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Effect of cover crops and straw on the humic substances in the clay loam *Cambisol*

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Abstract. The experiments were done on a productive clay loam *Gleyic Cambisol* used for agricultural production and were designed to estimate the effects of various cover crops – red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) mixture with Italian ryegrass (*Lolium multiflorum* Lamk.) and white mustard (*Sinapis alba* L.) biomass and wheat (*Triticum aestivum* L.) straw incorporated into the soil on the composition of humus. In the first year, incorporation of only the cover crops' biomass or together with straw increased the content of mobile humic acids (HA 1) by 10.7–28.0% compared with that before the trial was established.. Conditionally stable humic acids fractions (HA 2, HA 3) formed more intensively in the second year of the effects of the measures applied. Having incorporated cover crops' biomass together with straw, the fraction of humic acids HA 3 tended to increase or was the same as that before the trial establishment. An increase in the content of humic acids, compared with the levels before the trial establishment determined positive changes in the one of the main indicators of humus quality – humification rate; they were the most distinct having incorporated red clover phytomass together with straw. The incorporation of mineral nitrogen fertilizer N_{45} together with straw increased the soil organic matter mineralization rate and determined a reduction in humic acids content.

Key words: *Gleyic Cambisol*, cover crops, straw, humic acids

INTRODUCTION

In nature, organic matter accumulation depends on matter cycling in the biosphere between the above-ground and under-ground components of the ecosystem. The balance of the natural ecosystems' state is determined by the balancing of soil organic matter decomposition and synthesis processes in a closed nutrient cycle. In different agrocenoses, the largest part of phytomass produced by plants is removed from a field (farm) as marketable produce. Therefore plant residues (carbon fixed in them) are the main source of replenishing soil organic matter reserves. Moreover, the intensive anthropogenic effect – mechanical soil tillage, use of mineral fertilizers, especially nitrogen, nutrient leaching, shortage of organic fertilizers and other factors change the introduction of organic matter and the transformation processes in the soil, where mineralization prevails and humification processes are inhibited (Tripolskaja, 2005; Šlepetienė et al., 2007). Furthermore, farm specialisation in Lithuania's intensive farming regions is narrowing; only the 2–3 most profitable crop species are cultivated and livestock production is being abandoned, which makes the problem of soil fertility maintenance more acute. Cover crops, grown in many countries' agrosystems after main crop harvesting, are designed to effectively utilise solar energy, reduce nutrient leaching and physical degradation of the soil surface layer (Nieder et al., 2003). The objective of our study was to estimate the effects of the various cover crops on the composition of soil humic substances and their variation in agricultural, fertile heavy loam *Cambisol*.

MATERIALS AND METHODS

Research was done in the northern part of Central Lithuania's lowland on an *Endocalcari – Endohypogleyic Cambisol* during 2004–2006. The soil texture is heavy loam on silty clay with deeper lying sandy loam. The soil is medium in phosphorus (P_2O_5 118–128 mg kg^{-1} soil), high in potassium (K_2O 213–219 mg kg^{-1} soil) and moderate in humus (organic carbon 1.38 %). The study was carried out as a bi–factor field trial with the following experimental design: *Factor A:* utilisation of winter wheat straw: $A_{1.}$ straw removed from the field; $A_{2.}$ straw chopped and spread. *Factor B:* Cover crops: B_1 wthout cover crops (check treatment on A_1 background); B_2 Red clover (*Trifolium pratense* L.); B_3 White clover (*Trifolium repens* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) mixture; B_4 White mustard (*Sinapis alba* L.).

