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Biological and physicochemical changes in Orthic Luvisol in relation to the cultivation system

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A b s t r a c t. The research was carried out on soil from the long-term static field experiments in Osiny near Puławy. The field experiment consisted of two cultivation systems: 'conventional' with mineral fertilizers and 'ecological' with organic fertilizers. Microbiological and physicochemical measurements were carried out. The number of microorganisms was presented by standard methods. Soil acidity, organic carbon, specific surface area and water vapour adsorption isotherms were determined. The authors found changes in basic microbiological and physicochemical properties of the soil under cultivation with mineral and organic fertilization of winter wheat. The results of measurements of the number of microorganisms were influenced by: fertilization, vegetation stage of the plant and the content of organic carbon. There was a stimulating influence of organic fertilization on a number of the microorganisms. Soil samples taken from the 'conventional' cultivation system were characterised by lower values of the structural parameters. Samples from the soil organic fertilized tended to have a higher content of organic carbon and possessed a more pronounced microporous structure. The specific surface areas of soil samples from organic farming were slightly higher than of those originating from the 'conventional' soil system.

K e y w o r d s: cultivation system, physicochemical properties, microorganisms

INTRODUCTION

Biological processes of organic matter transformation play the major role in the development and activity of terrestial ecosystems. Microorganisms take part in different geochemical processes and their rate depends on microbiological activity. Biological activity and the fertility of the soil are mostly connected with organic matter. Most organic matter in the soil is derived from plant residues, root excreta and partly from microbial and microfauna biomass. The mineralization of organic matter in the soil generally ranges from 2 to 5% per year. This transformation depends on climatic conditions and the cultivation system applied. The effect of long-term tillage causes a decrease in the organic matter of the soil which in turn disturbs the nutritional cycle and degrades the soil's fertility and quality. The cultivation of properly chosen plants in the plant rotation system and the application of farmyard manure allow the high productivity of the soil to be maintained [14].

Mazur *et al*. [19] stated that progress in agriculture was connected with using the plant rotation system as well as organic and mineral fertilization. It allowed high crop yields to be obtained but at the same time the problem of ecological changes in the natural environment occurred.

Nawrocki [23] and Malicki [16] described the soil environment problem focusing on environmental protection. The authors pointed out that agricultural technology should be safe for the environment. They dealt with current soil conditions and properly used technology (e.g.: fertilizers, pesticides, mechanization).

Badura [1] pointed out the important role of microorganisms in the processes of soil structure formation, in the establishment of Eh, pH values and energy equilibrium in terrestrial ecosystems. Microorganisms are indispensable in decay processes and in the transformation of organic substances and humus formation in soil [5,14,20,21,28]. Microorganisms are one of the essential factors responsible for soil fertility and are partly responsible for the formation of some soil chemical and physical properties. Stotzky [32] stated that increased knowledge of how individual physicochemical factors affect microbes in soil may provide some clues as to how to manipulate such factors. Dąbek-Szreniawska *et al.* [4] described the relations between the

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number and activity of microorganisms, and soil's physical and chemical properties.

The aim of our research was to determine the changes in the number of microorganisms and some physicochemical properties of soil under ecological and conventional cultivation of winter wheat.

MATERIAL AND METHODS

Our research was carried out on soil from the long- term static field experiments in Osiny near Puławy. The experiment was established on pseudopodzolic soil formed from boulder clay (heavy loam sand and light loam - size fractions: 1-0.1 mm - 69%, 0.1-0.05 mm - 11%, 0.05-0.02 mm - 8%, <0.02 mm - 12%), i.e., on Orthic Luvisol according to FAO classification. The field experiment consisted of two cultivation systems: 'conventional' (with mineral fertilizers, herbicides and fungicides) consisting of 120 kg N (3 doses, ammonium nitrate and urea), 80 kg P_2O_5 (1 dose, superphosphate) and 100 kg K (1 dose, KCl) and 'ecological' with organic fertilizers (manure or compost, mechanical and manual weeding) consisting of. 33 t ha^{-1} of compost (0.65% N, 0.30% P_2O_5, 0.45% K_2O) were used in the years 1996/7/8. The following cropping system was applied: 'conventional' cultivation - rape, winter wheat and spring barley; 'ecological' cultivation system - potato, spring barley, red clover, red clover and winter wheat. The soil samples were taken three times each year from the arable humus layer of the soil under winter wheat at seedling stage, stem elongation stage, and then after harvest [15].

