CHANGES OF SOIL ORGANIC MATTER UNDER ECOLOGICAL AND CONVENTIONAL FARMING SYSTEMS

Bogumil[1] Rychcik, Lachacz Andrzej[2], Kalisz Barbara[2], Sadowski Tadeusz[1]

[1]Department of Agricultural Systems, University of Warmia and Mazury in Olsztyn, pl. Lodzki 3, 10-727 Olsztyn, Poland

[2]Department of Soil Science and Soil Protection, University of Warmia and Mazury in Olsztyn, pl. Lodzki 3, 10-727 Olsztyn, Poland; email: andrzej.lachacz@uwm.edu.pl

Abstract. *The paper presents changes in the organic matter of the arable layer (0-25 cm) of soil from crop rotations under the conventional and the ecological farming system. Organic matter quality was estimated based on the chemical fractionation of humus compounds. The susceptibility to oxidation of soil organic matter with potassium permanganate ($KMnO_4$) solutions was also analyzed. Changes in humus fractions caused by crop succession were generally slight, probably due to a short period of time that passed from the moment of converting two crop rotations to the ecological system. A higher content of free humic acids and the fraction of carbon most prone to oxidation in soil from conventional crop rotation may be related to the kind of plant remains and the application of mineral fertilizers. A higher content of humins and a lower content of free humic acids in soil from ecological crop rotations may indicate more favourable conditions for the formation of permanent mineral-humus bonds.*

Keywords: fulvic acids, humic acids, hunus fractions, susceptibility to oxidation, NE Poland

INTRODUCTION

One of the main factors affecting plant production levels is the organic matter content of soil. Specialized farming and non-livestock farming (without farmyard manure production) contribute to a decrease in soil organic matter and to soil nutrient depletion. The heaviest losses are caused by root crops, the effect of cereals is less degrading, whereas legumes and catch crops are known to exert a regenerative influence. Rational crop succession is the key factor enabling to maintain, and in some cases even to increase, the amount of soil organic matter (Körschens 2006; Kubát and Lipavský 2006).

Since Poland's accession to the European Union, ecological farming has been viewed as a promising direction of agricultural production development. In order to obtain the organic production certificate, a farm has to go through a conversion period of two years during which conventional plant and animal production systems must be converted to ecological methods (EU Regulation no. 834/2007). Over this period farmers cannot use chemical fertilizers or pesticides, and should try to increase the supply of organic materials to the soil by applying organic fertilizers as well by using a more diversified crop rotation including legumes and catch crops.

In view of the threats associated with intensive plant growing, the Department of Agricultural Systems, together with the Department of Soil Science and Soil Protection, University of Warmia and Mazury in Olsztyn, carried out field experiments and laboratory tests (2003-2006) to determine the effects of conventional and ecological farming systems on the content and composition of soil organic matter fractions.

MATERIAL AND METHODS

A field experiment concerning the response of major cultivated species in Poland to specialized plant production was established in 1987 at the Agricultural-Experimental Station in Bałcyny, University of Warmia and Mazury in Olsztyn (NE Poland), under conventional farming conditions. The experiment is located in a gently sloping area, on Haplic Luvisols developed from light silty loam. The content of clay particles (ø < 0.002 mm) in the arable layer ranges within 2-4%, and that of particles (ø 0.02-0.002 mm) ranges within 17-22%, and that of particles (ø 0.1-0.02 mm) – 26-39%.

For over ten years crops were grown in four six-course rotations, in accordance with the conventional farming system. In 2003 two of them were converted to the ecological system:

Ecological crop rotation – A
1. potato (manure – 30 t ha^{-1})
2. spring barley with lucerne and red clover
3. lucerne and red clover
4. lucerne and red clover
5. winter wheat + phacelia as catch crop
6. oat + white mustard as catch crop

Ecological crop rotation – B
1. potato (manure – 15 t ha^{-1})
2. spring barley with red clover
3. red clover
4. potato (manure 15 t ha^{-1})
5. winter wheat
6. winter rye + white mustard as catch crop

Conventional crop rotation – C
1. potato (manure – 30 t ha^{-1})
2. winter wheat
3. spring barley with red clover
4. red clover
5. winter wheat
6. winter rye

Conventional crop rotation – D
1. potato (manure – 15 t ha^{-1})
2. winter wheat
3. spring barley
4. potato (manure – 15 t ha^{-1})
5. winter wheat
6. winter wheat

Irrespective of the farming system, manure (30 t ha^{-1}) was applied to the potato crop once or twice per cycle in each rotation. In the ecological system crops were grown in accordance with the principles of organic farming, using a diversified crop rotation including legumes and catch crops. In the conventional system mineral fertilizers and pesticides were applied according to the relevant agrotechnological standards.

