Effect of leguminous crop and fertilization on soil organic carbon in 30-years field experiment

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ABSTRACT

The paper presents the results of over 30-years of field experiment on soil organic carbon accumulation under different crop rotation, manure and mineral N fertilization. The experiment was conducted with two crop rotations: A – recognized as soil exhausting from humus (potatoes, winter wheat, spring barley and corn) and B enriching soil with humus (potatoes, winter wheat, spring barley, and clover with grass mixture). In each crop rotation, five rates of manure – 0, 20, 40, 60 and 80 t/ha and four rates of mineral fertilizers N1, N2, N3 and N4 were applied. At the beginning of the experiment in 1979, the initial organic carbon content amounted to 0.74%, and after 33 years dropped to 0.61% in crop rotation without legumes. On the contrary, in crop rotation with clover – grass mixture, the tendency to stabilization of organic carbon quantity in soil was observed with the highest value 0.79% and the lowest one 0.72%. It was found that crop rotation enriching soil with humus produced organic matter ever more than those depleting the soil with humus, regardless of the manure fertilization. Mineral fertilization has modified soil organic carbon content.

Keywords: long-term experiment; manure; crop rotation; mineral fertilization, organic matter

Soil organic matter (SOM) has been recognized as the main factor of soil fertility. The most important role of SOM is its contribution to the soil productivity and long term yield stability. It is assumed that about 75–80% of organic matter which is introduced annually to the soil (organic fertilizers, plant and animal residues) undergoes the processes of mineralization, while 25–30% is transformed into humic substances (Dobrzański and Zawadzki 1999). Mineralization of the soil humus amounts from 2% to 5% per year, which means that the total circulation of organic matter occurs in 40–60 years (Kobus 1995). This process depends on the natural, agroclimatic condition as well as soil cultivation technology, fertilization or crop rotation. During the last ten years in EU countries, the progressive degradation of soil organic carbon is observed. Thus, this issue was reflected in the EU soil strategy (COM (2002) 179), in which the actual reduction of soil organic matter content was listed as one of the most important problems.

Long-term field experiments offer the best practical means to investigate the questions of sustainable crop production and a necessary tool for tracking changes in organic carbon content in the soil. In Europe, the most famous long-term experience with testing of different mineral and natural fertilizers and/or cultivation of various plant species was held at Rothamsted (England), Halle and Bad Laustädt (Germany), Prague-Ruzyně (Czech Republic) and Skierniewice (Poland) (Körschens 1996). The Institute of Soil Science and Plant Cultivation National Research Institute (IUNG-PIB) in Puławy is also involved in several kinds of long-term field studies, including soil organic carbon content monitoring, since 1979. A special trait of these experiments is that crop rotations included plants enriching and exhausting soil from humus, have been a permanent factor for the last 33 years.

The paper presents the results of the permanent experiment in which the effect of leguminous crop, manure application and mineral fertilization on the quantity of soil organic carbon (SOC) was evaluated.

MATERIAL AND METHODS

The study was conducted on the basis of a three factorial long-term field experiment carried on since 1979 at the Experimental Station Grabów (51°21'N, 21°40'E) of the Institute of Soil Science and Plant Cultivation in Puławy, on typical soil in Poland, classified as light loamy and sand texture according to the USDA soil classification. The experiment was designed in two crop rotations (I factor): A – recognized as soil exhausting from humus (potatoes, winter wheat, spring barley and corn for silage) and B – considered to enrich soil with humus (potatoes, winter wheat and mustard as aftercrop for ploughing, spring barley with undersown clover with grass mixture). In each crop rotation, five rates of manure (II factor) were applied under potatoes: 0, 20, 40, 60 and 80 t/ha every four years, which corresponds to 0, 188, 376, 564 and 752 kg N/ha. Through the first and the second rotation only two experimental factors were included – crop rotation A and B, and manure fertilization in the rates 0, 20, 40, 60 and 80 t/ha for 4 years. Since 1984 (the third rotation) in both crop rotations mineral fertilization was set (III factor). Each crop was supplied with four rates of mineral fertilizers: 0, 170, 340, 510 kg N/ha for one four-year rotation A and 0, 155, 310, 465 kg N/ha for rotation B, respectively. The experiment was performed in the split-block layout in two cycles moved by one year. Phosphorus fertilizer was applied equally throughout the experiment in the rate of 24 kg P/ha. Potassium fertilizer was applied as follows: 71 kg K/ha under spring barley, 83 kg K/ha under winter wheat, 95 kg K/ha under the clover-grass mix, 97 kg K/ha under maize, and 133 kg K/ha for potatoes. Soil samples were collected at the end of the growing season before ploughing (September–October) from 0–30 cm soil layer and analyzed for the content of soil organic carbon (C_{org}) by the Tiurin method. Soil organic carbon (%) was evaluated as the average values for treatments with different rates of manure and mineral N fertilizers. The data were processed by ANOVA, for each crop rotation, manure and mineral fertilization, using the Statgraphics 5.0 Plus package.