Determination of the number of microorganisms was performed by counting colony forming units (c.f.u.) of oligotrophics and zymogenous microorganisms on Fred, Waksman medium [10]. Estimation of ammonifying microorganisms and nitrate reductors most probable number (MPN) was made according to Pochon-Tardieux [25] and of fungi on Martin's medium [17].

Physicochemical analyses of soil samples were performed by Carlo Erba Mercury Porosimeter, Series 2000. The mercury pressures applied allowed us to study pores with equivalent radii ranging from 3.7 to 7500 nm. Before porosimetric analyses, the samples were oven-dried at 105°C and then outgassed up to 10^{-3} Pa to remove physically adsorbed water from their surface. The pore radii were calculated according to the Washburn equation [30,12]. The surface tension and the contact angle of mercury were assumed to be 0.48 N m^{-2} and 141.3°, respectively. Using the cylindrical pore model, the bulk density, surface area, average pore radius and the total porosity were calculated [11,12, 29]. The cumulative pore size distribution (CPSD) curves and the pore size distributions (PSD) for soil samples taken each year at the three sampling times specified were analysed. Organic carbon was determined acc. to Tyurin [34] and pH was determined by the electromertic method acc. to PTG [33]. The surface area of soil samples was evaluated from adsorption and from desorption isotherms. It is now generally accepted to use the Brunauer-Emmett-Teller (BET) method to derive specific surface area from the data on physical adsorption. The first step in the application of the BET method is the determination of the monolayer capacity (N_m) from the BET plot and the second one is the calculation of the surface area from the relation: $S = N_m \ L\,\omega$, where L is the Avogadro number and ω is the molecule cross-sectional area ($10.8 \cdot 10^{-20} m^2$ for water molecule).

RESULTS AND DISCUSSION

Tables 1-4 show the physicochemical characteristics of the soil samples taken from the experimental fields under winter wheat cultivation at seedling stage (I), stem elongation stage (II) and after harvest (III).

It has been found that the specific surface areas of soil samples from organic farming are significantly higher than those originating from the 'conventional' soil system. Higher values of the total porosity and lower average pore radii point to a more pronounced microporous structure of soil samples from the organic farming system. This relationship was observed in our experiment for each year sample (Tables 1 and 2). Similar results were also achieved by Sokołowska *et al*. [29] for soil samples under spring barley.

T a b l e 1. The BET surface area ($m^2 g^{-1}$) for investigated soil samples under winter wheat

Sampling period	1996		1997			1998			*S* average ($m^2 g^{-1}$)	s.d.
	II	III	I	II	III	I	II	III		
				From adsorption isoterms						
'Ecological' system	25.3	17.7	25.6	20.3	21.3	17.7	21.7	16.2	18.3	5.7
'Conventional' system	13.7	8.2	13.0	12.4	8.5	14.2	12.3	15.1	12.2	2.5
				From desorption isoterms						
'Ecological' system	29.1	21.5	27.5	24.2	27.5	20.9	25.8	21.6	24.8	3.2
'Conventional' system	15.7	9.0	13.8	16.6	12.8	16.6	14.5	17.1	14.5	2.7

I - seedlings, II - stem elongation stage, III - after harvest, s.d. - standard deviation.