Cover crops were grown in the same year as winter wheat (*Triticum aestivum* L.), with no separate field allocated. Post-sowing, ammonium nitrate (N_{45}) was applied for optimal growth of white mustard (on both straw backgrounds, treatment B_5) and straw (5 t ha^{-1}) (factor A_2) mineralization. In mid-October the biomass of cover crops was chopped and incorporated into the soil. The effects of the measures used on the changes in humic acids and $C_{org.}$ were monitored for two years by growing spring barley (*Hordeum vulgare* L.) employing conventional soil and crop management practices and N_{70}, P_{60}, K_{60} fertilization. Soil samples for the determination of organic carbon content and humic acids' fractional composition were collected from the 0–25 cm layer before trial establishment and in the first and second years of effect of cover crops' biomass and straw incorporation after spring barley harvesting. Soil organic carbon ($C_{org.}$) was measured by the Tyurin method (ISO 10694:1995 Po), humic acids fractional composition by the Tyurin method modified by Ponamareva and Plotnikova (1980). The mean daily air temperature and precipitation during the experimental period were similar to the long-term mean. The experimental data were processed by the analysis of variance and correlation-regression analysis methods using the software package 'Selekcija'.

RESULTS AND DISCUSSION

Humic acids are composed of mobile humic acids fraction (HA 1); humic acids are chemically bound with polyvalent cations of which the prevalent one is Ca^{+2} (HA 2) and bound with clay particles (HA 3). The latter two fractions are attributed to stable or partially inert humus forms, are more resistant to decomposition, and are characterised by a slower variation and higher humification degree compared with mobile humic acids. Mobile humic acids are attributed to young and active humus forms and are characterised by a more rapid turnover in the soil (Olk, 2006). This mobile part of soil organic matter can be utilised by micro-organisms as a source of carbon and energy. During the mineralization process of these acids the soil is enriched by nutrients necessary for plant nutrition and plant above-ground mass formation.

Our experimental evidence suggests that mobile humic acids (HA1) accounted for on average 17.7% of the total humic acids content (Table 1). Nitrogen-rich, readily mineralising biomass of all cover crop species (without straw incorporation) incorporated into the soil markedly increased (0.008–0.021% C) mobile humic acids content compared with the check treatment. Having incorporated straw into the soil (with mineral nitrogen fertilizer or cover crops' biomass) the content of mobile humic acids increased, however, this content was by on average 0.022% C lower compared with the treatments where straw had not been used as the fertilizer. It has been indicated that in the soils with low readily available nitrogen status nitrogen immobilization is possible in the first rapid decomposition stage. In the next decomposition stage the immobilized nitrogen becomes available to plants again. With increasing mobile humic acids content, a significant increase in nitrogen concentration in spring barley grain yield occurred (r = – 0.69, p < 0.05), which suggests that mobile humic acids took part in the plant nitrogen nutrition process (Arlauskienė et al., 2009).

Table 1. Change of humic acids fractions in the soil (0–25 cm) after cover crops biomass and straw incorporation (in the first year).

Cover crop (B)	Straw use (A)							
	Removed from the field				Chopped and spread			
	Humic acids fractions % C			DH*	Humic acids fractions % C			DH*
	HA 1	HA 2	HA 3		HA 1	HA 2	HA 3	
Without cover crop	0.075	0.110	0.240	29.5	0.064	0.103	0.192	27.0
Red clover	0.086	0.121	0.231	30.2	0.066	0.089	0.243	28.4
Mixture of white clover and Italian ryegrass	0.09	0.096	0.243	29.5	0.059	0.105	0.258	30.1
White mustard	0.083	0.118	0.234	31.0	0.061	0.118	0.243	31.0
Means for factor A	0.085	0.111	0.237	30.1	0.063	0.104	0.234	29.1

$LSD_{05\ (HA1)}$ A – 0.005; B – 0.009; AB – 0.013; $LSD_{05\ (HA\ 2)}$ A – 0.009; B – 0.016; AB – 0.022; $LSD_{05\ (HA3)}$ A – 0.009; B – 0.015; AB – 0.022; $LSD_{05\ (DH)}$ A – 1.09; B – 1.88; AB – 2.66

DH* – degree of humification %

The amount of the second fraction of humic acids (HA 2) accounted for on average 25.8% of the total humic acids content. The amount of these acids, compared with their status before the trial establishment, declined in all cases: with straw removal from the field by on average 0.012% C and with straw utilisation as fertilizer (+N45) by on average 0.019% C. The third fraction of humic acids (HA 3) in heavy loam *Camisol* accounted for the largest share of the total humic acids. The effects of the measures applied were one-to-many. Their content was significantly reduced by straw fertilization (+N45), which was incorporated only during autumn ploughing. However, having incorporated straw together with the biomass of white clover mixture with Italian ryegrass, red clover or white mustard, their amount increased compared with the treatments where only cover crops biomass had been incorporated.

