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APPLICATION OF ENVIRONMENTAL PROTECTION MEASURES FOR CLAY LOAM *CAMBISOL* USED FOR AGRICULTURAL PURPOSES

Aušra Arlauskienė[1], Stanislava Maikštėnienė[2], Alvyra Šlepetienė[3]

[1, 2]*Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry, Joniškėlis, LT-39301 Pasvalio distr., Lithuania*
[3]*Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Instituto al. 1, Akademija, LT-58344 Kėdainių distr., Lithuania*
E-mails: [1]joniskelio_lzi@post.omnitel.net (corresponding author); [3]alvyra@lzi.lt

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Abstract. Field experiments were done at the Joniškėlis Experimental Station of the Lithuanian Institute of Agriculture (LIA) during 2004–2006. The experiments were done on a productive clay loam *Gleyic Cambisol* used for agricultural production and were designed to estimate the effects of various catch 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 catch crops biomass or together with straw increased the content of mobile humic acids (C_{HA1}) by 10.7–28.0% compared with that before trial establishment. With increasing mobile humic acids content the contents of aggressive and free fulvic acids increased too (r = 0.80, p < 0.01; r = 0.85, p < 0.01, respectively). Conditionally stable humic acids fractions (C_{HA2}, C_{HA3}) formed more intensively in the second year of effects of the measures applied. The biomass of *Fabaceae* family plants incorporated alone or together with straw tended to increase the content of calcium-bound humic acids (C_{HA2}). Having incorporated catch crops biomass together with straw, the fraction of humic acids C_{HA3} tended to increase or was the same as that before trial establishment. A slight reduction in the total amount of fulvic acids and an increase in the content of humic acids, compared with the levels before the trial establishment determined positive changes in the main indicators of humus quality – $C_{HA} : C_{FA}$ ratio and humification rate; they were the most distinct having incorporated red clover phytomass together with straw. Incorporation of mineral nitrogen fertilizer N_{45} together with straw increased soil organic matter mineralization rate and determined a reduction in humic acids content.

Keywords: *Gleyic Cambisol*, catch crops, straw, humic and fulvic acids.

1. Introduction

Soil organic matter, which is a multi-component and constantly changing part of soil, exerts a marked effect on the entire ecosystem and its stability. Carbon (C) is the main constituent of organic matter. Plant and bacteria associations existing in the soil photosynthetically fix atmospheric carbon and other elements that are returned into the soil in the form of plant and animal residues (Nieder *et al*. 2003). Meanwhile, soil micro-organism associations break down plant residues by catalysing major biogeochemical reactions depending on specific soil conditions. This is not simply organic matter utilisation, but also humic matter formation in the soil. It is important that new compounds form in the soil that do not exist in live organisms but which are vital for incessant existence of contemporary life forms (Шинкарев, Гневашов 2001). Organic matter humification is a process conducive to the soil since thanks to it organic matter resources increase and as well as soil nutrient stocks available for plants. These processes determine supply of nutrient elements to plant and animal associations of the ecosystem and to large extent their quality and productivity (Baltrėnas *et al*. 2010). The amount of carbon which is annually incorporated into the composition of humic substances ranges from 0.6 to $2.5 \cdot 10^9$ t (Орлов 1990).

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 natural ecosystems' state is determined by balancing of soil organic matter decomposition and synthesis processes in a closed nutrient cycle. In differences agrocenoses, the largest part of phytomass produced by plants is removed from a field (farm) as a marketable produce. Therefore plant residues (carbon fixed in them) are the main source replenishing soil organic matter reserves. Moreover, intensive anthropogenic effect – mechanical soil tillage, intensive use of mineral fertilizers, especially nitrogen, nutrient leaching, shortage of organic fertilizers and other factors change organic matter introduction and transformation processes in the soil, where mineralization prevails and humification processes are inhibited (Bučienė 2003: 88–114; Feiza *et al*. 2005; Šlepetienė *et al*. 2007). Furthermore, farm specialisation in Lithuania's intensive farming regions is narrowing, 2–3 most profitable crop species are cultivated, livestock production is being abandoned, which makes the problem of soil fertility maintenance more acute.

