The impact of long-term application of inorganic nitrogen fertilizers and manure on changes of selected properties of organic matter in sandy loam soil

Wpływ wieloletniego nawożenia azotem i obornikiem na zmiany wybranych właściwości materii organicznej gleby lekkiej

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Abstract

The aim of the research was to assess the effect of long-term application of different doses of nitrogen fertilizers with or without manure to changes in the total organic carbon content, total nitrogen content, evaluation of dissolved organic carbon content and the value of absorbance coefficient ($A_{4/6}$) in sandy loam soil. The base of research was the long-term field experiment, established in 1979 at the Wierzchucinek Experimental Station close to Bydgoszcz city - Poland. The experiment was carried out in the three-course crop rotation, potato, rye, rye in randomized split-plot design. The experimental treatments were four levels of N fertilizers in 0, 47, 93, and 140 $kg \cdot ha^{-1} \cdot yr^{-1}$ (N_0, N_1, N_2, N_3) as a 1st factor of experiment, and the same doses of N fertilizers with farmyard manure application (30 $t \cdot ha^{-1}$) as a 2nd factor. After 36 years of experiment the content of total organic carbon was 26% lower and the content of total nitrogen 13% higher compared to the values determined before the experiment foundation (1979). The consequence of changes in the content of organic carbon and total nitrogen, are changes in the ratio of organic carbon content and total nitrogen content. It was noticed that the use of manure and different nitrogen doses resulted in a decrease of organic carbon content and total nitrogen content value. After application of different nitrogen doses, organic carbon content ranged from 122.4 to 152.2 $mg \cdot kg^{-1}$. The same nitrogen doses applied simultaneously with farmyard manure increased the organic carbon content, which ranged from 133.5 to 166.7 mg·kg^{-1}. The changes of the organic carbon content did not effect on percentage of this fraction in the total organic carbon. Percentage of organic carbon content in total organic carbon content was on averaged 1.6%. After the application of different nitrogen doses, humic acids of analyzed soils were characterized by lower average value of $A_{4/6}$ (5.4). However, the application of nitrogen doses with manure brought a higher - 6.3 - $A_{4/6}$ value. Farmyard manure application caused the formation of humic acids of lower molecular weight and a low humification degree.

Keywords: evaluation of dissolved organic carbon content, long-term experiment, manure, nitrogen doses, organic matter, total nitrogen content, total organic carbon content

Streszczenie

Celem pracy było zbadanie wpływu długookresowego nawożenia zróżnicowanymi dawkami azotu stosowanymi z obornikiem lub bez tego nawozu na zmiany zawartości ogólnego węgla organicznego (OWO), azotu ogółem (N_{og}), rozpuszczalnego węgla organicznego (RWO) w glebie oraz określenie wartości absorbancji ($A_{4/6}$). Podstawą badań było statyczne wieloletnie doświadczenie polowe, założona w 1979 roku w Stacji Badawczej w Wierzchucinku koło Bydgoszczy. Prowadzono je w trzyletnim, uproszczonym zmianowaniu: ziemniak – żyto ozime – żyto ozime. Pierwszym czynnikiem doświadczenia było zróżnicowane nawożenie azotem, dawki w kg·ha^{-1}·r^{-1} wynosiły: N_0, N_{47}, N_{93}, N_{140}, drugim zastosowane dawki azotu na tle obornika (30 t·ha^{-1}). Po 36 latach stosowanego nawożenia średnie zawartości węgla oznaczone w próbkach glebowych były średnio niższe o 26%, natomiast zawartości azotu ogółem w glebie były wyższe o 13% w porównaniu do zawartości określonych w glebie przed założeniem doświadczenia (1979). Konsekwencją zmian zawartości węgla organicznego i azotu ogółem, są zmiany wartości stosunku zawartości węgla do azotu ogółem. Stosowanie łącznie obornika i zróżnicowanych dawek azotu spowodowało zawężenie wartości stosunku zawartości węgla do azotu ogółem. Stwierdzono, że zawartości węgla organicznego w glebie po zastosowaniu zróżnicowanych dawek azotu, wahały się w zakresie od 122.4 mg·kg^{-1} do 152.2 mg·kg^{-1} natomiast aplikacja azotu na tle obornika spowodowała, że zawartości te mieściły się w zakresie od 133.5 mg·kg^{-1} do 166.7 mg·kg^{-1}. Zawartości węgla organicznego nie przełożyły się na procentowy udział tej frakcji w całkowitej zawartości węgla organicznego. Udział ten średnio wynosił 1.6%. Zauważono również, że po aplikacji badanych dawek azotu, kwasy huminowe analizowanych gleb charakteryzowały się średnio niższymi wartościami współczynnika $A_{4/6}$, który wynosił 5.4. Natomiast po zastosowaniu zróżnicowanych dawek azotu łącznie z obornikiem wynosił 6.3. Nawożenie obornikiem generowało powstawanie kwasów huminowych o mniejszej masie cząsteczkowej i o niskim stopniu humifikacji.

