field capacity (CC, % g/g - Figure 4) expressed the amount of water that a soil with good permeability and homogeneous profile retains sustainably after it was wetted and then drained. The values of field capacity were high in the surface horizon and low in the deeper horizons of the soil.

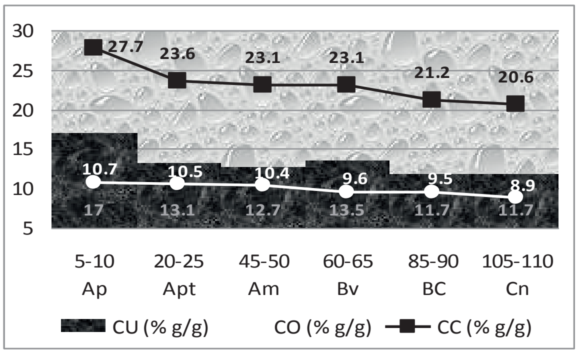

Figure 4. The hydrophysical indices

The available moisture holding capacity (CU, % g/g - Figure 4) is the main indicator of the potential water reserve of a soil, showing how much water (from rainfall and irrigation) can be stored in the soil for the subsequent supply of plants. CU was very high in the surface horizons and high to medium in the deeper horizons. The data showed a decrease of the water storage capacity from the top to the bottom profile.

The available moisture holding capacity gives indications of the amount of irrigation water that can be applied each tine.

Hydrophysical indices give precious information about the studied irrigated soil, as well as about the level of water supply in the important stages of soybean vegetation and the accessible water reserve for a good development of soybean crop.

The water accessibility for crop is higher as the soil moisture is closer to the value of the available moisture holding capacity.

In what concerns the chemical characteristics, the humus content was medium (3.42%) in the upper horizon, and gradually decreased (to 1.02%) in the deeper horizons.

The pH values ranged between 6.60-6.89 in the upper part of the soil profile (Figure 5) and slightly increased to 7.23-7.36 in the deeper horizons rich in calcium carbonate.

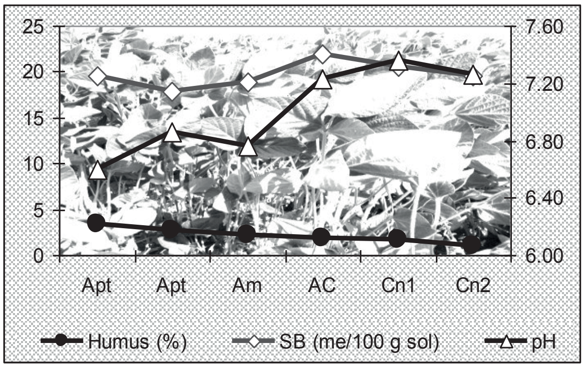

Figure 5. The humus content, the sum of the exchangeable bases (SB), and the pH values

The base saturation degree ($V_{8.3}$%) (at $pH_{8.3}$) was 87.5%-89.8% in the upper part of the soil profile (corresponding to the Ap-Apt-Am horizons) and reached the highest value, 100%, in the calcic horizons.

According to these values, the soil is eubasic in the upper part and saturated with bases in the deeper horizons.

The sum of the exchangeable bases (SB, me/100 g soil) was moderate and increased in the deeper horizons rich in calcium carbonate.

The land capability was quantified based on the values of the ecopedological indicators used for the land evaluation, both for land favourability and land quality (Table 1).

Land evaluation in natural conditions was assessed (according to RISSA Methodology, 1987) by using some synthetic ecopedological indicators, by calculating the land evaluation marks for each crop. In this respect, for soybean, 72 points were obtained, which included the land from the studied site in the IIIrd class of favourability (Table 1).

For the arable land use, the obtained 66 points included the land in the IVth class of favourability (Table 1).

Two of the ecopedological indicators act as limiting factors for crop production: annual average rainfall and the groundwater level. The limiting factors restrict suitability of the land for different kinds of use, in this case soybean crop, and decreased land evaluation marks. The value of the annual average rainfall is low and unequally distributed during the vegetation period, and especially during the summer, being below the water requirements within the vegetation period (IVth - IXth month).