In agricultural land, organic matter (organic carbon) content can be replenished by increasing plant diversity and stimulating plant biomass growth (with increasing plant residue amount) or by enriching the soil with exogenic organic matter (e.g. farmyard manure). Experimental evidence suggests that the largest amounts of plant residues in the 0–40 cm layer are accumulated in the crop rotations involving perennial grasses, while the least plant residue amounts are accumulated in the crop rotation composed of black fallow, row crops and cereals (Magyla *et al.* 1997). Root mass of cultivated crops can be enhanced by mineral NPK fertilization. However, increased root mass does not always cover soil organic mater mineralization losses. The way the root biomass will behave in the soil – whether it will fully mineralise and increase CO_2 emission and plant nutrient reserves, will assimilate and be fixed in micro-organism biomass or partly changed will be incorporated into much more stable humic substances composition (will humify), will depend on root chemical composition and environmental conditions (Тейт 1991; Moran *et al*. 2005). The rate and trend of soil-incorporated organic matter transformation processes are influenced by its carbon to nitrogen ratio, lignin content, substrate surface area and environmental conditions (Попов *et al*. 1998). The findings of long-term trials indicate that in specialised cereal farms the soil receives plant residues and straw with a high carbon to nitrogen rate. Due to the lack of nitrogen, this organic matter does not secure a positive humus balance (Magyla *et al.* 1997). A different situation is exhibited by the roots and residues of perennial and annual legumes – red and white clover, lucerne, and faba beans. Multifunctional effects of these plants in the agrosystems and an especially conducive C : N ratio for soil organic matter humification have long been known. They could be of great benefit for soil improvement; however, their use in crop production farms is limited. As a result, when organic fertilizer (farmyard manure) is not available it is vital to find ways to increase plant diversity and to enrich the soil with plant residues containing a different carbon to nitrogen ratio.

Catch crops, grown in many countries' agrosystems, after main crop harvesting are designed to effectively utilise solar energy, reduce nutrient leaching and physical degradation of soil surface layer (Catt *et al*. 1998; Nieder *et al*. 2003; Fischbeck 2005). The objective of our study was to estimate the effects of the above-ground biomass of various catch crops on the composition of soil humic substances and their variation in agricultural, fertile heavy loam *Cambisol*.

2. Materials and methods

Research was done in the northern part of Central Lithuania's lowland. The soil characteristic of the larger part of this region is *Endocalcari – Endohypogleyic Cambisol (CM-n-w-can)* of high potential productivity. The soil texture is clay loam on silty clay with deeper lying sandy loam. The pH_{KCl} of the topsoil is close to neutral. 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 (2.38%).

The study was carried out during the period 2004–2006 at the Lithuanian Institute of Agriculture, Joniškėlis Experimental Station 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:* Catch crops: B_1. Without catch 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.).

Catch crops were grown in the same year as winter wheat (*Triticum aestivum* L.), with no separate field allocated. Catch crops: undersown red clover, white clover mixture with Italian ryegrass (seed rate ratio 1:1) and post-crop white mustard. Catch crops were undersown into winter wheat early in spring when the soil had dried sufficiently. Post-crops were sown shortly after wheat harvesting (on the same day), the straw was either removed or chopped and spread (factor A). 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 the middle of October the biomass of catch crops was chopped and incorporated into the soil. The effects of the measures used on the changes in humic and fulvic acids and soil organic carbon (SOC) 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, humic and fulvic acids fractional composition were collected from 0–25 cm layer before trial establishment and in the first and second years of effect of catch crops' biomass and straw incorporation after spring barley harvesting. Soil organic carbon (SOC) was measured by Tyurin method (ISO 10694:1995), humic and fulvic acids fractional composition by Tyurin method modified by Ponomariova and Plotnikova (Пономарева, Плотникова 1980). Chemical analyses were done at the LIA Chemical Research Laboratory.

The mean daily air temperature and precipitation during the experimental period were similar to long-term mean. The experimental data were processed by the analysis of variance and correlation-regression analysis methods using a software package "Selekcija".