T a b l e 2. Structural parameters for soil samples under winter wheat obtained from mercury porosimeter data

Sampling period	1996		1997			1998			Average	s.d.
	II	II	I	II	III	I	II	III		
Parameters					‘Ecological’ system					
Total pore volume (mm^3g^{-1})	71.6	69.7	68.5	50.5	74.4	74.4	37.7	5.9	62.8	13.4
Bulk density (g cm^{-3})	2.12	2.16	21.5	2.15	21.5	1.84	2.22	2.16	2.12	0.11
Average pore radii (μ)	1.03	0.99	0.58	0.79	0.99	1.55	1.93	1.79	1.08	0.44
Total porosity (%)	15.11	15.0	14.5	10.9	16.0	13.7	8.4	12.1	13.21	2.56
					‘Conventional’ system					
Total pore volume (mm^3g^{-1})	35.8	45.1	34.4	43.7	45.7	52.6	38.2	7.3	42.8	6.22
Bulk density (g cm^{-3})	2.29	2.24	21.4	2.26	2.32	2.05	2.27	2.2	2.22	0.08
Average pore radii (μ)	1.23	2.48	1.93	1.58	1.98	1.93	1.58	0.4	1.63	0.62
Total porosity (%)	8.3	10.0	8.0	10.0	10.6	10.8	8.7	10.5	9.61	1.11

Explanations as in Table 1.

T a b l e 3. pH of the soil under winter wheat

Cultivation system	1996		1997			1998			Average
	II	III	I	II	III	I	II	III	
				Water					
‘Ecological’	6.91	6.10	6.28	6.54	6.30	6.69	6.41	6.25	6.44
‘Conventional’	5.92	4.85	6.31	6.45	6.38	6.54	6.44	6.40	6.16
				KCl					
‘Ecological’	5.30	5.95	5.61	5.68	5.43	6.07	5.58	5.24	5.61
‘Conventional’	4.90	4.10	5.91	5.51	5.63	6.11	5.74	5.48	5.42

I - seedlings, II - stem elongation stage, III - after harvest.

T a b l e 4. Organic carbon content (%) in the soil under winter wheat

Cultivation system	1996		1997			1998			Average
	II	III	I	II	III	I	II	III	
‘Ecological’	6.91	6.10	6.28	6.54	6.30	6.69	6.41	6.25	6.44
‘Conventional’	5.92	4.85	6.31	6.45	6.38	6.54	6.44	6.40	6.16

Explanations as in Table 3.

Schjonning *et al.* [26] and Rose [27] also reported a decrease of bulk density in plots receiving farmyard manure. The density effect can be ascribed to the increased volume of micropores as well as to decreased particle density in soil amended with organic manure.

The relatively better physical properties of soils from the organic farming (’ecological’ system) are most probably connected with the content of organic matter, which is important in the development of soil structure [12,30,31]. Organic matter plays an important role in the formation of soil structure and its fertility and in the protection of the soil environment. Protective properties of the soil organic matter arise from the nature and number of its functional groups reacting with mineral and organic compounds [2,8,16]. Maintaining or increasing the level of organic matter in soil, especially in light soils, by means of the proper choice of cultivated plants, manuring and melioration with clay minerals, is an important research goal [20,21].

Table 5 and Figs 1 and 2, illustrate microbiological research from 1997 because the mean values are closest to the ones obtained in that year. The values of microorganisms in relation to 1g of organic carbon are indicated on the Table 5 and graphs - Figs 1 and 2. The Table and graphs show stimulating influence of organic fertilization ('ecological' system) on the number of zymogenous bacteria and fungi in the second vegetation season of the winter wheat-stem-elongation stage (Fig. 1a,b). Fungi seem to be most attracted to organic fertilization in the second term of analyses. This fact was supported by the high number of fungi in organically fertilized fields as opposed to their numbers in mineral fertilized soil (the 'conventional' system). The number of oligotrophics (Fig. 1b) per 1 g of total organic carbon in soil examined in the first term of the analyses (seedling of winter wheat) shows a visible difference between 'conventional' and 'ecological' cultivation in favour of the former. In the second and third term of analyses, the differences are not clearly distinguishable in both fertilizations and, as may be seen in the graphs, the number of oligotrophics decreases. It may be explained by the fact that oligotrophics can survive on a relatively low amount of easily oxidizable carbon and other biogenic elements from the soil. These elements are utilised very intensively by growing plants. This fact may cause the decrease in the number of oligotrophics.