Table 1. Land evaluation for crop favorability and land quality

Land evaluation marks and land favourability classes (in natural conditions)															
Crop	Wheat	Barley	Maize	Sunflower	Potato	Beet	Soybean	Peas –Beans	Arable	Oil flax	Flax	Hemp	Alfalfa	Clover	Vegetables
Land evaluation mark	72	72	64	72	50	56	72	72	**66**	72	58	64	72	45	72
Favorability class	III	III	IV	III	VI	V	III	III	**IV**	III	V	IV	III	VI	III

Land evaluation marks and land quality classes (in natural conditions)					
Land use	Pasture	Meadow	Orchard	Vineyard	Arable
Land evaluation mark	56	48	61	65	66
Quality class	III	III	II	II	II

The recorded values of the annual average rainfall exceeded the evapotranspiration potential values, which produce an important hydro-climatic deficit, negatively influencing the crop development.

The groundwater level and its annual variation are strongly influenced by: the seasonal and annual regime of the hydrographic network, the microrelief, the soil texture and the lithology.

The average annual temperature of 10.6°C is not a limiting factor for the land quality. The temperature became a limiting factor only by its high values recorded in summer, when they generated high values of the evapotranspiration potential, which exceed the precipitations, and consequently induced thermal and water stress to crops (and respectively soybean).

This effect is very intense during the periods of drought due to high water deficiency in the soil, which is why irrigation is necessary.

The lack of water in the critical period of the plant growth, led to soil compaction, to wide cracks formation, and to very large soil aggregates genesis, inappropriate for a well-structured soil as the Chernozem. In this situation, the development of the soybean roots, and consequently of the *Rhizobium* nodules, is impeded by the advanced soil compaction.

2) Water quality and availability

Long-term benefits associated with high quality water resources and water availability are also considered public goods (associated with soybean crop).

In this respect, water samples were collected from the wells located in the studied plot, and analyzed.

The data showed that all the analyzed water parameters were in the normal limits (Table 2).

Table 2. The data of the analysed water samples

Location	Analysed indicators: pH, soluble salts, nitrates (mg and me per 100 g of soil)																				
	pH	HCO_3^-		SO_4^{2-}		Cl^-		Ca^{2+}		Mg^{2+}		Na^+		K^+		Electrical cond	Cond.* Rez.	Rez. min.**	NO_3	Total durity
		mg	me	mg	me	mg	me	mg	me	mg	Me	mg	me	mg	me	mS/cm	mg	mg	mg	gr.germ.
Perişoru	8.12	506	8.30	14	0.30	172	4.85	54	2.68	17	1.39	157	6.84	5.4	0.14	1171	773	926	3	11
* Total content of soluble salts determined by conductometry ** Total content of soluble salts determined by summing the anions and cations																					
NORMAL LIMITS for drinking water																					
Law 458/2002	6.5-9.5			250		250						200				2500			45	
STAS 1342/91	6.5-7.4			200				100		50						1000			50	20

In the studied plot, there were no major sources of pollution that could affect the water consumed by soybean plants.

The inappropriate management of animal manure and waste in households can be a source of water pollution, due to the lacking of an ecological platform for animal manure or domestic waste. However, the closest (to the studied site) anthropogenic activities (an intensive livestock farm) are well managed.

Regarding the irrigation water input, researches showed an important influence of irrigation on $CaCO_3$ quantity and distribution into the deeper pedogenetic horizons.

The carbonates had been removed from the first 150 cm, the data showing an amount of $CaCO_3$ ranging between 1.5% and 3.6%.

The depth of calcium carbonate occurrence in the soil profile is an important diagnostic character for soil classification at the soil type level.

3) Biodiversity of agricultural land

The biodiversity of agricultural land depends to a large extent on the areas where human intervention is minimal, such as uncultivated bands between crops, living fences and ponds etc.

In order to maintain or restore the biodiversity of agricultural land, specific practices need to be introduced to ensure the protection of habitats and the promotion of ecological links within agroecosystems.

The biodiversity of the agricultural land has mainly two components: the „above-ground" biodiversity (Figure 6) and the underground (soil) biodiversity (Figure 7).