3. Results and discussion

3.1. Catch crops

In Lithuania, the main crops cover the soil for 60–70% of the warm period (when positive daily air temperature is above +5 °C), and the rest of this period (30–40%) is used unproductively when physical and chemical soil degradation occurs. Seeking to utilise solar energy as long as possible, it is expedient to cultivate catch crops for which there is no need to allocate a separate field in the crop rotation. This extends a positive effect of plants (catch crops) on soil properties. Nutrients fixed in plant biomass, used as green manure, are returned into the soil and serve as a source of nutrition for plants cultivated the following year, and organic carbon replenishes organic matter reserves in the soil. When there are no plants which utilise and accumulate nutrients during the warm period, soil nutrients, especially nitrogen, migrate to deeper soil layers or are leached into ground water (Stancevičius, Trečiokas 1996). During the recent years, more attention has been devoted to soil conservation requirements with a special focus on the role of catch crops, however, research into their cultivation technologies is rather scarce in Lithuania.

During the experimental period, the weather conditions after winter wheat harvesting were favourable and the biomass of the above-ground part of catch crops amounted to 2.16–3.42 t ha^{-1} dry matter. A large amount (4.48–5.63 t ha^{-1}) of dry organic matter (aboveground + underground biomass) was incorporated into the soil (Table 1).

Literature references indicate that in the course of evolution roots of most plant species have formed so that they have a C to N ratio, which is optimal for humification, compared with the above-ground plant biomass part (Rasse *et al.* 2005). However, the data on the effects of plant green above-ground mass on humification are rather ambiguous and inconsistent. Intensive decomposition of herbaceous plants' above-ground biomass is affected by its high nitrogen status, which determines a narrow C to N ratio. Research findings suggest that catch crops' above-ground mass contained 1.3–1.7 times more nitrogen and less fibre compared with roots. In agrosystems, it is important to consider different nitrogen nutrition methods of *Fabaceae*, *Poaceae* and *Brassicaceae* plants. Red and white clover fixed the larger part of nitrogen (2/3) from the atmosphere and supplied the agrocenose with extra nitrogen. Italian ryegrass and white mustard during the August – October months utilised the remaining nitrogen which had not been utilised by the main crops or had accumulated in the soil due to intensive micro-organism activity. All this prevented nitrogen from migrating into deeper soil layers and leaching. From the viewpoint of environmental protection, catch crops of white mustard and white clover mixture with Italian ryegrass are valuable in terms of nitrogen utilisation from the soil after cereal harvesting. Catch crops' biomass is important for soil humic substances accumulation not only as organic carbon but also nitrogen source.

With cereal straw used as fertilizer the soil receives carbon-rich organic matter with a wide C to N ratio, which is 5.1–8.7 times higher compared with that for catch crops' biomass. As a result, in the initial straw decomposition stages the amount of nitrogen is too little and insufficient for mineralization and does not secure a normal micro-organism metabolism and straw decomposition (Moran *et al.* 2005). Research evidence of Lithuanian and foreign researchers shows that mineral nitrogen or organic fertilizer rich in nitrogen needs to be additionally applied together with straw in order to increase soil biological activity and to create preconditions for soil organic matter humification (Berecz *et al*. 2004; Hege and Offenberger 2006; Tripolskaja *et al.* 2008). Moreover, straw rich in lignin, which (and its breakdown products) is humified at a higher rate than readily-metabolisable organic compounds.

3.2. Humic acids

The paper discusses humic substances – humic and fulvic acids, which vary most and take an active part in soil chemical processes. Humic acids are composed of mobile humic acids fraction (C_{HA1}), humic acids are chemically bound with polyvalent cations of which the prevalent one is Ca^{+2} (C_{HA2}) and bound with clay particles (C_{HA3}). The latter two fractions are attributed to stable or partially inert humus forms and are more resistant to decomposition, are characterised by a slower variation and higher humification degree compared with mobile humic acids (De Nobili *et al*. 2008).

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 mineralization process of these acids the soil is enriched by nutrients necessary for plant nutrition and plant above-ground mass formation.

