POLISH JOURNAL OF SOIL SCIENCE
VOL. XLV/1 2012 PL ISSN 0079-2985

Soil Fertilization

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INFLUENCE OF LONG-TERM FERTILIZATION AND CROP ROTATION IN DIFFERENT SYSTEMS OF PLANTS CULTIVATION ON THE CONTENT OF DISSOLVED ORGANIC CARBON IN SOIL

Received May 17, 2011

Abstract. The aim of study was to assess the influence of cultivated plant species (potato and rye) in monoculture and in crop rotation as well as the impact of the applied fertilizers on the content of soil organic carbon which was extracted by a 0.004 M $CaCl_2$ solution (EOC). Soil samples were taken from a long-term static fertilization experiment carried out in Skierniewice, Poland. The content of TOC in the soil of the plots fertilized with manure was higher than in objects with mineral fertilization. In monoculture, the higher mean content of EOC was found in soil organic matter under the rye and in crop rotation system in soil under potato. Regardless to cultivated plant species as well as regardless to type of fertilization higher contribution of EOC was determined in crop rotation system than in monoculture. Regardless to cultivated plant species, EOC contribution in organic carbon (TOC) in both cultivation systems depended on fertilizer and was highest in the soil fertilized with NPK.

The soil organic matter has a differentiated and complex composition depending on the initial substrates, as well as bioecological conditions of its decomposition. In the soil material, beyond a group of humus compounds which are difficult to dissolve, there is a fraction of humus that is water soluble – SOM (Soluble Organic Matter) – considered the most mobile organic fraction of the soil. SOM may be composed of carbohydrates, protein, fat, hydrocarbons and their derivatives, low-particle fractions of humic acids, as well as many other simple organic compounds. The formed soluble and mobile SOM bindings with mineral components of the soil may be washed deeper into the soil profile and further into the ground waters [14]. The SOM content in cultivated soils changes depending on the means of fertilization or the species of cultivated plants, among other factors [1, 8, 10, 13]. The addition of the fresh organic matter to the soil increases the content of SOM [2],

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while soil cultivation may cause its decrease [9]. Cultivation of plants that increase the humus content in the soil also increases the SOM content [5]. Quantitative research on SOM in soils are based on measuring the content of organic carbon as a fraction extracted with water and/or weak solutions of neutral salts.

The aim of this paper was to evaluate the content of organic carbon and its soluble form in the soils from the rye and potato cultivation. The research was based on investigating the soil samples from a multi-year cultivation of these plants in monoculture and crop rotation with differentiated organic-mineral fertilization.

MATERIAL AND METHODS

The test soils were taken from a plot of the multi-year static fertilization experiment at the Research Station in Skierniewice, Poland. The original plot descriptions related to this experiment were used after Mercik [12]. The experimental plot is located on silt, pseudo-stagnic soils according to the WRB (2006) 'Stagnic Luvisols'. Soil samples were taken from the arable horizon (0-25 cm) of the plots after potato and rye cultivation in monoculture (plots D_5 and D_6) and five-field crop rotation (plots E_{1A} and E_{1E}) with the selected fertilization combinations. In the selected experimental variant, the first factor was the species of the cultivated plant – potato or winter rye, while the second factor was the fertilization method.

The soils from the plots with previous monoculture potato (D_5) and rye (D_6) cultivation were taken from the following fertilization combinations: Ca (control); NPK; CaNPK and Ca + manure (20 t $ha^{-1}year^{-1}$); and CaNPK + manure (30 t ha^{-1}every 4 years – starting in 1989). The samples from the fields with the five-field crop rotation (potato – 30 t ha^{-1} manure, spring barley, red clover, wheat, rye) were taken from under the potato cultivation E_{1A} and rye cultivation E_{1E} from the following objects: Ca (control); NPK; and CaNPK. In the bulk samples of the soil material (mean of 5 measurements), the content of organic carbon (C_{org}) was measured in g kg^{-1} soil – using the CHN analyzer (Model 1106, manufactured by Carlo-Erba Strumentazione, France). The extraction of the soluble organic matter was carried out using a 0.004M solution of $CaCl_2$. In the above solutions, the content of extracted compounds of organic carbon was assessed in mg C kg^{-1} d.m. soil sample – using the analyzer O-I-Analytical Model 1010 Wet Oxidation Total Organic Carbon (France). Tables 1-3 contain the calculated percentage content of the extracted organic carbon (EOC) in C_{org} (% in C_{org}). The extraction was carried out on air-dry soil samples in 1 h. The ratio of soil to the extractant was 1:10 [6].