Ammonifying microorganisms (Fig. 2a) were more numerous in the spring (1-seedlings) in mineral fertilized soil than in organic fertilized soil. In later vegetation periods (2-stem elongation stage, 3-after harvest) in soil under - wheat, the number of ammonifying microorganisms was similar in both fertilizations. The graphs show that nitrate reducing microorganisms were more numerous in the organic fertilized soil. Their dominance was varied in connection with the vegetation period of winter wheat.

Tables 3 and 4 show that the soil under ecological cultivation with organic fertilization tended to have a higher content of organic carbon and a slight decrease in soil pH both in H_2O and KCl in comparison to 'conventional' cultivation with mineral fertilization.

The changes in organic carbon and pH content are small but visible. The average organic carbon and pH content is slightly higher in 'ecological' samples. Sample inhomogenity had an influence on achieving biological and physicochemical results.

There is an increasing interest in ecological farming systems because they may reduce some of the negative effects of chemicals on the environment. Microorganisms received particular attention because they usually constitute the major fraction of the soil biomass [1,13].

T a b l e 5. The number of microorganisms under winter wheat in 1997

Microorganisms	Cultivation system	Term of analyses		
		I	II	III
Oligotrophics	'ecological'	7.92	5.29	2.67
		s.d. 3.35	s.d. 0.78	s.d. 0.79
CFU x 10^6/1 g of dry soil	'conventional'	7.30	4.29	2.15
		s.d. 3.55	s.d. 0.29	s.d. 0.28
Zymogenous	'ecological'	12.90	14.73	7.04
		s.d. 2.54	s.d. 2.38	s.d. 2.09
CFU x 10^6/1 g of dry soil	'conventional'	7.08	8.29	6.59
		s.d. 1.87	s.d. 2.16	s.d. 2.088
Fungi	'ecological'	1.75	5.94	3.55
		s.d. 0.12	s.d. 0.88	s.d. 0.42
CFU x 10^5/1 g of dry soil	'conventional'	1.34	2.71	2.99
		s.d. 0.24	s.d. 0.59	s.d. 0.21
Ammonifying microorganisms	'ecological'	1.132	6.697	1.525
MPN x 10^6/1 g of dry soil	'conventional'	3.758	6.379	1429
Nitrate reducers	'ecological'	1.925	3.348	0.410
MPN x 10^6/1 g of dry soil	'conventional'	0.752	9.569	1.869

