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SOIL ORGANIC MATTER PROPERTIES IN STAGNIC LUVISOLS UNDER DIFFERENT LAND USE TYPES

Jerzy Jonczak

Department of Geoecology and Geoinformation,
Institute of Geography and Regional Studies,
Pomeranian University in Słupsk
ul. Partyzantów 27, 76-200 Słupsk
e-mail: jerzy.jonczak@gmail.com

A b s t r a c t. The aim of the study was an assessment of the influence of land use type on some properties of soil organic matter (SOM) and susceptibility to oxidation of organic carbon in Stagnic Luvisols in the area of the Sławno Plain. Soil samples from humic horizon were taken in five replications from six stands under different land uses – more than 100-year old beech-oak forest (BOF), meadow (M), arable field (AF), fallow (F), post-arable afforestation with 15 year-old birch (SAB) and 30-year-old alder (SAA). Soil samples were analysed for chemical properties with standard methods used in soil science, fractional composition of humus with Shnitzer method, absorbance ratios of 0.01% alkaline solutions of humic acids and suscetibility to oxidation of organic carbon with 0.033, 0.167 and 0.333 mol dm^{-3} KMn O_4 solutions. The data obtained confirm a strong influence of land use type on SOM properties. Especially high differences were observed between forest soils, soils never used for agriculture, and arable or post-arable soils. Contribution of fulvic acids after dacalcification in total organic carbon (TOC) was the highest in the soils of fallow, slightly lower in secondary afforestation with birch and arable field, and much lower in the remaining stands. Some differences were also observed between the stands in the contribution of fulvic and humic acids in TOC. Humic acids predominated over fulvic acids in BOF, AF, F and SAB stands. Absorbance ratios of alkaline solutions of humic acids proves higher maturity of humus in stands under grass vegetation in relation to other stands. The content of $KMnO_4$-oxidisable fractions of organic carbon varied among the stands, especially between forest and arable/post-arable soils. Statistically significant, positive correlation coefficients between the contribution in TOC of the most susceptible to oxidation carbon fraction and light absorbance ratios of alkaline solutions of HA indicate higher susceptibility to oxidation of young humic acids over more mature ones.

K e y w o r d s : soil organic matter, soil organic carbon, Stagnic Luvisols, forest soils, arable soils

INTRODUCTION

A huge role of organic matter in shaping of many properties of soils and their resistance to different external factors, functioning of natural and modified ecosystems, as well as in global balance of matter and energy is confirmed in many studies. The content, forms and properties of soil organic matter are varied in space and over time, and they are a result of past and contemporary, broadly understood, conditions of soil-made environment. Species composition of natural and modified plant communities, site conditions, as well as the character and intensity of human impact are the most important factors in this regard (e.g. Masciandaro *et al.* 1998, Pulleman *et al.* 2000, Dziadowiec and Lutowska 2005, Tobiašová *et al.* 2005, Drąg *et al.* 2007, Gonet and Dębska 2007, Grandy and Robertson 2007, Kondratowicz-Maciejewska 2007, Szombathová and Simansky 2007, Simansky 2007, Lòpezr *et al.* 2008, Chen *et al.* 2009, Dębska *et al.* 2009). Especially large quantitative and qualitative changes in soil organic matter are generated by changes in land use and agricultural practices (Pisarek 2003, Szombathová *et al.* 2004, Gonet *et al.* 2009, Kalembasa and Becher 2009, Partyka and Hamkalo 2010, Łabaz *et al.* 2011, Martins *et al.* 2011, Tobiašová 2012). Detailed recognition of the influence of various factors on soil organic matter is necessary for the development of strategies for its protection.

The aim of the study was an assessment of the influence of land use type (from beech-oak forest, through meadow, arable field, fallow to secondary afforestation with birch and alder) on some properties of humus and susceptibility to oxidation of organic carbon in Stagnic Luvisols.