RESULTS AND DISCUSSION

In the monoculture cultivation of potato (D5) and rye (D6), the mineral fertilization caused a decrease in the content of organic carbon (C_{org}) in relation to the control (Table 1). There was an increase in the content of the EOC fraction and

TABLE 1. EOC CONTENT (mg kg^{-1}), EOC CONTRIBUTION (%) IN SOIL ORGANIC CARBON POOL (% TOC) AND pH IN SOIL UNDER POTATO AND RYE CULTIVATED IN MONOCULTURE AND CROP ROTATION

Plants	Fertilization*	TOC** (g kg^{-1})	EOC (mg kg^{-1})	EOC % TOC	pH_{KCl}
Potato, field D_5	Ca/control	7.6	49.14	0.65	6.08
	NPK	5.4	61.02	1.13	5.07
	Ca NPK	5.5	69.93	1.27	5.09
	Ca + manure	8.6	72.63	0.84	6.07
	CaNPK + manure	8.5	65.75	0.77	5.82
Rye, field D_6	Ca/control	9.7	62.24	0.64	6.36
	NPK	8.8	95.99	1.09	4.79
	Ca NPK	9.9	67.50	0.68	6.10
	Ca + manure	16.2	81.00	0.50	6.10
	CaNPK + manure	12.4	102.47	0.83	5.87
Potato, field E_{1A}	Ca/control	9.7	102.87	1.06	5.83
	NPK	9.9	137.57	1.39	5.22
	Ca NPK	10.1	115.97	1.15	5.86
Rye, field E_{1E}	Ca/control	8.6	98.15	1.14	5.69
	NPK	9.7	130.55	1.35	4.25
	Ca NPK	9.9	72.36	0.73	6.11

*Doses since 1976: field D: Ca – 1.6 t ha^{-1} CaO every 4 years; field E: 2 t ha^{-1} CaO every 5 years , N – 90 kg ha^{-1}, P – 26 kg ha^{-1}, K – 91 kg ha^{-1} ; EOC – extractable organic carbon, C_{org}; TOC – total organic carbon; ** results of Author studies [3, 4].

its content in C_{org}. The highest content of EOC in the soil of the D5 plot was noted in the CaNPK object (69.93 mg kg^{-1} and 1.27% in C_{org}), while in the D6 plot, the highest EOC content was observed in the NPK object (95.99 mg kg^{-1} and 1.09% in C_{org}). The introduction of manure into the potato and rye cultivation systems caused an increase in the accumulation of organic carbon. The growth of the C_{org} content in the soil of the D5 plot (8.6 g kg^{-1}) was accompanied by the increase in the content of EOC from 72.63 mg kg^{-1} (47.8% in relation to the control). In the case of rye D6 (12.4 g $kg^{-1}C_{org}$), the highest content of EOC – 102.47 mg kg^{-1} (a 65% increase in relation to the control) was also noted in the object with manure, but in combination with CaNPK. The EOC content expressed in % of C_{org} content on these objects ((D5 (Ca+manure 20 t ha^{-1} $year^{-1}$) and D_6 (CaNPK+manure 30 t ha^{-1} every 4 years)) was comparable (0.84 and 0.83), which corresponds to an approx. 30% increase in relation to the control object (Table 1). The obtained results

TABLE 2. VARIATION ANALYSIS FOR EOC CONTENT (mg kg^{-1}), EOC CONTRIBUTION (%) IN SOIL ORGANIC CARBON POOL (% TOC) AND pH IN SOIL UNDER POTATO AND RYE CULTIVATED IN MONOCULTURE

Experimental factors		EOC (mg kg^{-1})		EOC (% TOC)		TOC* (g kg^{-1})		pH_{KCl}	
I: plant	potato field D5	63.7	LSD 0.28	0.90	LSD 0.004	7.10	LSD 0.54	5.63	LSD 0.004
	rye field D6	81.9		0.72		11.4		5.84	
II: fertilization	Ca/control	55.6	LSD 0.64	0.64	LSD 0.009	8.7	LSD 0.54	6.22	LSD 0.010
	NPK	78.6		1.11		7.1		4.93	
	Ca NPK	68.7		0.89		7.7		5.59	
	Ca + manure	76.8		0.62		12.4		6.09	
	CaNPK + manure	84.1		0.80		10.5		5.84	

*Results of Author studies [3, 4].