In the first year (2004) of effect of the measures applied, mobile humic acids (C_{HA1}) accounted for on average 17.7% of the total humic acids content (Table 2). Nitrogen-rich, readily mineralising biomass of all catch crop species (with straw removed from the soil) incorporated into the

Table 1. Biomass of catch crops and straw incorporated into the soil and their quality

Catch crop	DM t ha^{-1}	Chemical composition				
		N%	P%	K%	crude fibre%	C : N
Above-ground biomass						
– red clover	3.0	3.58	0.26	3.15	17.4	12.5
– mixture of white clover and Italian ryegrass	2.32	2.90	0.26	3.54	24.0	18.1
– white mustard	3.42	2.1	0.34	4.28	20.3	19.3
Underground biomass						
– red clover	2.53	2.09	0.39	1.75	28.3	17.1
– mixture of white clover and Italian ryegrass	2.16	1.89	0.40	1.76	31.4	18.4
– white mustard	2.21	1.62	0.26	1.17	39.0	21.2
Straw	5.0	0.41	0.06	0.90	–	109

Table 2. Change of humic acids (C_{HA}) fractions (C g kg^{-1} of soil) in the soil (0–25 cm) after catch crop biomass and straw incorporation

Catch crop (B)	Straw use (A)							
	removed from the field				chopped and spread			
	C_{HA1}	C_{HA2}	C_{HA3}	ΣC_{HA}	C_{HA1}	C_{HA2}	C_{HA3}	ΣC_{HA}
Before trial establishment	0.35	1.23	2.57	4.15				
first year (2004)								
Without catch crop	0.75	1.10	2.40	4.25	0.64	1.03	1.92	3.59
Red clover	0.86	1.21	2.31	4.38	0.66	0.89	2.43	3.98
Mixture of white clover and Italian ryegrass	0.96	0.96	2.43	4.35	0.59	1.05	2.58	4.22
White mustard	0.83	1.18	2.34	4.35	0.61	1.18	2.43	4.22
Means for factor A	0.85	1.11	2.37	4.33	0.63	1.04	2.34	4.00
C_{HA1} LSD_{05} A–0.05; B–0.09; AB–0.13; C_{HA2} LSD_{05} A–0.09; B–0.16; AB–0.22; C_{HA3} LSD_{05} A–0.09; B–0.15; AB–0.22; ΣC_{HA} LSD_{05} A–0.17; B–0.30; AB–0.43								
second year (2005)								
Without catch crop	0.44	1.61	2.39	4.44	0.34	1.25	2.39	3.98
Red clover	0.47	1.40	2.30	4.17	0.37	1.40	2.63	4.40
Mixture of white clover and Italian ryegrass	0.52	1.41	2.26	4.19	0.30	1.44	2.51	4.25
White mustard	0.45	1.23	2.54	4.22	0.34	1.37	2.60	4.31
Means for factor A	0.47	1.41	2.37	4.26	0.34	1.37	2.53	4.24
C_{HA1} LSD_{05} A–0.07; B–0.13; AB–0.18; C_{HA2} LSD_{05} A–0.12; B–0.21; AB–0.30; C_{HA3} LSD_{05} A–0.09; B–0.16; AB–0.22; ΣC_{HA} LSD_{05} A–0.19; B–0.33; AB–0.49								

soil markedly increased (0.08–0.21 C g kg^{-1}) mobile humic acids content compared with the check treatment. Having incorporated straw into the soil (with mineral nitrogen fertilizer or catch crops' biomass) the content of mobile humic acids increased, however, this content was by on average 0.22 C g kg^{-1} lower compared with the treatments where straw had not been used as 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 (Vinten *et al.* 2002). 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 plant nitrogen nutrition process.

The amount of the second fraction of humic acids (C_{HA2}) accounted for on average 25.8% of the total humic acids content. The amount of these acids, compared with their status before trial establishment, declined in all cases: with straw removal from the field by on average 0.12 C g kg^{-1} and with straw utilisation as fertilizer (N_{45}) by on average 0.19 C g kg^{-1}. The third fraction of humic acids (C_{HA3}) in clay loam *Cambisol* accounted for the largest share of the total humic acids. After incorporation of catch crops' biomass and straw the content of these acids declined by on average 0.22 C g kg^{-1}, compared with the initial level before trial establishment. The effects of the measures applied were one-to-many. Their content was significantly reduced by straw fertilization (N_{45}), 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 catch crops biomass had been incorporated.