RESULTS AND DISCUSSION

The analysis of variance (Tukey's test) demonstrated the importance of main effects and random effect (year of study) as well as the interaction of all the experimental factors on C_{org} (*P*-value 0.0000 for all tests). The changes in organic carbon content in soil through the years 1979–2012 as the average of manure and mineral nitrogen rates for crop rotation enriching (A) and exhausting (B), were presented in Figure 1. The error bars demonstrate the significant differences between means at the 95% confidence interval.

At the beginning of the experiment in 1979, the initial organic carbon content amounted to 0.74%. For the first two four-year rotations, up to 1984, the experimental scheme included only manure application. For the first eight years of the experiment the slight drop in C_{org} content in soil was observed. The reduction of C_{org} in the following years as compared to the initial value, is not significantly related with manure rates and can be explained rather by a slow depleting of the total pool of humus in agricultural

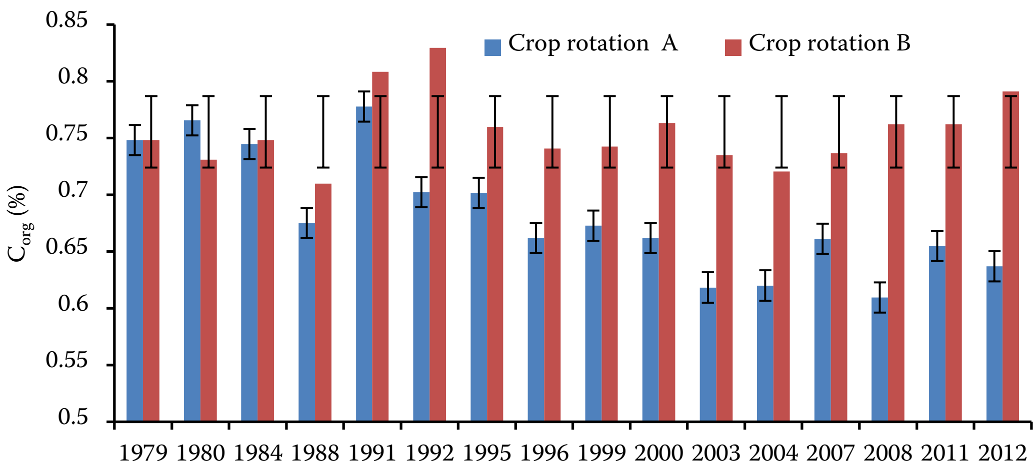

Figure 1. Effect of crop rotation on organic carbon (C_{org}) content in soil (0–30 cm) through 1979–2012

Table 1. The effect of manure application on soil organic carbon content (%) depending on crop rotation

Crop rotation	Manure rates (t/ha)								
	0	20	increase (%)	40	increase (%)	60	increase (%)	80	increase (%)
A	0.62[a]	0.62[a]	0.0	0.67[b]	8.1	0.74[c]	19.3	0.71[d]	14.5
B	0.69[a]	0.74[b]	7.2	0.76[c]	10.1	0.79[d]	14.5	0.81[e]	17.4

Different letters indicate significant differences at $P < 0.05$

soil as the effect of tillage intensity and regular removal of straw from the field (Kuszelewski 1993, Fotyma and Filipiak 2006).

Some authors claim to have found that a general decrease of SOC content was observed in the first 10 years of experiment, followed by an approach to a steady state (Körschens 1996). After eight years of this scheme of experiment, in crop rotations with clover grass mixture (B), organic carbon content oscillated around the initial value and amounted to 0.78%.