In the soybean agro-ecosystem many „above-ground" species (as well as the specialized species that accompany the soybean crop) were observed (Figure 6).

A vital component of the agricultural land biodiversity is soil biodiversity.

In this respect, the most important link between soybeans and soil fauna is the decomposition of the vegetal remains with the release of nutrients (necessary for soybean growth and development), as well as the construction of a comfortable habitat for soybean roots and the *Rhizobium* nodules development.

Figure 6. The „above-ground" biodiversity in soybean crop

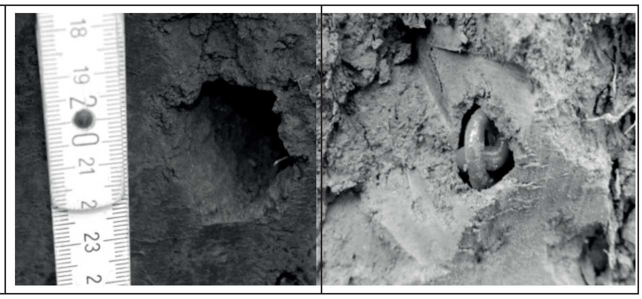

Figure 7. Underground (soil) biodiversity in soybean crop

Fauna activity left visible traces in the soil, traces that can be studied in the oriented soil thin sections (Figure 8). These traces are biological pedofeatures (represented by: coprolites and pedotubuls) and bio-pores (represented by: channels and chambers filled more or less with coprolites).

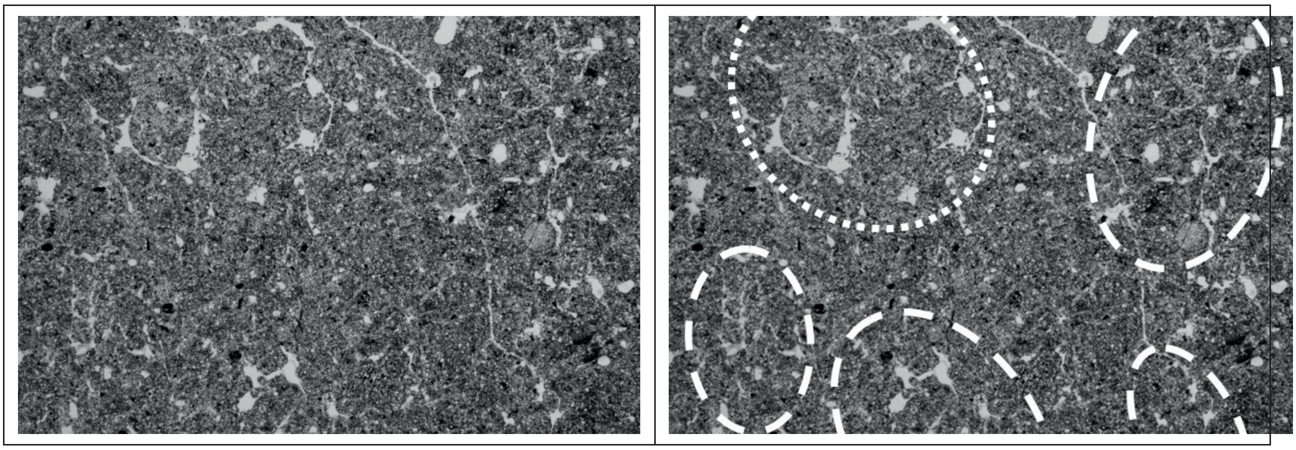

Figure 8. Biological activity: coprolites generated by soil macrofauna and integrated into the soil matrix (circle with dotted line); zones with mezofauna activity (circles with discontinued line)

Many biological pedofeatures contain different types of plant debris in different degrees of fragmentation and decomposition (tissue fragments, cell groups etc.). This is also one of the reasons why coprofagus mesofauna consumed a part of the coprolites generated by macrofauna (lumbrics). This shows that the soil material is repeatedly ingested by the different species living in soil (each of them having specific sizes and characteristics, reflected also by the pedofeatures).