Słowa kluczowe: dawki azotu, doświadczenie wieloletnie, materia organiczna, obornik, zawartość azotu ogółem, zawartość rozpuszczalnego węgla organicznego, zawartość węgla ogółem

Introduction

Intensive long-term cultivation of soils including unbalanced fertilization, produces changes in their chemical properties. Moreover such procedures affect biological activity, acidification, lead to reduction of humus content and sorption capacity which in turn leads to the decrease of soil fertility (Jaskulska, 2003; Nardi et al., 2004; Haynes 2005; Mercik et al., 2005; Gregorich and Beare, 2007; Pałosz, 2009). Soil humus has complex chemical composition with specific properties, and is not protected against dissolution and leaching. Organic matter included humus, especially its organo-mineral associations, are recognized as the total organic carbon (TOC). This parameter as well as total nitrogen (TN) are treated as indicators of the changes in soil abundance and fertility. The determining factors of accumulation and transformation processes of TOC and TN are among others intensity of the applied tillage, mainly applied mineral and organic fertilizers (Blair et al., 2006; Constantin et al., 2010). In contrast, the dissolved organic matter fraction (DOM) is a sensitive indicator of changes in the soil environment. This fraction, expressed as the content of dissolved organic carbon (DOC), represents the most mobile hence accessible part of the soil organic matter (SOM), and also significantly depends on fertilization (Bolan et al., 2004; Haynes, 2005; Brookers et al., 2007).

As a result of this, research has been undertaken to determine the impact of the long-term application of varied doses of nitrogen with or without manure, on the changes in total carbon content (TOC), total nitrogen (NT), and dissolved organic carbon (DOC). An additional aspect of the study was to characterize humic acids by assessing the value of absorbance coefficient ($A_{4/6}$).

Materials and methods

The base of research was the long-term field experiment, established in 1979 at the Wierzchucinek Experimental Station of the UTP University of Science and Technology in Bydgoszcz (17^{o}51´E, 53^{o}13´N; Figure 1). The experiment was carried out in the three-course crop rotation, potato, rye, rye in randomized split-plot design in four replications (Figure 2, Table 1).

The experimental treatments were four levels of N fertilizers in 0, 47, 93 and 140 kg·ha^{-1}·yr^{-1} (N_0, N_1, N_2, N_3) as a 1st factor of experiment, and the same doses of N fertilizers with farmyard manure (FYM) application (30 t·ha^{-1}) as a 2nd factor. The experiment was conducted on Albic Luvisols (IUSS 2014), formed from glacial till, with Ap, Et, Bt, BC, C horizon sequence in soil profile, and sandy loam (18% of clay) texture in ploughing horizon. According to Żarski et al. (2014), average annual precipitation on investigated area is 307.6 mm, and it is one of the lowest values in Poland. The multi-year average sums of precipitation and temperature (1981 - 2014) for Poland is 537 mm and 8 ^{0}C, respectively (Żarski et al., 2010). In 1979 the soil reaction was slightly acid (5.6 pH), with 6.63 g·kg^{-1} of TOC and 119.4 mg·kg^{-1} of DOC. The total nitrogen content (TN) and the content of available forms of P and K were: 0.78 g·kg^{-1}, 42.7 mg·kg^{-1} and 62.3 mg·kg^{-1} respectively.