Meanwhile, in crop rotation without legumes (A) C_{org} value dropped to 0.72%. Since 1984 (the third rotation) in both crop rotations mineral fertilization has been set. In the following years, fields under plants exhausting soil with soil organic matter (A), organic carbon quantity decreased regularly through the experiment and after 33 years dropped to 0–61%. On the contrary, in crop rotation with clover-grass mixture, the tendency to stabilization of organic carbon quantity in soil was observed with the highest value 0.79% in 1988 and the lowest one 0.72% in 2004.

In Tables 1 and 2 the effect of main factors – manure application and mineral fertilization on C_{org}, content in soil was presented. The results of Table 1 indicated, that the effect of manure on soil organic carbon content was strongly linked to the crop rotation. In both crop rotations, manure application increased soil organic carbon. However, in crop rotations with plants exhausting soil from soil organic carbon even the highest manure rates 60 and 80 t/ha were not sufficient to secure SOC content at the initial level over the years, which confirms the results presented by Figure 1. Meanwhile, in crop rotation with legumes, only 20 t/ha manure per hectare was required to obtain such content.

For the research presented, the effect of crop rotation had a larger impact on organic carbon accumulation in soil that the effect of manure applications. Similar results were obtained in long-term field experiments at Rothamsted (Jenkinson 1990) and at Skierniewice (Mercik et al. 1995). Those results could be explained by the fact that clover mixture with grasses results in a greater amount of humus in soil compared with manure application. Moreover, carbon from manure is more prone to undergo mineralization process (Mercik et al. 1995, Antil et al. 2011).

In the own research, the significant effect of mineral nitrogen fertilization was proven (Table 2). In crop rotation without legumes mineral fertilization increased C_{org} content by 3% as compared to the control treatment, and in crop rotation with clover by 4.6%, respectively. The role of mineral nitrogen fertilization remains unclear. Some authors have described that application of high amounts of mineral fertilizers might accelerate mineralization process and therefore diminish organic carbon. According to Gregorich et al. (1994) and Janowiak (1995) prolonged application of mineral N fertilizers on lessive and brown soils may cause a decrease of carbon content in soil of about 21% compared with soils not supplied with mineral fertilizers. The reduction of organic fertilizers, even while maintaining stable doses

Table 2. The effect of nitrogen fertilization on soil organic carbon content (%) depending on crop rotation

Crop rotation	Nitrogen fertilization level						
	0	N1	increase (%)	N2	increase (%)	N3	increase (%)
A	0.66[a]	0.66[a]	0.0	0.67[a]	1.5	0.71[a]	7.6
B	0.73[a]	0.77[a]	5.5	0.77[a]	5.5	0.75[a]	2.7

Different letters indicate significant differences at $P < 0.05$. Rates of mineral fertilizers A/B: N1 – 43/39, N2 – 86/78, N3 – 129/117 kg/ha of mineral nitrogen fertilization causes a steady decrease in the SOC level in soil. A distinctive difference was observed in the evolution of organic carbon content in soil over time for crop rotation that included plants recognized to deplete humic substances or plants that can enrich the organic carbon content in soil (Gonet 1989, Campbell et al. 1996). Adamus et al. (1989) maintained, that the combined application of manure and mineral nitrogen fertilizers enhances the mineralization process of humus. However, there exists a strong consensus in the literature that mineral nitrogen has beneficial effect for humus stabilization (Gonet 1989, Gonet and Wegner 1990, Mercik et al. 2005).

Generally, higher fertilization provokes higher SOC increments (Jagadamma et al. 2007, Khan et al. 2007, Sainju et al. 2010), however, numerous experiments have shown that N fertilization results in SOC increase over time not only by promoting crop biomass production but also by chemically stabilizing SOC (Paustian et al. 1992, Kusińska 1999, Snyder et al. 2009). A positive effect was proven on SOC accumulation in time, while organic matter is added and N is supplied in both organic and inorganic forms (Adamus et al. 1989, Paustian et al. 1992, Wiater 2000, Spychaj-Fabisiak et al. 2003, Nardi et al. 2004).

The results of the experiment confirm that including legumes into crop rotation might provide an effective method to preserve the optimal level of humus. Although the positive effect of regular manure application on humus formation, was proven in the rotation without clover with grasses, even the largest rates of manure (60–80 t/ha for four crop rotation) did not maintain the initial value of soil organic carbon in soil.

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