The most intensive humification processes (accumulation of humic acids ΣC_{HA}) occurred in the soil having incorporated the biomass of various cover crops (without straw incorporation). The lowest contents of these acids were identified in the soil where straw had been spread on the soil surface and nitrogen fertilizer had been applied for its mineralization.

In the second year of effect of the measures applied (2005), the formation of more stable humic acids was noted (Table 2). The content of mobile humic acids compared with that in the first year of effect almost halved (accounting for 9.5% of the total humic acids content). However, the content of these acids when straw had been removed still remained higher compared with the treatments with straw fertilization. This suggests that incorporation of cover crops' biomass and straw (with mineral nitrogen fertilizer or plant biomass) increased the mobile humic acids content for two years in succession. The content of the second fraction of humic acids (HA 2) increased (by on average 0.031% C, compared with the first year of effect) and accounted for on average 32.7% of ΣC_{HA}. This agrees with the data found in literature suggesting that the content of readily metabolizable compounds declines and only stable humic substances persist and build up and secure long-term, continuous nutrient and energy supply (De Nobili et al., 2008). Straw utilization as fertilizer increased the content of humic acids bound with calcium (HA 2) by on average 0.033% C, in the treatments with straw removal by on average 0.030% C, compared with the findings from the first year of effect. In the second year after cover crops' biomass incorporation the content of these acids was by on average 0.016% C higher compared with that before the trial establishment. In the treatments where the straw had been removed from the field and no agricultural practices had been applied HA 2 fraction was found to be the highest. However, in a similar treatment but with straw fertilization the content of these acids was significantly lower (0.036% C, compared with that in the check treatment).

Table 2. Change of humic acids fractions in the soil (0–25 cm) after cover crops biomass and straw incorporation (in the second year).

Cover crop (B)	Straw use (A)							
	Removed from the field				Chopped and spread			
	Humic acids fractions % C			DH*	Humic acids fractions % C			DH*
	HA 1	HA 2	HA 3		HA 1	HA 2	HA 3	
Without cover crop	0.044	0.161	0.239	30.4	0.034	0.125	0.239	28.6
Red clover	0.047	0.140	0.230	30.1	0.037	0.140	0.263	31.3
Mixture of white clover and Italian ryegrass	0.052	0.141	0.226	29.3	0.030	0.144	0.251	29.0
White mustard	0.045	0.123	0.254	29.0	0.034	0.137	0.260	30.0
Means for factor A	0.047	0.141	0.237	29.7	0.034	0.137	0.253	29.7

$LSD_{05\ (HA1)}$ A – 0.007; B – 0.013; AB – 0.018; $LSD_{05\ (HA2)}$ A – 0.012; B – 0.021; AB – 0.030; $LSD_{05\ (HA3)}$ A – 0.009; B – 0.016; AB – 0.022; $LSD_{05\ (DH)}$ A – 1.12; B – 1.94; AB – 2.74

DH* – degree of humification %

The biomass of red clover and white clover mixture with Italian ryegrass incorporated into the soil tended to increase the content of these acids in the treatments both with and without straw. With increasing humic acids content in the first and second year of effect the content of humic acids bound with clay minerals (HA 3) declined, whereas straw utilization as fertilizer promoted the build up of these acids. All the agricultural practices used in combination with straw increased the content of humic acids bound with soil clay particles. Humic acids fraction HA 3 increased the most, having used straw as fertilizer together with red clover or white mustard biomass. Literature references suggest that decomposition cycles of readily degradable and conditionally resistant to degradation organic matter are related since readily degradable organic matter provides micro-organisms, participating in aromatic polymers degradation, with carbon, energy and nutrients, so they could degrade rather stable compounds (Orlov, 1990; Olk, 2006).