Figure 1. Location of experimental station - kujawy pomeranian region – Poland

Rysunek 1. Lokalizacja stacji badawczej – woj. kujawsko-pomorskie - Polska

32 N_0	31 N_1	30 N_2	29 N_3	28 N_0	27 N_1	26 N_2	25 N_3
24 N_1	23 N_0	22 N_2	21 N_3	20 N_0	19 N_2	18 N_3	17 N_1
16 N_1	15 N_2	14 N_3	13 N_0	12 N_2	11 N_3	10 N_1	9 N_0
8 N_3	7 N_2	6 N_0	5 N_1	4 N_3	3 N_2	2 N_0	1 N_1

■ – FYM application, □ – no FYM application, 1-32 – plot no, N_0-N_3 – nitrogen doses

■ – Nawożenie obornikiem, □ – bez nawożenia obornikiem, 1-32 – numery poletek, N_0-N_3 – dawki azotu

Figure 2. Scheme of experiment

Rysunek 2. Schemat doświadczenia

After the 12th rotation in 2015, soil samples were collected for analysis where the following parameters were determined:

- total organic carbon content (TOC) by sulfochromic wet oxidation method in the potassium dichromate solution - $K_2Cr_2O_7$ (ISO 14235, 1998),
- total nitrogen content (TN) – Kjeldahl method prior mineralization in concentrated H_2SO_4 in a ratio 1:2 soil: acid (Tecator Kjeltec System 1026 Distilling Unit, Denmark),

- dissolved organic carbon content (DOC) with the SKALAR TOCN FORMACS™ analyzer (Dębska and Gonet, 2002). Extraction with 0.004 M $CaCl_2$ from air dry samples was carried out for 1 h at the soil: extractant ratio of 1:10. DOC content was expressed in mg C·kg^{-1} D.M. of soil sample and in % organic C.

Additionally, a determination of the optical properties of humic acids in the UV-VIS range, at wavelengths of 465 nm and 665 nm, was carried out using a Perkin-Elmer Lambda 20 spectrophotometer. On the basis of these values the value of the absorbance coefficient $A_{4/6}$ (Schnitzer and Khan, 1978) was calculated. The relationship between the measured parameters was calculated statistically using Tukey's test on Statistica10.0.

Table 1. Crop rotation and doses of fertilizers

Tabela 1. Zmianowanie i dawki zastosowanych nawozów

Crop Zmianowanie	Dose of fertilization Dawki nawozów					
	P	K	N_0	N_1	N_2	N_3
Potato Ziemniaki	35	100	0	60	120	180
Rye Żyto	35	66	0	40	80	120
Rye Żyto	35	83	0	40	80	120

Results and discussion

Long-term application of fertilizers is often the cause of changes in soil fertility, mainly in organic carbon (TOC) and total nitrogen (TN) (Slepetiene and Slepatys, 2005; Blair et al., 2006; Liu et al., 2006; Khalid et al., 2007).

Independently of fertilizing variant in 2015, the content of total organic carbon (TOC) in average was 26% lower in comparison to the values determined before the experiment foundation (1979-13 g·kg^{-1}). It was found that after the 36 years of the experiment TOC content was significantly determined by the applied nitrogen doses and the interaction of investigated factors (total nitrogen and total nitrogen with manure). After application of different nitrogen doses, the content of this parameter ranged from 8.07 to 10.38 g·kg^{-1}, however after fertilization with nitrogen and manure the content ranged from 7.06 to 11.49 g·kg^{-1} (Table 2). These values are lower than the average value (12.8 g·kg^{-1}) for sandy soils in Poland (Stuczyński et al., 2007). The highest TOC values were found in the soil after the nitrogen application in dose

N_1 and N_3 with FYM, the lowest in N_0. Similar trends have been identified by other authors (Jaskulska, 2003; Blair et al., 2006; Sosulski and Korc, 2011).