MATERIAL AND METHODS

The studies were conducted in a complex of Stagnic Luvisols formed from glacial till of the Pomeranian phase of Baltic glaciation, located in the area of the Sławno Plain, near Stary Kraków (54°26'N; 16°36'E). Soil samples were collected in April 2012, from six stands with different land uses – over 100-year old beech-oak forest (BOF), meadow (M), arable field (AF), fallow (F), post-arable afforestation with 15 year-old birch (SAB) and post-arable afforestation with 30-year-old alder (SAA). Samples were taken in five replications from 10 x 10 m plots located in every stand as cores form A-horizons and as volumetric samples using 100 cm^3 steel rings, from the central part of the horizons, dried in 40°C, sieved through 2 mm sieve and analysed. The following analyses were done:

- Texture, with mixed pipette and sieve methods (Polish Soil Science Society classification of texture 2008 was applied in a division into granulometric fractions and groups),

- bulk density, with gravimetric method using 100 cm^3 steel rings,
- water content (% v/v), in volumetric samples with gravimetric method,
- pH, potentiometrically in water (Elmetron CP-401),
- total organic carbon content (TOC), with Tiurin method,
- total nitrogen content (TN), with Kjeldahl method,
- fractional composition of humus, with Shnitzer method (Dziadowiec and Gonet 1999). Following fractions were isolated: carbon of fulvic acids in solution after decalcification (FA_{deca}), carbon of fulvic acids (FA), carbon of humic acids (HA), carbon in post-extraction residue – humins (HUM),
- light absorbance of 0.01% alkaline solutions of humic acids at wavelengths 280, 465 and 665 nm. Based on the data absorbance ratios $A_{2/4}$, $A_{2/6}$ and $A_{4/6}$ were calculated,
- content of carbon fractions after extraction in 0.033, 0.167 and 0.333 mol dm^{-3} solutions of $KMnO_4$. Based on the data the content of four carbon fractions of different susceptibility to oxidation – FI (the highest susceptibility), FII, FIII and FIV (the lowest susceptibility) was calculated (Dziadowiec and Gonet 1999).

Statistica software was applied for statistical analysis of the data.

RESULTS AND DISCUSSION

Soil characteristics

Humic horizon, as the surface layer of soils, is the most vulnerable to the impact of external factors, including anthropogenic ones. Long-term spatially differentiated use-type in the investigated complex of Stagnic Luvisols was reflected in spatial heterogeneity of A-horizon (Tab. 1). Low bulk density (0.84 ± 0.09 g cm^{-3}) and high content of TOC (51.2 ± 13.5 g kg^{-1}), observed in BOF stand, are typical for forest soils associated with humid habitats. Relatively small thickness (9.2 ± 0.8 cm) and lack of sharp border with luvic horizon indicate that the soil was never tilled. Greater thickness of humic horizon in the remaining stands (26.4-35.6 cm) is an effect of tillage. bulk density in the soils ranged from 1.17 g cm^{-3} in SAA stand to 1.59 g cm^{-3} in AF stand. In arable and post-arable soils, compared to forest soil, lower concentrations of TOC (9.2 ± 0.8-21.4 ± 5.1 g kg^{-1}) and TN (0.82 ± 0.11-1.60 ± 0.28 g kg^{-1}) were noted, but higher stocks of the components per area unit (Tab. 1). Arable and fallow soils were characterised with higher pH_{H2O} (5.62-6.25) than forest and secondary afforested soils (pH_{H2O} 4.05-5.12).

Table 1. Selected properties of A-horizon of the investigated soils (mean ± SD)