Fauna has an important role in the bioturbation process (by transporting from one horizon to another soil material with different compositions: humic material from the top Am horizon was deposited in the deeper horizons; while material rich in $CaCO_3$ was brought into the upper horizons).

The material transported from the upper horizons to the lower ones is rich both in plasmic organic constituents (humus) and biotic constituents (living microorganisms or their resistance forms as spores or sclerotia). After deposition, the transported material is further enriched (coated) with mucilaginous polysaccharides (an organic source of food for microorganisms and coprofagus mesofauna).

Although the amount of material brought by the soil fauna from the lower horizons and deposited in the upper horizons is significant, this aspect has been very little discussed in the literature.

The passage of soil material through the body of different species (lumbrics, *Collembola*, insect larvae etc.) has complex effects on soil material from several points of view: organic material is transformed and spatially reorganized; the organic component is depleted in some compounds consumed selectively by each species; enriched in specific polysaccharides (which coated both pedotubuls and coprolites).

The material brought from the deeper calcic horizons in the surface horizons being rich in $CaCO_3$ (and other elements that had been leached from the top soil), preserves the soil youth and maintains the biochemical processes to a favourable level that allows calcium humates formation.

Biological pedofeatures, although poorly conserved (due to their high degree of integration into the soil matrix under soil compaction) highlighted the intense activity of fauna that continuously builds the key elements (bio-aggregates and bio-pores). This activity created a good development of biochemical processes and good air and water permeability in the studied soil, despite of a very active compaction process.

The values of the indicators for soil structural hydrostability emphasized a risk for soil destructuration, but the high activity of soil fauna reinforced the structural elements by their polysaccharides (sticking together the soil constituents). Through it the soil has a high potential of „self-healing".

The micromorphological observation „visualized" (Figure 8) the important aspects related to the activity of soil biodiversity, counter-balancing, in a positive sense, the analytical information related to the structural elements and the porous space.

At macroscopic level, the diversity of composition, localization and conservation of biological pedofeatures pointed out no notable multi-annual variation of soil biodiversity (macro- and mesofauna) in soybean crop.

At microscopic level, the microbiological analysis (Figure 9) revealed a high number of bacteria in the upper part of the soil profile, namely Ap-Apt-Am horizons, the number of which ranged from 42.95 to 35.20 millions/1 g dry soil. In the deeper horizons (AC-Ck_1-Ck_2) the bacteria number decreased to less than 10.00 millions/1 g dry soil).

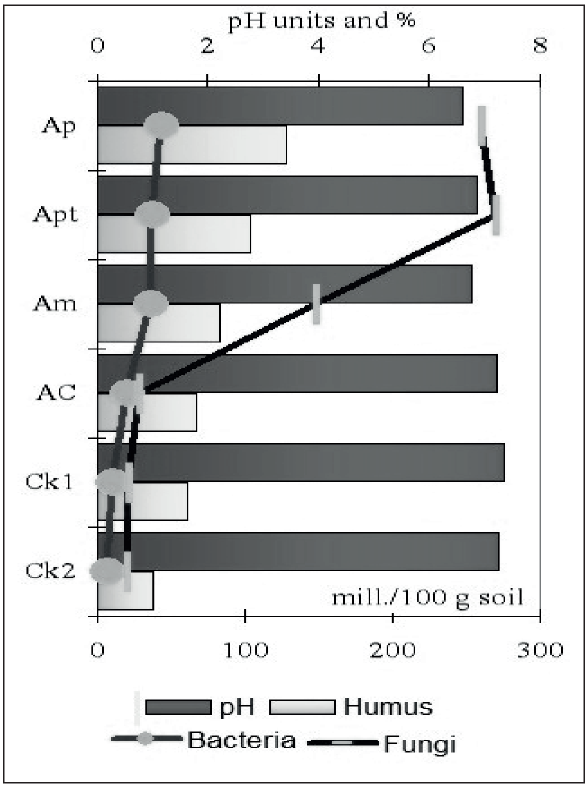

Figure 9. Bacteria and fungi distribution in relation to pH and humus content

The fungi drastically decreased within the profile, from 259.78 million/100 g dry soil in the surface horizon, to 20.03 mg/1 g dry soil in the deeper horizons. The higher number of the fungi in the top soil was favoured by the higher compaction, while the decrease was influenced by the $CaCO_3$.