The most intensive humification processes (accumulation of humic acids) occurred in the soil having incorporated biomass of various catch crops (without straw incorporation). The amount of humic acids (ΣC_{HA}) was most appreciably influenced by mobile humic acids. Having incorporated the biomass of only catch crops – red clover, white clover and Italian ryegrass mixture and white mustard, ΣC_{HA} content increased (0.10–0.13 C g kg^{-1}), compared with the check treatment. Straw incorporated together with the biomass of white clover and Italian ryegrass mixture or *Brassicaceae* plants also tended to increase the total humic acids content. 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 (2005) of effect of the measures applied, formation of more stable humic acids was noted. The content of mobile humic acids compared with that in the first year of effect almost halved (accounted 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 catch crops' above-ground biomass and straw (with mineral nitrogen fertilizer or plant biomass) increased mobile humic acids content for two years in succession, which is confirmed by the correlation between mobile humic acids contents in the first and second year of effect (r = 0.98, $p < 0.01$). The content of the second fraction of humic acids (C_{HA2}) increased (by on average 0.31 C g kg^{-1}, 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 (C_{HA2}) by on average 0.33 C g kg^{-1}, in the treatments with straw removal by on average 0.30 C g kg^{-1}, compared with the findings from the first year of effect. In the second year after catch crops' biomass incorporation the content of these acids was by on average 0.16 C g kg^{-1} higher compared with that before trial establishment. In the treatments where the straw had been removed from the field and no agricultural practices had been applied C_{HA2} fraction was found to be the highest. However, in a similar treatment but with straw fertilization the content of these acids was significantly lower (0.36 C g kg^{-1}), compared with that in the check treatment.

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. Statistical analysis showed that during the experimental period, with increasing humic acids content in the first (r_1) and second (r_2) year of effect the content of humic acids bound with clay minerals declined (r_1 = –0.67, $p < 0.05$ and r_2 = –0.64, $p < 0.05$), whereas straw utilization as fertilizer promoted the build up of these acids. Averaged data indicate that their highest content (0.16 C g kg^{-1} more) was recorded having used straw as fertilizer compared with the treatments where straw had been removed from the field. All the agricultural practices used in combination with straw increased the content of humic acids bound with soil clay particles. Humic acids fraction C_{HA3} increased 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 microorganisms, participating in aromatic polymers degradation, with carbon, energy and nutrients, so that they could degrade rather stable compounds (Орлов 1990; Olk 2006).

In the second year of effect of the measures applied, soil organic matter humification was increased by both catch crops biomass alone and in combination with straw. The total humic acids 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, $p < 0.005$. The total content of humic acids increased by on average 0.10 C g kg^{-1} compared with that before trial establishment. In the intensive cereal crop rotation involving straw fertilization with the addition of mineral nitrogen fertilizer (N_{45}), like in the first year of effect, the total content of humic acids significantly declined (0.46 C g kg^{-1}), compared with the check treatment or by 0.17 C g kg^{-1} 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 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 catch crops.

Research conducted in other soils with a lower potential productivity showed that humus in sandy loam *Luvisol* is composed of a higher percentage of mobile humic acids C_{HA1} (45.2–50.5%) and a lesser percentage of conditionally resistant to degradation C_{HA3} (35.8–40.2%) (Tripolskaja *et al.* 2008). While in gleyic *Eutric Panosol* humic acids composition was dominated by the fraction of humic acids bound with calcium (41.2–49.4%) (Jodaugienė *et al.* 2001). 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 soil organic matter (Wiseman, Püttmann 2006). Environmental factors, such as climatic conditions and soil properties, are thought to significantly interact with specific management practices determining soil carbon accumulation and mineralization rate (Marinari *et al.* 2010).

3.3. Fulvic acids

Fulvic acids are characterised by a lower carbon and elevated oxygen contents, are more readily-water – soluble and have a lower molecular mass compared with humic acids. Some authors attribute them to the predecessors of humic acids, others to their breakdown products (Тейт 1991). Compared with the status before trial establishment, the most variable were found to be the first three fractions (C_{FA1a}, C_{FA1}, C_{FA2}), especially in the treatments where green biomass of catch crops had been incorporated (Table 3). In the first year these fractions in the total fulvic acids accounted for a different share – 13.1, 20.2, 12.7%, respectively (averaged data). Correlation regression analysis suggests that with increasing humic acids content, the content of fulvic acids C_{FA1a} and C_{FA1} fractions increased also (correlation coefficients r = 0.796, $p < 0.01$; r = 0.848, $p < 0.01$). The total content of mobile fulvic acids (C_{FA1a} + C_{FA1}) was markedly higher (by on average 0.86 C g kg^{-1}), and the content of the second fraction of fulvic acids (C_{FA2}) was considerably lower (by on average 0.47 C g kg^{-1}) compared with the respective humic C_{HA1} and C_{HA2} acids. The content of "aggressive" (1a) fulvic acids fraction was most significantly reduced (by on average 0.08 C g kg^{-1}) by straw use for fertilization. The content of fulvic acids fraction C_{FA1} was enhanced by the incorporated biomass of red clover and white clover mixture with Italian ryegrass. The content of these acids also increased having incorporated straw with mineral nitrogen fertilizer (N_{45}) and with red clover biomass.