Soil properties	BOF	M	AF	F	SAB	SAA
Thickness of A-horizon (cm)	9.2 ± 0.8	31.6 ± 3.2	26.4 ± 5.8	30.4 ± 3.7	35.6 ± 2.6	28.4 ± 2.5
Textural group	sand	sandy loam	sandy loam	sandy loam	sandy loam	sandy loam
Sand (%)	83.9	61,0	50.9	64.0	66.3	66.0
Silt (%)	16.1	36.9	43.4	34.8	30.8	33.3
Clay (%)	0.0	2.1	5.7	1.2	2.9	0.7
Volumetric density (g cm^{-3})	0.84±0.09	1.38±0.02	1.59±0.06	1.41±0.17	1.53±0.07	1.17±0.10
Water content (% v/v)	31.8±2.2	34.6±2.1	28.2±1.6	27.6±3.1	25.0±1.4	38.4±5.0
pH_{H2O}	4.05±0.17	6.25±0.12	6.01±0.18	5.62±0.40	5.12±0.17	4.23±0.11
TOC (g kg^{-1})	51.2±13.5	13.2±0.6	16.0±2.7	12.8±0.7	9.2±0.8	21.4±5.1
TOC stocks (kg m^{-2})	3.85±0.69	4.39±0.62	6.94±1.19	5.35±1.15	3.93±0.55	11.65±2.92
TN (g kg^{-1})	3.05±0.82	1.12±0.02	1.22±0.10	1.12±0.12	0.82±0.11	1.60±0.28
TN stocks (kg m^{-2})	0.23±0.04	0.37±0.04	0.53±0.04	0.47±0.08	0.35±0.07	0.86±0.14
TOC:TN	16.8±0.6	11.8±0.6	13.0±1.5	11.4±1.0	11.3±0.9	13.4±1.3

Fractional composition of humus and light absorbance ratios of HA

Litterfall represents the primary source of soil organic matter, and dissolved organic matter is a product of its biochemical decomposition. Secondary synthesis of low-molecular organic particles leads to the formation of humus – the most specific component of soils. Humus is a mixture of organic compounds which can be isolated using suitable analytical procedures. Quantitative proportions between the components depend on many factors, especially the properties of substrate (plant litter fall) in humification, and the complex of physical, physicochemical and chemical properties of soils. Changes in land use usually cause both changes in species composition of plant communities, and soil properties.

In general, the highest content of every analysed component of humus, like fulvic acids isolated during decalcification (FA_{deca}), fulvic acids (FA), humic acids (HA) and humins (HUM), was noted in BOF stand (Fig. 1), which is a result of the highest concentration of SOM in the soils (Tab. 1). Differences were also observed between the remaining stands, and in most cases the differences were statistically significant (Tab. 2). The percentage of carbon of particular fractions of humus in TOC was varied. The lowest contributions of FA_{deca} in TOC were observed in M (1.82%) and BOF (2.86%) stands, while the highest in F stand (6.64%). The contribution of FA ranged from 9.49% in BOF stand to 22.48% in M stand, and HA from 13.21% in M stand to 29.63% in BOF stand.

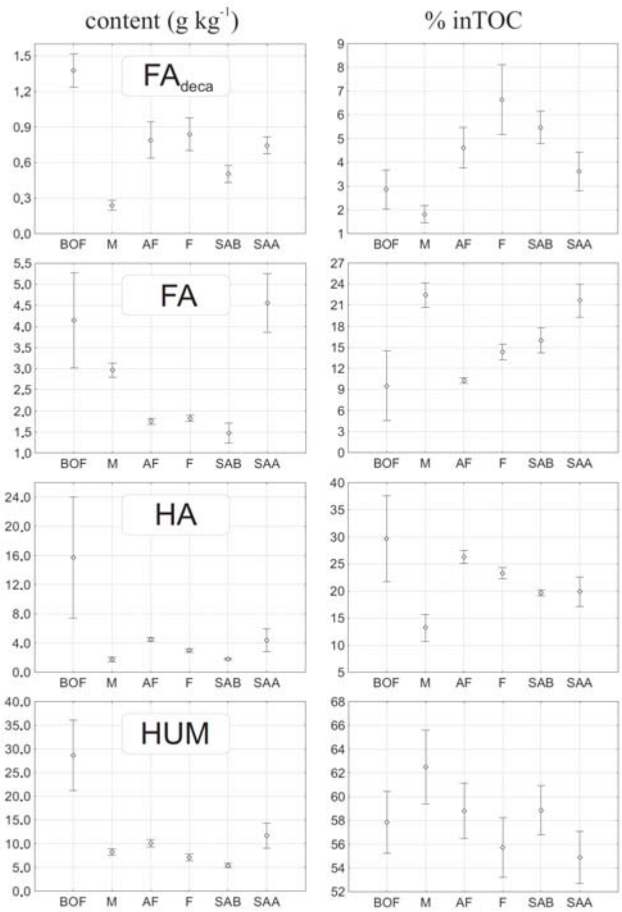

Fig. 1. Content of carbon of humus fractions and its contribution in TOC (mean ± SD) in the soils under different use types