Table 2. Investigated soil parameters (year 1979 and 2015)

Tabela 2. Badane cechy gleby (1979 i 2015 rok)

Fertilization Nawożenie		TOC OWO $g \cdot kg^{-1}$	TN N_{og} $g \cdot kg^{-1}$	TOC/TN OWO/N_{og}	DOC RWO $mg \cdot kg^{-1}$	$A_{4/6}$
1979 Initial value Wartości początkowe		6.63	0.78	8.5	119.4	-
2015 Without FYM Bez obornika	N_0	8.07^{c}	0.74^{b}	10.9	122.4	5.13
	N_1	8.08^{c}	0.79^{ab}	10.2	142.5	5.54
	N_2	10.38^{a}	0.81^{a}	12.8	140.9	5.37
	N_3	9.1^{b}	0.85^{a}	10.7	152.2	5.56
	Mean Średnia	8.9^{*}	0.8^{*}	11.6	139.5^{*}	5.4
2015 With FYM Z obornikiem	N_0	7.06^{b}	0.75^{c}	9.4	133.5	6.17
	N_1	11.49^{a}	0.96^{b}	12	156.9	6.55
	N_2	11.38^{a}	0.97^{b}	11.7	160.6	6.26
	N_3	11.45^{a}	1.15^{a}	10	166.7	6.25
	Mean Średnia	10.35^{*}	0.96^{*}	10.78	154.4^{*}	6.3

* The mean values for the tested parameter in the column marked with * differ significantly depending on the applied manure doses ($P<0.05$), [a, b, c] the mean values for the tested parameter marked with different letters in the column differ significantly depending on the applied nitrogen doses ($P<0.05$), TOC - total organic carbon content; TN - total nitrogen content; DOC - dissolved organic carbon content; $A_{4/6}$ - absorbance coefficient

***** Wartości średnie dla badanego parametru umieszczone w kolumnie oznaczone ***** różnią się istotnie w zależności od aplikacji obornika ($P<0.05$), [a, b, c] wartości średnie dla badanego parametru umieszczone w kolumnie oznaczone [a, b, c] różnią się istotnie w zależności od aplikacji dawek azotu ($P<0.05$), OWO - ogólny węgiel organiczny; N_{og} - azot ogólny; RWO - rozpuszczalny węgiel organiczny; $A_{4/6}$ - współczynnik absorbancji

Otherwise the content of total nitrogen (TN) was on average 13% higher compared to the values determined in 1979-0.78 g·kg^{-1}. The content of total nitrogen (TN) in the soil, following the application of different doses of nitrogen fertilizers (1st factor), ranged from 0.74 to 0.85 g·kg^{-1}, and in the case of combined nitrogen/manure application (2nd factor), it ranged from 0.75 to 1.15 g·kg^{-1}. The highest total nitrogen content in the soil was noted after the application of the highest dose of nitrogen N_3 (140 kg·ha^{-1}·yr^{-1}) and manure (30 t·ha^{-1}).