The content of C_{FA2} fraction, compared with its status before trial establishment, declined (by on average 0.31 C g kg^{-1}). The content of these acids was most markedly reduced by *Fabaceae* catch crops biomass and straw used with nitrogen fertilizer. With increasing contents of mobile humic (C_{HA1}) and fulvic acids (C_{FA1}), the status of C_{FA2} fraction significantly declined (correlation coefficient $r = -0.67$, $p < 0.05$; $r = -0.83$, $p < 0.01$). Of all fulvic acids fractions C_{FA3} was the most abundant. It increased with an increase in humic acids fraction C_{HA3} (correlation coefficient $r = 0.685$, $p < 0.05$). The lowest content of this fraction was identified in the treatments with no organic additives or with straw incorporation (N_{45}). However, when catch crops' biomass had been used as fertilizer or biomass together with straw, the content of these acids increased compared with the check treatment.

In the first year, after catch crops biomass incorporation the total content of fulvic acids was (by on average 0.63 C g kg^{-1}) higher compared with that of humic acids. Fulvic acids content ΣC_{FA} after the measures applied increased, except for the treatment where straw had been used as fertilizer, compared with that before trial establishment. Averaged data indicate that the highest fulvic acids content was in the treatments with only catch crop biomass incorporation. The correlation-regression analysis shows that the sum of fulvic acids increased with an increase in C_{FA3} fraction, C_{HA3} fraction and sum of humic acids ΣC_{HA} (correlation coefficients $r = 0.913$, $p < 0.01$; $r = 0.637$, $p < 0.05$; $r = 0.658$, $p < 0.05$, respectively).

In the second year after all catch crops' biomass incorporation fulvic acids mobile fractions C_{FA1a} and C_{FA1} tended to decline, compared with the first year of effect of measures applied. The content of "aggressive" fulvic acids (C_{FA1a}) declined already in the second year after catch crops' biomass incorporation and almost reached the same level which had been before trial establishment. The lowest content of this fraction was measured having incorporated white mustard biomass together with straw. "Aggressive" C_{FA1a} fraction increased with an increase in mobile humic acids C_{HA1} and fulvic acids C_{FA1a} fraction in the first year (correlation coefficients $r = 0.656$, $p < 0.05$; $r = 0.655$, $p < 0.05$, respectively). The content of humic acids fractions in the first and second year influenced mobile fulvic acids C_{FA1}, which varied in a similar pattern as mobile humic acids (correlation coefficients $r = 0.766$, $p < 0.01$; $r = 0.818$, $p < 0.01$). The second fraction of fulvic acids C_{FA2}, compared with its status in the first year, increased: having used catch crops' biomass as fertilizer by on average 0.16 C g kg^{-1}, having incorporated straw together with catch crop biomass by on average 0.24 C g kg^{-1}, compared with respective data from the first year of effect. The content of these acids differed little between the treatments when catch crops' biomass had been used together with straw. The lowest content of these acids was found having incorporated only red clover or white mustard biomass compared with the check treatment. The third fraction of fulvic acids (C_{FA3}) tended to declined compared with the first year of effect.

The lowest content of these acids was recorded having incorporated red clover biomass together with straw, while the highest content was measured having incorporated white mustard biomass together with straw.