Table 2. Statistical significance of differences between the soils under different use types in the content of carbon fractions and their contribution in TOC and some properties of humus (++ differences statistically significant at $p<0.01$; + differences significant at $p<0.05$; – no statistically significant differences)

Carbon fraction	BOF vs M	BOF vs AF	BOF vs F	BOF vs SAB	BOF vs SAA	M vs AF	M vs F	M vs SAB	M vs SAA	AF vs F	AF vs SAB	AF vs SAA	F vs SAB	F vs SAA	SAB vs SAA
Carbon fractions after extraction with Shnitzer method															
FA_{deca} (g kg^{-1})	++	++	++	++	++	+	++	++	++	–	–	–	++	–	++
FA (g kg^{-1})	–	+	–	+	–	++	++	++	++	–	–	++	++	++	++
HA (g kg^{-1})	+	+	+	+	–	–	++	–	++	–	+	–	++	–	++
HUM (g·kg^{-1})	+	+	+	+	–	–	+	++	+	–	–	–	++	++	++
FA_{deca} (% in TOC)	+	–	++	++	–	+	++	++	++	+	–	–	–	++	++
FA (% in TOC)	++	–	+	++	++	++	++	++	–	++	++	++	–	++	++
HA (% in TOC)	–	–	–	–	–	–	++	++	++	–	–	–	++	+	–
HUM (% in TOC)	–	–	–	–	–	–	++	+	++	–	–	–	+	–	+
HA:FA	–	–	–	–	–	+	++	++	++	–	–	–	++	++	+
$A_{2/4}$	++	–	++	++	–	–	–	+	+	–	–	–	+	++	++
$A_{2/6}$	++	–	++	++	–	–	–	+	++	–	–	–	–	++	++
$A_{4/6}$	+	–	++	++	++	–	–	–	++	–	–	–	–	++	++
Carbon fractions after extraction in $KMnO_4$ solutions															
FI (g kg^{-1})	++	++	++	++	++	++	–	++	++	++	++	–	++	++	++
FII (g kg^{-1})	++	++	++	++	+	–	–	–	–	–	–	+	+	+	++
FIII (g kg^{-1})	++	++	++	++	++	–	–	–	++	–	–	+	–	+	++
FIV (g kg^{-1})	++	++	++	++	++	+	–	++	++	+	++	+	++	++	++
FI (% in TOC)	+	–	+	++	–	++	–	–	+	+	++	–	–	–	+
FII (% in TOC)	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
FIII (% in TOC)	++	+	–	+	–	–	–	–	++	–	–	+	–	–	+
FIV (% in TOC)	–	+	–	++	–	–	–	–	–	+	–	++	++	–	++

Predominance of HA over FA was observed in BOF (4.54), AF (2.56), F (1.64) and SAB (1.25) stands, while in M and SAA stands FA dominated (Fig. 2). A clear difference was observed between forest and arable or post-arable soils. The obtained data suggest that HA:FA ratio formed under tillage is relatively stable over time. High ratio HA:FA observed in contemporary cultivated soils can be a result of organic fertilisation (Kwiatkowska and Maciejewska 2003, Pisarek 2003). Thirty years of secondary afforestation with alder, and fifteen years with birch did not cause any increase of the ratio over the values observed in contemporary cultivated soils.