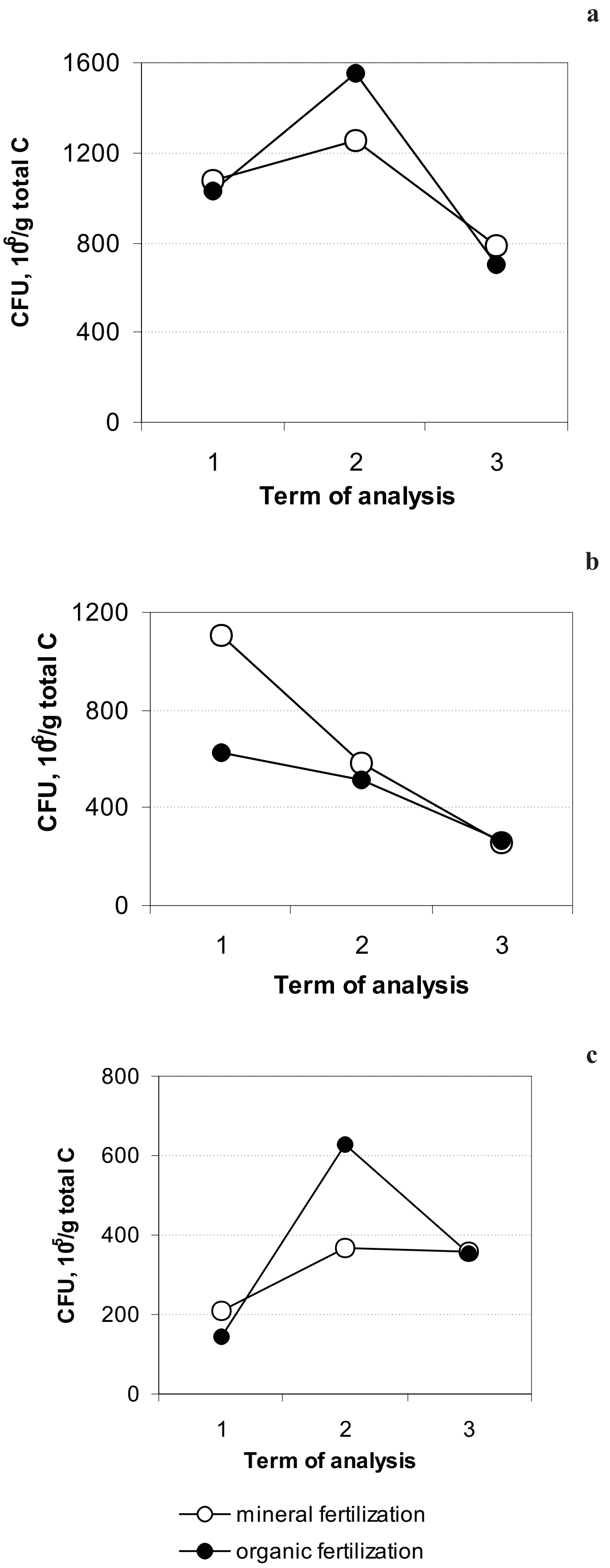

Fig. 1. Number of zymogenous microorganism (a), oligotropics microorganism (b), and fungi (c) (in terms of colony forming units, CFU) per unit of total organic C content in Orthic Luvisol under winter wheat at stages of: seedlings (1), stem elongation (2) and after harvesting (3).