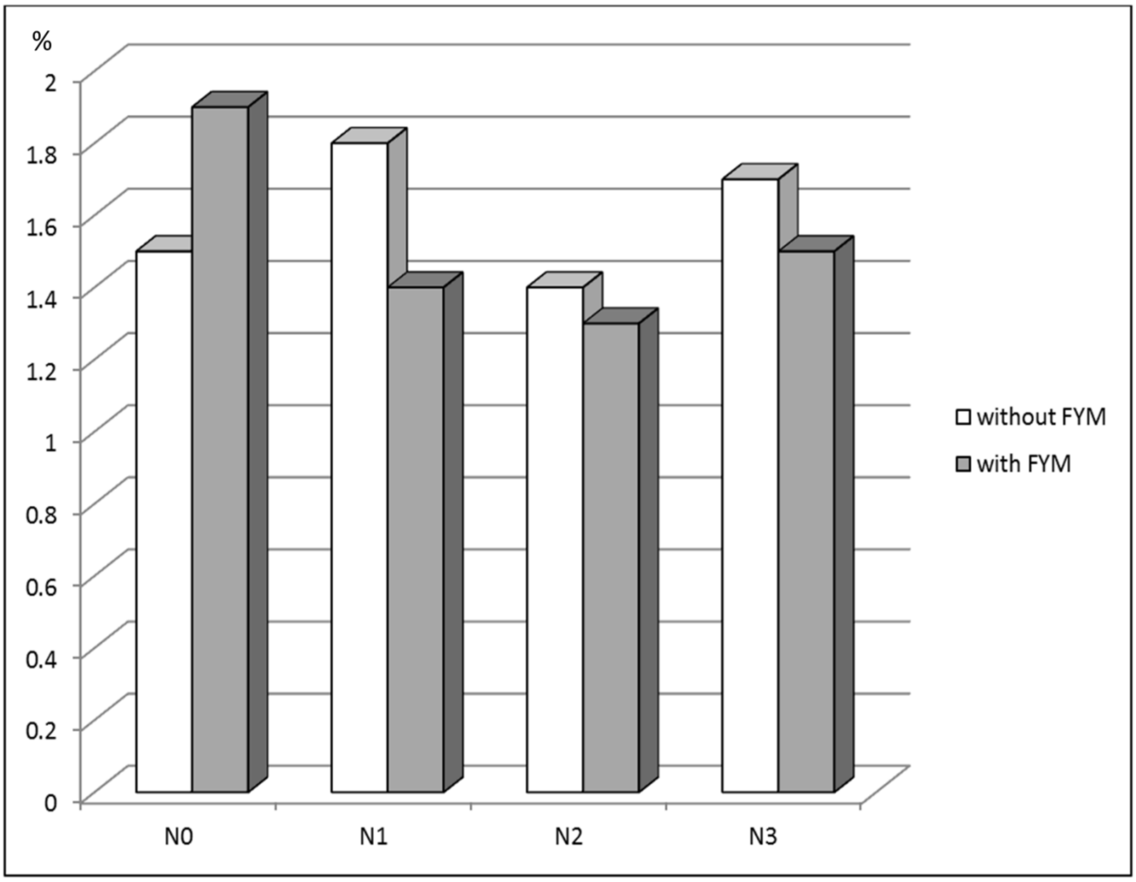
It should be emphasized that, on average, both TOC and TN values were higher after the application of mineral nitrogen fertilizers with farmyard manure. Similar trends have been noticed by other authors (Jaskulska, 2003; Blair et al., 2006; Sosulski and Korc, 2011). According to many authors (Lenart et al., 2005; Piechota, 2005; Gong et al., 2009) regular use of manure, or the combined use of organic and mineral fertilization, increases organic matter content in soils, and may have positive influence on the soil quality.

The consequence of changes in the content of organic carbon and total nitrogen, are changes in the ratio of TOC/TN. It is generally known that the FYM application results the reducing of this ratio value, due to increased concentration of nitrogen than carbon. It has been calculated that the TOC/TN ratio under the influence of investigated fertilization ranged from 9.4 to 12.8 (Table 2). The highest values of this ratio were found after N_2 dose (93.3 kg·ha^{-1}·yr^{-1}). It was also noted that the use of manure and different nitrogen doses resulted in a slight decrease in the ratio of TOC/TN, which certainly did not cause the intensity of mineralization in soil (Mando et al., 2005).

Changes in the content of total organic carbon in soil, as a result of fertilization (particularly manure application), are leading to changes in the content of dissolved organic matter - DOM (Schulz et al., 2002). It is the most mobile fraction consisting mainly of low-molecular-weight organic compounds, including low-molecular fraction of humic substances. The mobility of dissolved organic carbon in the soil is a crucial factor in the transport of carbon in the ecosystem and the formation of organic matter (Neff and Asner, 2001).