In the second year of effect of the measures applied, the soil organic matter humification was increased by both cover crops' biomass alone and in combination with straw. The total humic acids (ΣC_{HA}) content (y) was significantly increased by the fractions of humic acids bound with calcium and humic acids strongly bound with clay minerals (r_1, r_2, respectively). These relationships are statistically significantly reflected by the correlation coefficients $r_1 = 0.68$, $p < 0.05$ and $r_2 = -0.67$, $p < 0.05$. The total content of humic acids increased by on average 0.010% C compared with that before the trial establishment. In the intensive cereal crop rotation involving straw fertilization with the addition of mineral nitrogen fertilizer ($+N_{45}$), as in the first year of effect, the total content of humic acids significantly declined (0.046% C), compared with the check treatment or by 0.017% C compared with that before the trial establishment. Mineral nitrogen fertilizer is a means to rapidly increase the productivity of arable land but it does not provide a long-term and stable effect. Unused nitrogen fertilizer is often leached from the soil during the autumn-winter period. The greatest positive influence on ΣC_{HA} formation was exerted by straw utilisation as fertilizer together with the biomass of red clover or white mustard cover crops.

When estimating soil humification processes, humification degree is an important factor which indicates a share of humic acids in the total sum of humic substances ($\Sigma C_{HA} : C_{org.} \times 100$). In the first year after various cover crops' biomass incorporation, the humification degree in most cases increased or remained unaltered, except for the treatments where straw had been incorporated with mineral nitrogen fertilizer, compared with that before the trial establishment. In the second year of effect, the degree of humification tended to decline. However, the biomass humification degree was highest when straw was incorporated together with red clover biomass.

Soil organic carbon (SOC) content in the first year of the cover crops' effect increased by on average 0.025 percentage point compared with that before the trial establishment. However, when straw had been used as a fertilizer with mineral nitrogen addition (+N45) the SOC content was the lowest (0.06 percentage points less compared with its status before the trial establishment). In the second year of effect the SOC content increased (by on average 0.05 percentage point) in all treatments compared with its status before the trial establishment.

The findings about humic acids fractions suggest that humic substances of heavy loam are characterised as being of low mobility and strongly bound, which is determined by a high content of clay particles that interact with the soil organic matter (Wiseman & Püttmann, 2006). Organic matter humification in the soil occurs due to oxidation, reduction, hydrolysis, condensation and other chemical reactions with the participation of micro-organisms. The newly formed products of various complexity are involved again in organic matter synthesis and destruction processes that occur continuously (Orlov, 1990). However, the stability of humic substances in the soil is determined by a regular introduction of a certain amount of organic matter, which determines the formation of new humic substances and their destruction due to the formation of a stable amount of active humus forms (Teit, 1991).

CONCLUSIONS

In clay loam *Gleyic Cambisol* used for agricultural production, biomass of cover crops (red clover, white clover mixture with Italian ryegrass, white mustard) incorporated alone or together with winter wheat straw, in the first year increased the content of mobile humic acids (HA 1), which are essential for plants and soil micro–organisms as nutrient and energy potential. Conditionally stable humic acids fractions HA 2 and HA 3 formed more intensively in the second year of effect of measures applied. Having incorporated the cover crops' biomass together with straw, the HA 3 fraction tended to increase or remained unaltered as it had been before the trial establishment. An increase in humic acids content, compared with their status before the trial establishment, determined positive changes in the main humus quality indicator – the degree of humification; increases were the most marked having incorporated red clover biomass together with straw into the soil. Mineral nitrogen N_{45} incorporation together with straw increased the soil organic matter mineralization rate and determined a reduction in humic acids content.

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