Table 3. Change of fulvic acids (C_{FA}) fractions (C g kg^{-1} of soil) in the soil (0–25 cm) after catch crop biomass and straw incorporation

Catch crop (B)	Straw use (A)									
	removed from the field					chopped and spread				
	C_{FA1a}	C_{FA1}	C_{FA2}	C_{FA3}	ΣC_{FA}	C_{FA1a}	C_{FA1}	C_{FA2}	C_{FA3}	ΣC_{FA}
Before trial establishment	0.053	0.72	0.092	0.254	0.470					
first year (2004)										
Without catch crop	0.67	0.86	0.73	2.46	4.72	0.56	1.00	0.45	2.13	4.14
Red clover	0.68	1.13	0.48	2.51	4.80	0.60	0.94	0.67	2.75	4.96
Mixture of white clover and Italian ryegrass	0.67	1.14	0.38	2.79	4.98	0.58	0.81	0.71	2.81	4.91
White mustard	0.65	0.99	0.68	2.72	5.04	0.60	0.85	0.76	2.63	4.84
Means for factor A	0.67	1.03	0.57	2.62	4.89	0.59	0.90	0.65	2.58	4.71
C_{FA1a} LSD_{05} A–0.03; B–0.04; AB–0.06; C_{FA1} LSD_{05} A–0.11; B–0.18; AB–0.26; C_{FA2} LSD_{05} A–0.14; B–0.25; AB–0.35; C_{FA3} LSD_{05} A–0.11; B–0.19; AB–0.27; ΣC_{FA} LSD_{05} A–0.15; B–0.25; AB–0.36										
second year (2005)										
Without catch crop	0.56	0.98	0.85	2.36	4.75	0.51	0.80	0.83	2.57	4.71
Red clover	0.54	0.95	0.64	2.46	4.59	0.55	0.75	0.86	2.33	4.49
Mixture of white clover and Italian ryegrass	0.55	0.91	0.78	2.50	4.74	0.54	0.81	0.83	2.58	4.76
White mustard	0.56	0.88	0.66	2.47	4.57	0.52	0.65	1.02	2.77	4.96
Means for factor A	0.55	0.93	0.73	2.45	4.66	0.53	0.75	0.89	2.56	4.73
C_{FA1a} LSD_{05} A–0.03; B–0.04; AB–0.06; C_{FA1} LSD_{05} A–0.08; B–0.14; AB–0.20; C_{FA2} LSD_{05} A–0.10; B–0.17; AB–0.24; C_{FA3} LSD_{05} A–0.17; B–0.30; AB–0.43; ΣC_{FA} LSD_{05} A–0.12; B–0.21; AB–0.30										

Table 4. Change of organic carbon and humic matter in the soil (0–25 cm) after catch crop biomass and straw incorporation

Catch crop (B)	Straw use (A)							
	removed from the field				chopped and sprayed			
	$\Sigma C_{HA}+\Sigma C_{FA}$, %	$C_{HA}:C_{FA}$	degree of humification, %	SOC, %	$\Sigma C_{HA}+\Sigma C_{FA}$, %	$C_{HA}:C_{FA}$	degree of humification, %	SOC, %
Before trial establishment	62.8	0.88	29.4	1.38				
first year (2004)								
Without catch crop	62.3	0.90	2.5	1.44	58.5	0.86	27.0	1.32
Red clover	63.3	0.91	30.2	1.45	63.8	0.80	28.4	1.40
Mixture of white clover and Italian ryegrass	63.4	0.87	29.5	1.47	65.2	0.86	30.1	1.40
White mustard	67.0	0.86	31.0	1.40	66.6	0.87	31.0	1.36
Means for factor A	64.0	0.89	30.1	1.44	63.5	0.85	29.1	1.37
$C_{HA}+C_{FA}$ LSD_{05} A–1.88; B–3.26; AB–4.61; $C_{HA}:C_{FA}$ LSD_{05} A–0.035; B–0.061; AB–0.086; Degree of humification LSD_{05} A–1.09; B–1.88; AB–2.66; SOC LSD_{05} A–0.030; B–0.052; AB–0.074								
second year (2005)								
Without catch crop	61.7	0.93	30.4	1.46	62.4	0.84	28.6	1.39
Red clover	63.2	0.91	30.1	1.39	63.3	0.98	31.3	1.40
Mixture of white clover and Italian ryegrass	62.3	0.88	29.3	1.43	61.6	0.89	29.0	1.46
White mustard	60.3	0.92	29.0	1.46	64.5	0.87	30.0	1.44
Means for factor A	61.9	0.91	29.7	1.44	63.0	0.90	29.7	1.42
$\Sigma C_{HA}+\Sigma C_{FA}$ LSD_{05} A–1.50; B–2.59; AB–3.67; $C_{HA}:C_{FA}$ LSD_{05} A–0.044; B–0.076; AB–0.107; Degree of humification LSD_{05} A–1.12; B–1.94; AB–2.74; SOC LSD_{05} A–0.031; B–0.054; AB–0.076								