The paper presents the dynamics of changes in the organic matter content of the arable layer (0-25 cm) of soil from crop rotations under the conventional system and under the ecological system, following the conversion period. In 1999, 2003 and 2006 the total organic carbon content of soil was determined with a spectrophotometer, after carbon oxidation with a potassium dichromate (VI) solution (ISO 1998).

Organic matter quality was estimated in soils sampled in 2006 based on the chemical fractionation of humus compounds, according to the method proposed by Duchaufour and Jacquin (1966), modified by Kuźnicki and Sklodowski (1968). The method involves the extraction of humus compounds, which allows to obtain three fractions (fulvic acids, humic acids and humins) using the following extraction solvents:

– a mixture of 0.1 M sodium pyrophosphate ($Na_4P_2O_7$) and 7.5% sodium sulfate (Na_2SO_4) at pH 7.0, used to extract the most mobile (free) humus compounds;
– 0.1 M sodium pyrophosphate ($Na_4P_2O_7$), used to extract humus compounds bounded with cations;
– 0.1 M sodium hydroxide (NaOH), used to extract strongly bounded humus compounds.

Humic acids were isolated by precipitation in the acid environment (pH = 1.0), and then dissolved with sodium base. The carbon content of the extracts and the carbon content of humic acids was determined spectrophotometrically following oxidation with a solution of potassium dichromate ($K_2Cr_2O_7$). The carbon content of fulvic acids was determined based on the difference between the carbon content of the extracts and the carbon content of humic acids. The ratio between humic acids and fulvic acids, and the proportions of fulvic acids and humic acids in total carbon were also calculated. Part of the organic matter that was not extracted is referred to as humins. Humins are insoluble humus compounds tightly bound to particles of clay minerals or colloidal iron and aluminium hydroxide (Stevenson 1982).

The susceptibility to oxidation of soil organic matter was also analyzed in a neutral medium (Loginow *et al*. 1987). Soil samples (containing 15-30 mg of carbon) were oxidized in a neutral medium with potassium permanganate ($KMnO_4$) solutions at the following increasing concentrations: 0.0333 M; 0.1667 M; 0.3333 M. Solution concentration before and after reaction was determined by titration with 0.05 M oxalic acid ($C_2H_5O_4$). In order to increase reaction rate, the samples were heated to 80 °C. The reduction of Mn^{+7} ions to Mn^{+2} ions is possible only in an acid medium, so the solutions were acidified with sulfuric acid. The content of carbon that oxidized as a result of reaction was calculated based on the difference between the concentration of potassium permanganate before and after the reaction.

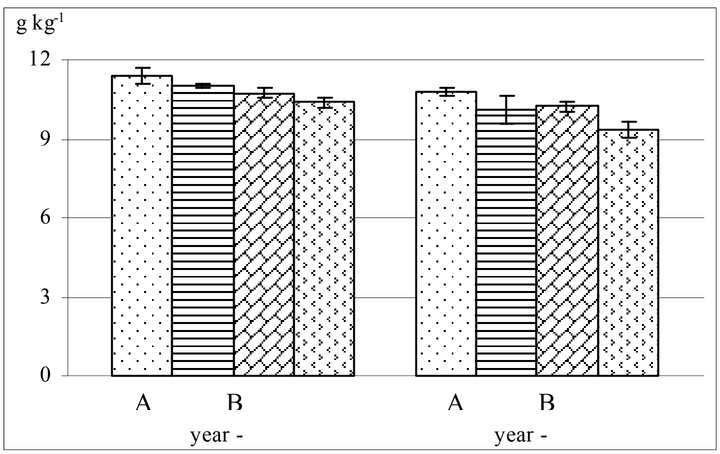
This method permits the extraction of four fractions of humic compounds showing different susceptibility to oxidation. Fraction I (F_I) is most susceptible to oxidation, fractions II and III (F_{II}, F_{III}) are more difficult to oxidize, while fraction IV (F_{IV}) is the residue that is not prone to oxidation by the method applied in the study.