In the present study soluble organic matter was determined as dissolved organic carbon (DOC), which depends primarily on the type of deposited/delivered organic material to soil and microbial activity (Marinari et al., 2010). The content of the DOC before the foundation of the experiment was 234.04 mg·kg^{-1}. However, after 36 years of application of different nitrogen doses without FYM, DOC ranged from 122.4 to 152.2 mg·kg^{-1} (Table 2). The application of same nitrogen doses simultaneously with FYM increased the DOC content, which ranged from 133.5 to 166.7 mg·kg^{-1}. The value of this parameter was significantly determined only by the 2nd factor, application of nitrogen and manure, and it was 10.7% higher in comparison with 1st factor – different doses of nitrogen. According to the literature (Neff and Asner, 2001; Dębska and Gonet, 2002; Nardi et al., 2004; Sosulski et al., 2013), the content of dissolved carbon in agricultural soils varies depending on the method of fertilization and species of cultivated plants, which was also confirmed in the present studies. It should be noted that changes in the DOC content did not affect the percentage of this fraction in the total organic carbon (TOC) (Table 2, Figure 3). Percentage of DOC in total organic carbon content (TOC) was 1.6% on average, and before the foundation of the experiment was 1.8%. Low share of this carbon fraction may indicate that it depends directly on the absolute amount of organic matter or is also related to the type of soil (Gonet and Dębska, 2006). There was no significant influence of applied nitrogen fertilization with and without manure, on the percentage of this carbon fraction in the total organic carbon content in analyzed soil.

The essential information about, the characteristics of humic substances in the soil provides a ratio of absorbance at two wavelengths of 465 and 665 nm. This ratio is widely used to characterize humic substances (Jing-an et al., 2007; Kondratowicz-Maciejewska et al., 2011). With the increase of molecular weight and the degree of condensation of aromatic rings of humic acids (HA), the ratio $A_{4/6}$ decreases (Senesi et al., 2003; Kalembasa and Becher, 2009).



N_0-N_3 – nitrogen doses, □ – without FYM application, ■ – FYM application

N_0-N_3 – dawki azotu, □ – bez nawożenia obornikiem, ■ – nawożenie obornikiem

Figure 3. The percentage of dissolved organic carbon (DOC) fraction [%] in total organic carbon (TOC) content

Rysunek 3. Procentowa zawartość frakcji rozpuszczonego węgla organicznego (RWO) [%] w zawartości ogólnego węgla organicznego (OWO)

After the application of different nitrogen doses, humic acids of analyzed soils were characterized by lower value (5.4 on average) of $A_{4/6}$ indicator in comparison to the value of this indicator after application of nitrogen doses with manure - 6.3 (Table 2). Farmyard manure application can cause the formation of humic acids of lower molecular weight and a low humification degree. This indicates the higher content of humus in the early stages of its formation and aliphatic structure of humic acids (Kondratowicz-Maciejewska, 2009; Xiang-yun et al., 2014).

Conclusions

After 36 years of using different nitrogen doses together with farmyard manure and the cultivation of plants in a simplified crop rotation (potato-rye-rye) it was found that TOC, TN, DOC in a sandy loam soil were higher compared to the values of these parameters determined only after mineral nitrogen fertilizers application. Long-term application of mineral nitrogen (46.7, 93.3 and 140 $kg \cdot ha^{-1} \cdot yr^{-1}$) with manure (30 $t \cdot ha^{-1}$), which is the source of organic matter in soil in the early transformation stages of humus, resulted in an increase in the value of the absorption ratio ($A_{4/6}$). This indicates an increased content of low-molecular-weight humic substances. These compounds are a fraction of labile organic matter and therefore more available to the plant, which was confirmed by the content of DOC (156.9-166.7 $mg \cdot kg^{-1}$). Thus, no negative long-term effect can be concluded with respect to different doses of nitrogen fertilizer and manure on the quality of sandy loam soil in terms of the characteristics of organic matter.

References

Blair, N., Faulkner, R. D., Till, A. R., Korschens, M., Schulz, E. (2006) Long-term management impacts on soil C, N and physical fertility. Part II: Bad Lauchstadt static and extreme FYM experiments. Soil and Tillage Research, 91, 39-47. DOI: 10.1016/j.still.2005.11.001

Bolan, N. S., Adriano, D. C., De-la-Luz, M. (2004) Dynamics and environmental significance of dissolved organic matter in soil. In: Singh B., 3rd Australian New Zealand Soils Conference Super Soil 2004. Sydney, Australia, 5-9 December 2004, Sydney, Australia: University of Sydney, published on CDROM. http://www.regional.org.au/au/asssi/supersoil2004/s10/oral/1568_bolann.htm