(Tables 1 and 2) indicate, similar to the research of Gonet *et al*. [6] and Zsolnay and Gorlitz [15], that the use of fertilization with manure also caused an increase in the EOC content. The statistical analysis (Table 2) of the results obtained from the soil samples of the potato and rye monoculture indicated that the factor that had a significant impact on the EOC fraction was the species of the cultivated plant, as well as fertilization. Higher (by about 30%) content of EOC was found in the organic matter from rye cultivation D6 as compared to the potato cultivation D5 (81.9 and 63.7 mg kg^{-1}, respectively). Regardless of the species of the cultivated plant, the average content of EOC in C_{org} ranged from 0.62 to 1.11% and was found to be the highest in the object with NPK.

In the 5-field crop rotation (Table 3), no significant difference in the content of C_{org} was stated in the soil from the objects of potato (E1A) and rye (E1E) cultivation at the investigated fertilization combinations. The content of C_{org} was between 8.6 and 10.1 g kg^{-1} (Table 1). The factors that significantly differentiated the content of the EOC fraction in the soil were (similar to the monoculture) the species of the cultivated plant and the fertilization method (Table 3). Higher (by about 20%) content of EOC was found in the organic matter of the soil from potato cultivation (118.8 mg kg^{-1}) as compared to rye (100.3 mg kg^{-1}) – opposite to the case of monoculture. The lower content of EOC in the humus of the rye soil E1E could be a consequence of the order in which rye is cultivated in the crop-rotation. On the E1E plot, rye is cultivated in the last (5th) year after manure (the activity of the manure is weakened) and the second year after papilionaceous plants. The soil samples from the potato cultivation E1A were taken from the plots fertilized with manure in the fall of the previous year. The results confirm the prediction that the content of water-soluble organic matter in cultivated soils depends on the organic matter introduced into the soil and on the agrotechnical measures [6]. The

TABLE 3. VARIATION ANALYSIS FOR EOC CONTENT (mg kg^{-1}), EOC CONTRIBUTION (%) IN SOIL ORGANIC CARBON POOL (% TOC) AND pH IN SOIL UNDER POTATO AND RYE CULTIVATED IN CROP ROTATION

Experimental factors		EOC (mg kg^{-1})		EOC (% TOC)		TOC* (g kg^{-1})		pH_{KCl}	
I: plant	potato field D5	118.8	LSD 1.19	1.20	LSD 0.016	9.9	LSD n.s.	5.64	LSD 0.028
	rye field D6	100.3		1.07		9.4		5.35	
II: fertilization	Ca/control	100.6	LSD 1.82	1.10	LSD 0.025	9.7	LSD n.s.	5.76	LSD 0.349
	NPK	134.1		1.36		9.9		4.74	
	Ca NPK	94.2		0.93		10.1		5.99	

n.s. – not significant differences, *results of Author studies [3, 4].

post-harvest residue of the plants contains various amounts of material extracted using water solutions, such as wheat straw 8.9-19% [8, 13] and red clover, corn or vetch 31-35% [10].

Regardless of the species of the cultivated plant, the mean content of EOC in C_{org} ranged from 0.93 to 1.36% and was the highest in the object fertilized only with NPK (Table 3). The contents of EOC (Table 1) in the potato cultivation soil (137.57 mg kg^{-1}) and rye cultivation soil (130.55 g kg^{-1}) in crop rotation were also the highest in the objects with NPK (by 33.7 and 33.01% in relation to the control). The content expressed in % of C_{org} was respectively 1.39 and 1.35%, which corresponds to the growth by 31.13% and 18.42% as compared to the control sample. Higher contents of EOC were observed in the soil fertilized with NPK (pH 4.93 and 4.74) as compared to the objects with other fertilization combinations with liming (Tables 1-3). This confirms the research by Schuman [11], who stated that the presence of calcium ions in the soil may have a stabilizing effect on the structure of organic matter and can decrease the freeing of the mobile organic matter. Therefore, indirectly this process depends on the soil reaction, which may have a stimulating effect on the freeing of the mobile organic matter [8], at least as a result of liming or acid rainfall. The naturally acid soils, such as forest soils, contain more mobile organic matter [7]. In the described experiment on limed soils with various fertilization variations, the content of soluble carbon in the total carbon was lower than in the soil fertilized with NPK. This indicates sequestration and thus prevents the washing and losses of soluble carbon, as also observed by Zsolnay [16].