The determination of susceptibility to oxidation provides a basis for humus quality estimation. It allows to characterize the conditions of organic matter mineralization as well as to analyze changes in organic matter composition as dependent on crop species, crop rotation and applied fertilizers. The susceptibility to oxidation of various materials introduced into the soil may be also evaluated (Lefroy *et al*. 1993; Loginow *et al*. 1987).

The results obtained were subject to the analysis of variance (Statistica 7.1), and the significance of the differences was determined using the t-Duncan test at the significance level of P=0.05.

RESULTS AND DISCUSSION

During the conversion period (2003-2006) organic carbon content decreased slightly (Fig. 1), i.e. by respectively 0.60 and 0.90 g kg^{-1} in crop rotations A and B converted to the ecological system, and by respectively 0.51 and 1.04 g kg^{-1} in conventional crop rotations C and D. It should be noted that organic matter content in conventional crop rotation D was significantly lower than in the other crop rotations. It probably resulted from the fact that this rotation included neither perennial legumes nor catch crops. The relation between cultivated crops and organic matter balance was also pointed out by Marriott and Wander (2006), Varvel *et al*. (2002), and Rychcik *et al*. (2006). Numerous authors, e.g. Gonet (1989) share the opinion that manure application affects the content and composition of humus fractions. Regular manuring increases the concentrations of humic acids and humins. Apart from fertilization system, also crop sequence has a significant effect on the amount and quality indices of soil organic matter. It was also stated that the kind of crop residues affects the fractional composition of soil humus (Rychcik *et al*. 2008).



I - *standard deviation*

Fig. 1. Content of organic carbon of dry soil matter, g kg^{-1}

An analysis of humus fractions (Table 1) revealed slight differences between soils sampled from particular crop rotations, probably due to a short period of time that passed from the moment of converting two crop rotations to the ecological system. The $C_H : C_F$ ratio in the first extract, representing free humic acids, was higher in soil samples obtained from the conventional crop rotations, in comparison with the ecological ones. This could be related to a lower content of plant remains in soil from crop rotations C and D. According to Zalba and Quiroga (1999), the fraction of fulvic acids is more affected by farming system, compared to the total organic carbon content of soil.

Table 1

Humus composition in % of organic carbon

Feature	Ecological farming system			Conventional farming system			$LSD_{0.05}$
	A	B	average	C	D	average	
C_I	16.19	17.79	16.99	17.76	19.54	18.65	2.21
C_H	7.35	8.51	7.93	8.71	9.76	9.23	1.29
C_F	8.83	9.28	9.05	9.05	9.78	9.42	n.s.
C_{II}	11.05	11.12	11.08	11.73	12.71	12.22	n.s.
C_H	4.66	4.78	4.72	4.79	5.61	5.20	n.s.
C_F	6.38	6.34	6.36	6.94	7.10	7.02	n.s.
C_{III}	17.94	19.61	18.78	19.87	20.27	20.07	n.s.
C_H	8.70	9.41	9.06	9.32	9.79	9.56	n.s.
C_F	9.24	10.20	9.72	10.54	10.48	10.51	0.84
Humins	54.82	51.48	53.15	50.63	47.47	49.05	n.s.

extraction I – active humus compounds extracted with 0.1 mol $Na_4P_2O_7 \cdot dm^{-3}$ + 7.5% Na_2SO_4 (of pH=7.0);
extraction II – humus compounds bounded with cations educed during the extraction of 0.1 mol $Na_4P_2O_7 \cdot dm^{-3}$;
extraction III – strongly bounded humus compounds educed during the extraction of 0.1 mol NaOH dm^{-3};
C_F – carbon of fulvic acids;
C_H – carbon of humic acids.