Brookers, P. C., Beyaert, R. P., Voroney, R. P. (2007) Soil microbial biomass C, N, P, and S. In: M. R. Carter, E. G. Gregorich, eds. (2007) Soil sampling and methods of analysis. Inc. Boca Raton, FL: CRC Press, 637-651. DOI: 10.1201/9781420005271.ch49

Constantin, J., Mary, B., Laurent, F., Aubrion, G., Fontaine, A., Kerveillant, P., Beaudoin, N. (2010) Effects of catch crops, no till and reduced nitrogen fertilization on nitrogen leaching and balance in three long-term experiments. Agriculture, Ecosystems & Environment, 135 (4), 268-278. DOI: 10.1016/j.agee.2009.10.005

Dębska, B., Gonet, S. S. (2002) Wpływ zmianowania oraz nawożenia obornikiem i azotem na zawartość węgla rozpuszczalnego w glebie płowej. Fertilizers and Fertilization, 1, 209-214.

Gonet, S. S., Dębska, B. (2006) Dissolved organic carbon and dissolved nitrogen in soil under different fertilization treatments. Plant, Soil and Environment, 52 (2), 55-63.

Gong, W., Yan, X., Wang, J., Hu, T., Gong, Y. (2009) Long-term manure and fertilizer effects on soil organic matter fractions and microbes under a wheat-maize cropping system in northern China. Geoderma, 149, 318-324. DOI: 10.1016/j.geoderma.2008.12.010

Gregorich, E. G., Beare, M. H. (2007) Physically uncomplexed organic matter. In: E. G. Gregorich, M. R. Carter, eds. (2007) Soil sampling and methods of analysis. Inc. Boca Raton, FL, USA: CRC Press, 607−615.

Haynes, R. J. (2005) Labile organic matter fractions as central components of the quality of agricultural soils. Advances in Agronomy, 85, 221-268. DOI: 10.1016/S0065-2113(04)85005-3

ISO 14235 (1998) Soil quality - determination of organic carbon by sulfochromic oxidation.

Jaskulska, I. (2003) Wpływ wieloletniego zróżnicowanego nawożenia na niektóre właściwości chemiczne warstwy ornej i podornej gleby lekkiej. Fragmenta Agronomica, 20 (1), 29-39.

Jing-an, S., Xiao-hong, T., Chao-fu, W., De-ti, X. (2007) Effects of conservation tillage on soil organic matter in paddy rice cultivation. Acta Ecologica Sinica, 27 (11), 4434-4442. DOI: 10.1016/S1872-2032(08)60001-3

Kalembasa, D., Becher, M. (2009) Humic acids from mucky-peat soils of the upper valley of Liwiec river. Soil Science Annual, 60 (3), 100-106.

Khalid, M., Soleman, N., Jones, D. L. (2007) Grassland plants affect dissolved organic carbon and nitrogen dynamics in soil. Soil Biology and Biochemistry, 39 (1), 378-381. DOI: 10.1016/j.soilbio.2006.07.007

Kondratowicz-Maciejewska, K. (2009) Effects of agrotechnical treatments on spectrophotometric properties of humic acids in Albic Luvisols. Humic Substances in Ecosystems, 8, 122-128.

Kondratowicz-Maciejewska, K., Kobierski, M., Zdrodowski, T. (2011) Effect of soil management practices in orchards and cultivated fields on selected properties of humus substances. Polish Journal of Soil Science, 44 (2), 167-176.

Lenart, S., Mercik, S., Łabętowicz, J., Mazur, T., Urbanowski, S. (2005) Zmiany właściwości fizycznych gleby pod wpływem różnych systemów nawożenia w pięciu wieloletnich doświadczeniach polowych. Fragmenta Agronomica, 22 (1), 161-170.

Liu, X., Herbert, S. J., Hashemi, A. M., Zhang, X., Ding, G. (2006) Effects of agricultural management on soil organic matter and carbon transformation - a review. Plant, Soil and Environment, 52 (12), 531-543.