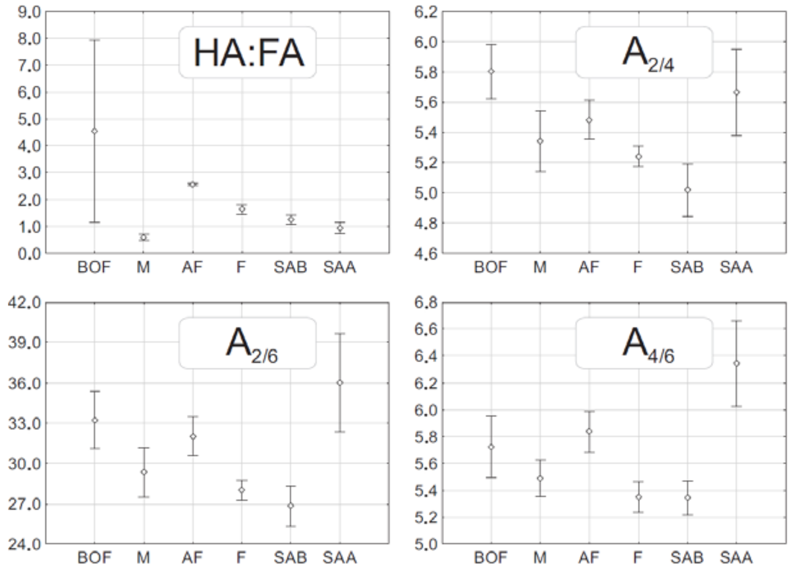

Fig. 2. HA:FA ratios and absorbance ratios $A_{2/4}$, $A_{2/6}$ and $A_{4/6}$ of alkaline solutions of humic acids (mean ± SD) in the soils under different use types

Light absorbance ratios $A_{2/4}$, $A_{2/6}$ and $A_{4/6}$ are indicators of humus maturity (Chen *et al.* 1977). In the investigated soils $A_{2/4}$ ratio ranged from 5.0 in SAB stand to 5.8 in BOF stand, $A_{2/6}$ from 26.8 in SAB stand to 36.0 in SAA stand, and $A_{4/6}$ from 5.3 in SAB stand to 6.3 in SAA stand. The ratios suggest higher maturity of humus in stands with grass vegetation (M, F) and afforestation with birch, where grass also occurred. Results of many studies indicate that grass vegetation improves humus quality (e.g. Drąg *et al.* 2007, Pospisilova *et al.* 2007).

Susceptibility to humus oxidation in $KMnO_4$ solutions

The lowest content of every $KMnO_4$-oxidisable fraction of organic carbon was noted in SAB stand, and the highest in BOF stand. The content of the fraction most susceptible to oxidation, FI, ranged from 0.16 g kg^{-1} to 1.36 g kg^{-1} (1.71-2.59% in TOC), fraction FII from 0.23 to 1.33 g kg^{-1} (2.10-3.06% in TOC), fraction FIII from 0.07 to 0.74 g kg^{-1} (0.59-1.50% in TOC), and fraction FIV from 8.77 to 47.75 g kg^{-1} (93.28-95.03% in TOC) (Fig. 3, Tab. 2). The differences observed between the stands are partially a result of different content of TOC (Blair *et al.* 1995), and partially an effect of differences in humus quality under different land uses. Results of the studies by Kondratowicz-Maciejewska (2007) show that