The content of humins, i.e. extraction residues, was the highest in soil from ecological crop rotations A and B, and significantly lower in soil from conventional crop rotations, particularly D. This may indicate a tendency towards the formation of permanent humus-clay bonds under organic farming conditions. Free humic acids (extraction I) accounted for 16.2% to 19.5% of total organic carbon content (Table 1). Their proportion was the highest in soil samples from conventional crop rotation D (19.5%), and lower in those from ecological crop rotations A and B. Carbon of fraction II, representing humic acids bound to basic cations, constituted from 11.0% to 12.7% of total carbon content. The highest contribution of this fraction was recorded in soil from crop rotation D. Carbon of fraction III (humic acids strongly bound to iron oxides and aluminium oxides) made up 17.9% to 20.3% of total carbon content. Humins constituted from 51.5% to 54.8% of organic carbon in soil from ecological crop rotations A and B, and from 47.5% to 50.6% in soil from conventional crop rotations C and D.

Table 2

Fractions of organic carbon based on susceptibility to oxidation

Feature		Ecological farming system			Conventional farming system			$LSD_{0.05}$
		A	B	average	C	D	average	
F_I	$g\ kg^{-1}$	0.56	0.60	0.58	0.50	0.58	0.54	0.06
F_{II}		1.13	0.83	0.98	0.84	0.78	0.81	0.16
F_{III}		0.54	0.42	0.48	0.33	0.32	0.33	0.11
F_{IV}		8.55	8.27	8.41	8.54	7.66	8.10	0.83

The susceptibility of soil organic matter to oxidation with $KMnO_4$ solutions is presented in table 2. The oxidability of soil organic matter is related to farming intensity (Lefroy *et al*. 1993). Fraction I, representing organic compounds most prone to oxidation, accounted for 4.9% to 6.2% of total carbon content. The highest proportion of this fraction in soil from crop rotation D corresponds to the highest content of free humic acids, observed also in soil from this crop rotation (Fig. 2). The high (79.2-83.5%) contribution of fraction IV (carbon compounds not prone to oxidation by the applied method) was related primarily to the content of clay minerals stabilizing humic compounds (Kalisz *et al*. 2010).

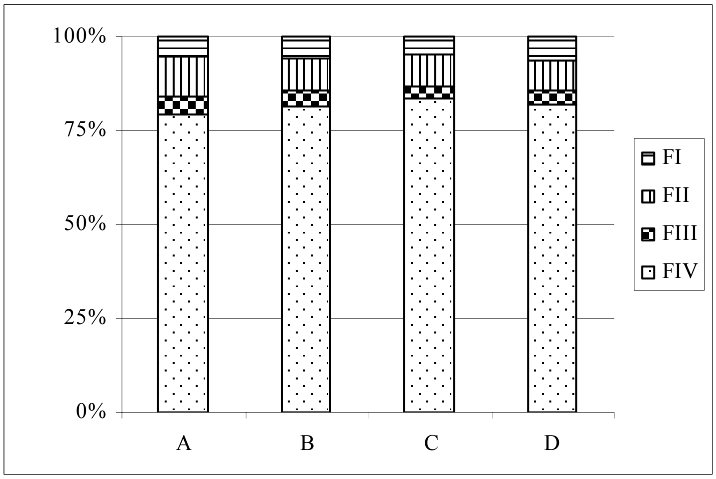


Fig. 2. Fractions of organic carbon, % of total $C_{org.}$

CONCLUSIONS

1. Changes in humus fractions caused by crop succession were generally slight, probably due to a short period of time that passed from the moment of converting two crop rotations to the ecological system.
2. A higher content of free humic acids and the fraction of carbon most prone to oxidation in soil from conventional crop rotation D may be related to the kind of plant residues and the application of mineral fertilizers, which could affect humification conditions.
3. A lower content of free humic acids and a higher content of humins in soil from ecological crop rotations may indicate more favourable conditions for the formation of permanent mineral-organic bonds.

ACKNOWLEDGEMENTS. The research was financially supported by the Ministry of Science and Higher Education, Poland, grants: No. 3 P06R 01024 and No. N N305 157639.

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