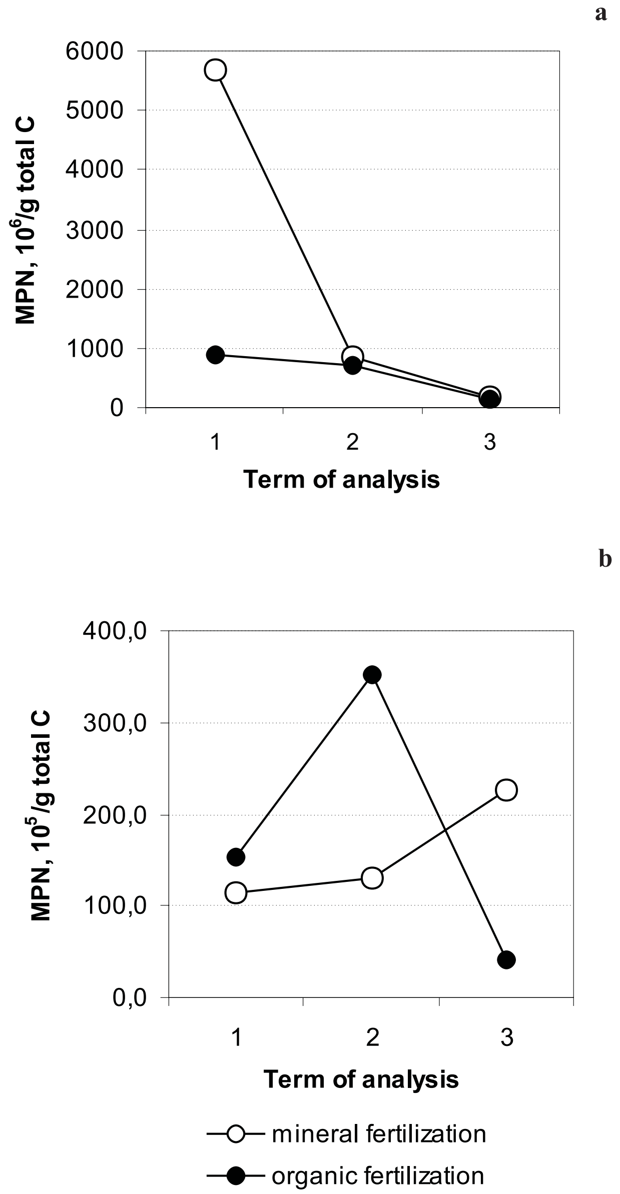

Fig. 2. Number of ammonifying microorganisms (a) and nitrate-reducers (b) (in terms of most probable number, MPN) per unit of total organic C content in Orthic Luvisol under winter wheat at stages of: seedlings (1) and stem elongation (2) and after harvesting (3).

Reganold *et al.* [24] stated that organically farmed soil after 5 years of cultivation had a significantly higher organic matter content, thicker top-soil depth, a higher polysaccharide content and less soil erosion than 'conventionally' farmed soil.

Sokołowska *et al.* [29] stated that the removal of dissolved organic matter alters the surface properties of the soil. Sokołowska *et al.* [31] and Hajnos *et al.* [12] found a relation between basic chemical, physicochemical and structural properties of soil and the method of cultivation. In comparison to 'conventional' cultivation, the soils under ecological cultivation were characterised by significantly better investigated parameters. Soil acidity and the content of organic carbon were higher in the ecological cultivation system. Soil samples from ecological cultivation also possessed a better structure and exhibited a higher specific surface area.

Dąbek-Szreniawska [3], Myśków *et al.* [22], Dąbek-Szreniawska *et al*. [4,6,7], Dąbek-Szreniawska and Wilke [5] described the relations between the microbial activity and their number and soil physical and chemical properties. The authors drew the conclusion that there was a close relation between the cultivation system and soil microbiological and physicochemical properties.

Fraser *et al*. [9] stated that soil chemical properties were significantly influenced by chemical management and the application of beef feedlot manure in the organic management system. Total organic carbon, Kjeldahl nitrogen and potentially mineralizable nitrogen in manure-amended surface soils (0-7.5 cm) were 22 to 40% greater than non-manured soils receiving fertilizer and/or herbicide. The soil bulk density and organic carbon content of the surface from 0 to 7.5 cm layer of manure-treated soils were 5% lower and 36% greater, respectively, than those of chemically treated soil. Soil chemical properties were significantly influenced by the type of management and crop growth at the time of sampling. Soil pH was lowest (6.5 to 6.9) in soils planted by continuous corn, which received fertilizers, herbicides, and insecticides.

On the basis of our research it is possible to observe that the number of soil microorganisms was influenced by the content of organic carbon in the soil, which is, in turn, related to the cultivation system and vegetation stage of the plant. These conclusions are compatible with the results of other authors [13,22,25,27].

CONCLUSIONS

1. The presented results indicate statistically significant positive effect of organic fertilization on some of the examined microbiological and physicochemical indices. In the soil samples from the ecological cultivation the average amount of total organic carbon and pH content were slightly higher.

2. There was observed a statistically significant stimulating influence of organic fertilization ('ecological' system) on the number of zymogenous bacteria and fungi as opposed to their numbers in mineral fertilized soil ('conventional' system). During vegetation season of winter wheat the significant decrease in the number of oligotrophics was stated.

3. Soil samples taken from the conventional cultivation system were characterised by lower values of the structural parameters. Samples from the soil organic fertilized possessed more pronounced microporous structure. The specific surface areas of soil samples from organic farming were significantly higher than those originating from 'conventional' cultivation system.

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