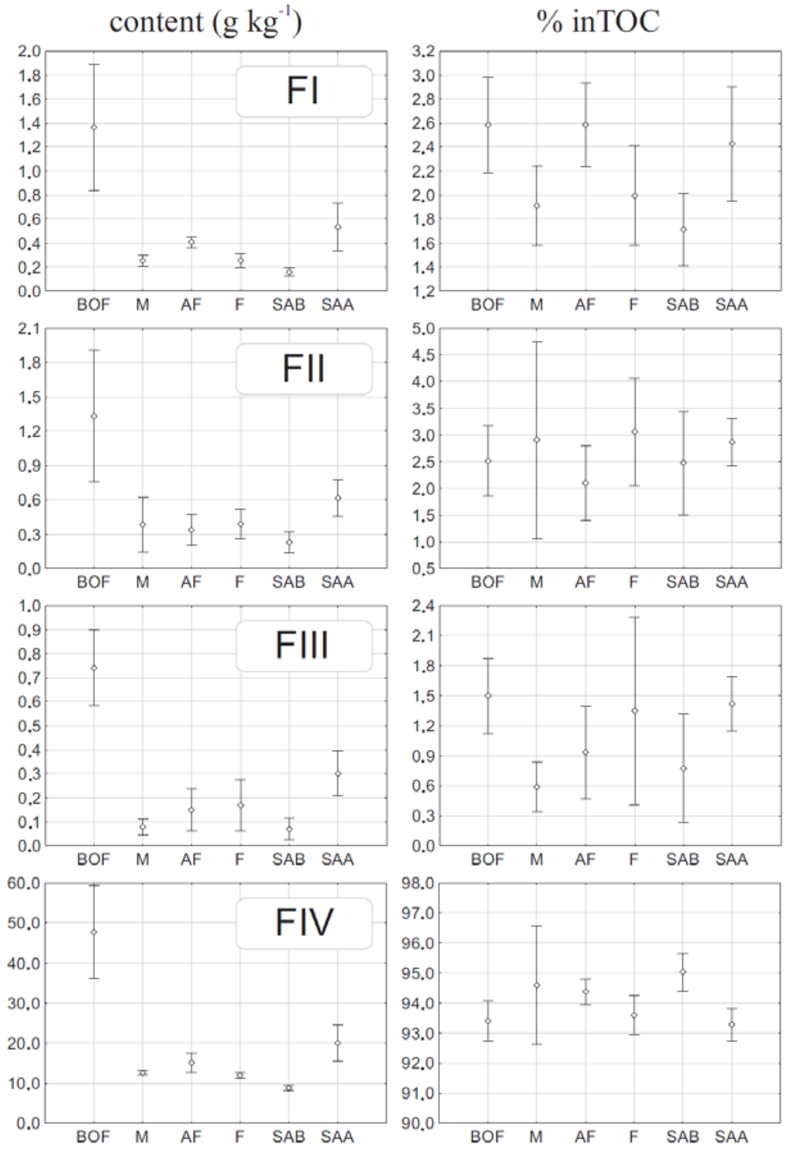

Fig. 3. Content of carbon fractions of different susceptibility to oxidation with $KMnO_4$ solutions (FI-FIV) and their contribution in TOC (mean ± SD) in the soils under different use types

low concentration of easy-oxidisable fractions of organic carbon in soil can be an effect of increase of biological activity as affected by organic fertilisation. Statistically significant correlation coefficients were noted between the contribution in TOC of FI fraction and that of HA. The observed close and positive correlation between contribution in TOC of FI fraction and light absorbance ratios of alkaline solutions of humic acids (Tab. 3) suggests higher susceptibility to oxidation of young humic acids, where aliphatic structures predominate over aromatic.

Table 3. Correlations between percentage content of $KMnO_4$-oxidisable carbon fractions and of FA_{deca}, HA, FA, HUM in TOC, and absorbance ratios of alkaline solutions of HA (in bold correlations statistically significant at $p<0.05$)

	FA_{deca}	FA	HA	HUM	$A_{2/4}$	$A_{2/6}$	$A_{4/6}$
FI	–0,290	**–0,404**	**0,591**	–0,246	**0.711**	**0.672**	**0.587**
FII	–0,048	0,190	–0,156	–0,001	0.000	–0.021	–0.035
FIII	0,286	–0,122	0,274	**–0,441**	0.276	0.276	0.255
FIV	0,010	0,064	–0,258	0,347	**–0.453**	**–0.417**	–0.356

CONCLUSIONS

1. Land use type had a strong impact on the properties of soil organic matter, as well as on the content of TOC and its susceptibility to oxidation in A-horizons of Stagnic Luvisols. Forest soils, and soils never used for agriculture, in relation to arable or post-arable soils, contained much higher amount of TOC, as well as almost every fraction of humus, but at the same time about two times lower stocks of the components in humic horizon. The observed high stocks of TOC in arable and post-arable soils were an effect of increase of A-horizon thickness as affected by tillage.
2. Contribution of FA_{deca} (labile form of carbon) in TOC was the highest in the soils of fallow, slightly lower in secondary afforestation with birch and arable field, and much lower in the remaining stands. In a few cases statistically significant differences between the stands were also observed in the contribution of FA and HA in TOC.
3. HA predominated over FA in beech-oak forest, arable field, fallow and secondary afforestation with birch, while in meadow and secondary afforestation with alder a dominance of FA was observed.
4. The values of absorbance ratios of alkaline solutions of HA ($A_{2/4}$, $A_{2/6}$ and $A_{4/6}$) suggest higher maturity of humus in stands with grass vegetation (meadow, fallow, afforestation with birch with dense grass cover in forest floor) in relation to other stands.