CONCLUSIONS

1. In the monoculture cultivation, a higher mean content of extracted organic carbon (EOC) was found in the organic matter of the soil from rye cultivation, while in the crop-rotation cultivation, the higher EOC content was observed in the soil organic matter from potato cultivation.

2. The highest content, as well as the highest content of EOC in the total carbon, regardless of the species of the cultivated plants, was found in the soils from the objects fertilized with NPK, both in monoculture and in crop-rotation cultivation.

3. The use of liming in the multi-year mineral, organic and mineral-organic fertilization resulted in a decrease in the content and the EOC content in the total carbon, which may indicate the increased sequestration of carbon in the soil.

REFERENCES

[1] Angers D. A., Bissonnette N., Legere A., Samson N.: Can. J. Soil Sci., **73**, 39, 1993.

[2] Asmar F., Eland F., Nielsen N. E.: Biol. Fert. Soils, **17**, 32, 1994.

[3] Cieścińska B.: Humic Subst. Ecosys., **7**, 45, 2007.

[4] Cieścińska B., Dębska B.: Roczn. Glebozn., **60**, 3, 39, 2009.

[5] Dębska B., Gonet S. S.: Nawozy i Nawożenie, **1**, 209, 2002.

[6] Gonet S., Dębska B., Pakuła J.: 2002. Zawartość rozpuszczonego węgla organicznego w glebach i nawozach organicznych. PTSH, Wrocław, 76, 2002.

[7] Herbauts J.: Plant Soil, **54**, 317, 1980.

[8] Hadas A., Feigenbaum S., Sofer M., Molina J. A. E., Czapp C. E.: Soil Sci. Soc. Am. J., **57**, 996, 1993.

[9] Linn D. M., Doran J. W.: Soil Sci. Soc. Am. J., **48**, 1267, 1984.

[10] Mckenney D. J., Wang S. W., Drury C. F., Findlay W. I.: Soil Sci. Soc. Am. J., **57**, 1013, 1993.

[11] Schuman G.: J. Plant Nutr. Soil Sci., **163**, 523, 2000.

[12] Mercik S.: Wieloletnie statyczne doświadczenia nawozowe w Skierniewicach. SGGW, Warszawa-Skierniewice, 9, 2000.

[13] Reinersten S. A., Elliott L. F., Cochran V. L., Campbell G. S.: Soil Biol. Biochem., **16**, 459, 1984.

[14] Zaujec A.: Soil organic matter as indicator of soil quality and human influences on agroecosystem and natural forest ecosystem. [In]: Soil Anthropization. Ed. J. Sobocka. Proc. Int. Workshop, Bratislava, Slovakia, 165, 2001.

[15] Zsolnay A., Görlitz H.: Soil Biol. Biochem., **26**, 1257, 1994.

[16] Zsolnay A.: The Prediction of the Environmental Function of the Dissolved Organic Mater (DOM) in Ecosystems. ESF Exploratory Workshop, Beilngries, Germany. Sci. Report, 1, 2001.

WPŁYW WIELOLETNIEGO NAWOŻENIA W RÓŻNYCH SYSTEMACH UPRAWY ROŚLIN NA ZAWARTOŚĆ ROZPUSZCZALNEGO WĘGLA ORGANICZNEGO W GLEBIE

Celem badań była ocena zawartości węgla organicznego i jego rozpuszczalnej formy w glebie pod uprawą żyta i ziemniaka. Próbki glebowe pochodziły z wieloletniego doświadczenia w Skierniewicach, z uprawy tych roślin w monokulturze i zmianowaniu, przy zróżnicowanym nawożeniu organiczno-mineralnym. Udział EWO w węglu organicznym w obu systemach uprawy, niezależnie od uprawianej rośliny, istotnie zależał od rodzaju nawożenia i był najwyższy w glebie nawożonej NPK. Zastosowanie wapnowania w wieloletnim nawożeniu mineralnym, organicznym i mineralno-organicznym powodowało zmniejszenie zawartości jak również udziału EWO w puli węgla organicznego, co może wskazywać na sprzyjanie sekwestracji węgla w glebie.