The global soil microbial activity indicator, represented by soil respiration, showed a medium activity, data ranging from 35.200 to 40.077 mg CO_2/100 g dry soil. In the deeper Ck_1-Ck_2 horizons, this activity decreased, the soil respiration values being 21.713-29.262 mg CO_2/100 g dry soil.

Analyzing the biodiversity (at microscopic level), the richness of the microscopic species (12 species of heterotrophic bacteria and 26 fungi species) detected in the studied agro-ecosystem, it results that there was no notable multi-annual variation of public environmental goods in soybean crop.

To conclude, multi-annual variations or changes in soil biodiversity from soybean intensive/irrigated crops were closely related to the crop rotation and consequently to the current changes of the specialized biodiversity that accompanies each crop.

Regarding the multi-annual variation of the biodiversity, under the soybean crop, the biodiversity did not change, but the activity of the mesofauna prevailed, due to a more compacted elementary fabric and a lower porosity that was poorly continuous.

Multi-annual changes or variations in soil biodiversity under intensive/irrigated soybean crops were closely related to the plant changes during the crop rotation and consequently to the specialized biodiversity that accompanies each crop within the crop rotation. This was much more evident above the ground then underground (in the soil).

Soil biodiversity indicators

As biodiversity issues are multiple and can not be measured completely, „biodiversity indicators" had been developed.

Indicators need to be quick and easy to use „tools" to understand the current status of biodiversity in agro-ecosystems, but also a solid support point to develop medium and long-term prognosis on the general and the particular biodiversity trends and biodiversity protection policies.

The intensity of biological activity in the soil can be evaluated at macroscopic level based on the assessment criteria that show either numerically (the number of biological neoformations present in the soil profile) or as percentage (the proportion of these neoformations relative to the pedogenetic horizon volume/area).

Table 3. The intensity of biological activity (at microscopic scale, in thin sections)

Symbol	Appreciation	% occupied by pedofeatures
fr	Very rare	> 10
ra	Rare	10 - 25
fc	Frequents	25 - 50
ff	Very frequents	< 50

To appreciate the loss and/or multi-annual variation of biodiversity, the study at micromorphological level are necessary, and also a tool for easy quantification, without high gasps between macro- and microscopic soil descriptions.

In this respect a set of indicators (at microscopic scale, in the oriented thin sections) for the biodiversity loss in the soils of agro-ecosystems cultivated with soybeans was elaborated (Table 3).

CONCLUSIONS

The main environmental public goods associated with the soybean crop and analyzed in this paper were: 1) soil quality and land capability; 2) water quality and availability; 3) biodiversity of agricultural land.

Soil quality was analyzed based on the analytical data of physical, hydro-physical and chemical parameters of the soil. The land capability was quantified based on the values of the ecopedological indicators used for the land evaluation, both for land favourability and land quality. In this respect, for soybean, 72 points were obtained, which included the land from the studied site in the third class of favourability.

The study of the quality and the availability of the water resources showed normal limits for all analyzed water parameters.

Despite the fact that the Chernozem is known as an exceptional soil for the most agricultural crops due to its natural characteristics (mainly a self-restoration of the structure), we recommend technological variants with the lowest soil traffic to minimize the negative impact on soil structure and biodiversity („soil structure engineers"), as well as controlled irrigation.

The biodiversity of the soybean intensive/irrigated crop has two components: upper-ground biodiversity and under-ground (soil) biodiversity.

The multi-annual variation of the upper-ground biodiversity in soybean intensive/irrigated crops was closely related to crop rotation, manly due to the specialized biodiversity that accompanied each crop in part during crop rotation. This was more evident at upper-ground level than at under-ground level (i.e. soil biodiversity).

To appreciate the loss and/or multi-annual variation of biodiversity, a set of indicators (at microscopic scale, in the oriented thin sections) was elaborated.

The data of the indicators for soil structural hydrostability emphasized the high risk for soil destructuration, but the high activity of soil fauna showed that the studied soil has a high potential of „self-healing‟.

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