5. The content of $KMnO_4$-oxidisable fractions of organic carbon also varied among the stands (especially between forest and arable/post-arable soils). The most resistant to oxidation, fraction FIV, predominated in the pool with contribution in TOC between 93.28 and 95.03%. Statistically significant, positive correlation coefficients between the contribution in TOC of the most susceptible to oxidation fraction FI and light absorbance ratios of alkaline solutions of HA indicate higher susceptibility to oxidation of young humic acids over more mature.

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WŁAŚCIWOŚCI MATERII ORGANICZNEJ W RÓŻNY SPOSÓB UŻYTKOWANYCH GLEB PŁOWYCH STAGNOGLEJOWYCH

Jerzy Jonczak

Zakład Geoekologii i Geoinformacji, Instytut Geografii i Studiów Regionalnych,
Akademia Pomorska w Słupsku
ul. Partyzantów 27, 76-200 Słupsk
e-mail:jerzy.jonczak@gmail.com

S t r e s z c z e n i e. Celem badań była ocena wpływu typu użytkowania gleb płowych stagnoglejowych na właściwości ich materii organicznej i podatność na utlenianie węgla organicznego. Badania przeprowadzono w jednym kompleksie gleb na obszarze Równiny Sławieńskiej. Próbki gleb z poziomu próchnicznego pobrano w pięciu powtórzeniach z sześciu w różny sposób użytkowanych stanowisk – ponad 100-letni las bukowo-dębowy (BOF), łąka (M), pole uprawne (AF), ugór (F), zalesienie porolne brzozą w wieku 15 lat (SAB) i porolne zalesienie olchą w wieku 30 lat (SAA). W próbkach oznaczono wybrane właściwości chemiczne stosując standardowe metody wykorzystywane w gleboznawstwie, a ponadto skład frakcyjny próchnicy metodą Shnitzera, absorbancję światła w 0,01% alkalicznych roztworach kwasów huminowych przy długościach fal 280, 465 i 665 nm oraz podatność na utlenianie węgla organicznego w roztworach $KMnO_4$ o stężeniach 0,033, 0,167 i 0,333 mol·dm^{-3}. Uzyskane wyniki potwierdzają silny wpływ charakteru użytkowania na zawartość, zasoby i właściwości materii organicznej gleb. Szczególnie duże różnice obserwowano pomiędzy nigdy nie użytkowanymi rolniczo glebami leśnymi a glebami uprawnymi i leśnymi porolnymi. W glebach leśnych obserwowano wyższe stężenia, ale około 2-krotnie mniejsze zasoby węgla organicznego niż w glebach rolnych i porolnych, które charakteryzowały się obecnością pouprawnego poziomu próchnicznego. Największe różnice pomiędzy stanowiskami obserwowano pod względem udziału w ogólnej zawartości węgla organicznego frakcji kwasów fulwowych wyizolowanych w trakcie dekalcytacji próbek. Największy udział był w glebach ugorowanych, nieco niższy we wtórnie zalesionych brzozą i pola uprawnego, i znacznie niższy na pozostałych stanowiskach. Mniejsze różnice obserwowano pod względem udziału w puli węgla organicznego kwasów fulwowych i kwasów huminowych. Na stanowiskach BOF, AF, F i SAB obserwowano ilościową przewagę kwasów huminowych nad fulwowymi. Współczynniki absorbancji alkalicznych roztworów kwasów huminowych wskazują na większą dojrzałość próchnicy na stanowiskach z diminacją lub znacznym udziałem roślinności trawiastej. Dodatnie, istotne statystycznie współczynniki korelacji pomiędzy udziałem najbardziej podatnych na utlenianie w roztworach $KMnO_4$ frakcji węgla organicznego a wartościami współczynników absorbancji roztworów kwasów huminowych świadczą o większej podatności na utlenianie młodych kwasów huminowych niż bardziej dojrzałych.

Słowa kluczowe: materia organiczna gleb, węgiel organiczny, gleby płowe stagnoglejowe, gleby leśne, gleby rolne