Mando, A., Bonzi, M., Wopereis, M. C. S., Lompo, F., Stroosnijder, L. (2005) Long-term effects of mineral and organic fertilization on soil organic matter fractions and sorghum yield under Sudano-Sahelian conditions. Soil Use and Management, 21 (4), 396-401.

Marinari, S., Liburdi, K., Fliessbach, A., Kalbitz, K. (2010) Effects of organic management on water-extractable organic matter and C mineralization in European arable soils. Soil and Tillage Research, 106, 211-217. DOI: https://doi.org/10.1016/j.still.2009.12.010

Mercik, S., Stępień, M., Stępień, W., Sosulski, T. (2005) Dynamic of organic carbon content in soil depending on long-term fertilization and crop rotation. Soil Science Annual, 56 (3/4),53-60.

Nardi, S., Morari, F., Berti, A., Tosoni, M., Giardini, L. (2004) Soil organic matter properties after 40 years of different use of organic and mineral fertilizers. European Journal of Agronomy, 21 (3), 357-367. DOI: 10.1016/j.eja.2003.10.006

Neff, J. C., Asner, G. P. (2001) Dissolved organic carbon in terrestrial ecosystems: Synthesis and a model. Ecosystems, 4 (1), 29-48.

Pałosz, T. (2009) Rolnicze i środowiskowe znaczenie próchnicy glebowej i metodyka jej bilansu. Roczniki Ochrony Środowiska, 11, 328-338.

Piechota, T. (2005) Effect of long-term cropping system and fertilization on physical soil properties. Fragmenta Agronomica, 22 (2), 158-165.

Schnitzer, M., Khan, S. U. (1978) Soil organic matter. Amsterdam: Elsevier Scientific Publishing Company.

Schulz, E., Travnikova, L. S., Titova, N. A., Kogut, B. M., Körschens, M. (2002) Influence of soil type and fertilization on stabilization of organic carbon in different SOM fractions. In: 12th International Soil Conservation Organization Conference, Sustainable utilization of global soil and water resources, Beijing, China, 26-31 May 2002, Beijing: Tsinghua University Press, 304-308.

Senesi, N., D´Orazio, V., Ricca, G. (2003) Humic acids in the first generation of Eurosoils. Geoderma, 116 (3-4), 325-344. DOI: 10.1016/S0016-7061(03)00107-1

Slepetiene, A., Slepetys, J. (2005) Status of humic in soil under various long-term tillage systems. Geoderma, 127, 207-215.

Sosulski, T., Korc, M. (2011) Effects of different mineral and organic fertilization on the content of nitrogen and carbon in soil organic matter fractions. Ecological Chemistry and Engineering, 18 (4), 601-609.

Sosulski, T., Szara, E., Stępień, W. (2013) Dissolved organic carbon in Luvisol under different fertilization and crop rotation. Soil Science Annual, 64 (3), 114-119.

Stuczyński, T., Kozyra, J., Łopatka, A., Siebielec, G., Jadczyszyn, J., Koza, P., Doroszewski, A., Wawer, R., Nowocień, E. (2007) Przyrodnicze uwarunkowania produkcji rolniczej w Polsce. (In): A. Harasim, ed. (2007) Współczesne uwarunkowania organizacji produkcji w gospodarstwach rolniczych. Puławy, Poland: Dział Upowszechniania i Wydawnictw IUNG - PIB w Puławach, 7, 77-115.

Xiang-yun, S., Shu-tang, L., Qing-hua, L., Wen-ju, Z., Chun-guang, H. (2014) Carbon sequestration in soil humic substances under long-term fertilization in a wheat-maize system from north China. Journal of Integrative Agriculture, 13 (3), 562-569. DOI: 10.1016/S2095-3119(13)60713-3

Żarski, J., Dudek, S., Kuśmierek-Tomaszewska, R. (2010) Trends of air temperature changes in Bydgoszcz area. Infrastructure and Ecology of Rural Areas, 2, 131-141.

Żarski, J., Dudek, S., Kuśmierek-Tomaszewska, R., Bojar, W., Knopik, L., Żarski, W. (2014) Agro-climatological assessment of the growing season rainfall in the Bydgoszcz region. Infrastructure and Ecology of Rural Areas, 3, 643-656.