The content of C_{FA3} declined with an increase in mobile fulvic acids C_{FA1a} and C_{FA1} (correlation coefficients $r = -0.77$, $p < 0.01$; $r = -0.69$, $p < 0.05$). The total fulvic acids content (ΣC_{FA}) was most markedly increased by fulvic acids C_{FA2} and C_{FA3} (correlation coefficient $r = 0.68$, $p < 0.05$; $r = 0.69$, $p < 0.05$, respectively). The content of these acids was most markedly reduced by red clover biomass, incorporated alone or together with straw and by white mustard biomass incorporated alone. However, having incorporated white mustard biomass together with straw, the content of these acids was the highest (0.26 C g kg^{-1} higher compared with that before trial establishment). Averaged data indicate that the total content of fulvic acids inappreciably declined, while the total humic acids content increased compared with their status before trial establishment.

3.4. Humus quality indicators

The total content of humic substances ($\Sigma C_{HA} + \Sigma C_{FA}$) in the first year of effect tended to increase after catch crop (red clover, white clover mixture with Italian ryegrass, white mustard) biomass incorporation compared with that in the check treatment (Table 4), whereas straw used as fertilizer increased humic substances content only when applied with red clover biomass. In the second year of effect, the lowest sum of humic and fulvic acids was recorded for the treatments where no soil ameliorating measures had been applied (check treatment). The largest increase in the sum of humic and fulvic acids occurred having incorporated biomass of red clover, white clover mixture with Italian ryegrass and white mustard compared with that of the check treatment and with that before trial establishment.

Having used straw as fertilizer, the sum of $\Sigma C_{HA} + \Sigma C_{FA}$ was increased only when straw had been incorporated together with red clover or white mustard biomass compared with the check treatment. Humus quality is best reflected by the ratio of humic to fulvic acids ($C_{HA}:C_{FA}$). In the first year of plant biomass incorporation the highest $C_{HA}:C_{FA}$ ratio was established in the check treatment with no soil ameliorating organic additives and in the treatment with red clover biomass incorporation. In all other cases this ratio tended to decline. In the second year of effect of measures applied the ratio of C_{HA} to C_{FA} tended to increase. The highest ratio was determined having incorporated straw together with red clover biomass.

When estimating soil humification processes, humification degree is an important factor, which indicates a share of humic acids in the SOC (ΣC_{HA} : SOC × 100). Statistical analysis suggests that with increasing ratio of humic to fulvic acids humification degree increased ($r = 0.75$, $p < 0.05$). In the first year after various catch crops' biomass incorporation, humification degree in most cases increased or remained unaltered, except for the treatments where straw had been incorporated with mineral nitrogen fertilizer or red clover biomass. In the second year of effect, degree of humification tended to decline. However, having incorporated straw together with red clover biomass humification degree was the highest.

Soil organic carbon (SOC) content in the first year of catch crops' effect increased by on average 0.025 percentage point compared with that before trial establishment. However, when straw had been used as fertilizer with mineral nitrogen addition (N_{45}) SOC content was the lowest (0.06 percentage point less compared with its status before trial establishment). In the second year of effect SOC content increased (by on average 0.05 percentage point) in all treatments compared with its status before trial establishment.

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 into organic matter synthesis and destruction processes that occur continuously (Орлов 1990). However, the stability of humic substances in the soil is determined by a regular introduction of certain amount of organic matter, which determines formation of new humic substances and their destruction due to the formation of a stable amount of active humus forms (Marinari *et al*. 2010).

In *Endocalcari – Endohypogleyic Cambisol* used for agricultural production, biomass of catch 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 (C_{HA1}), which are essential for plants and soil micro-organisms as nutrient and energy potential. With increasing mobile humic acids content an increase occurred in the amount of so-called "aggressive" and free fulvic acids ($r = 0.80$, $p < 0.01$; $r = 0.85$, $p < 0.01$, respectively). Conditionally stable humic acids fractions C_{HA2} and C_{HA3} formed more intensively in the second year of effect of measures applied. The biomass of *Fabaceae* family catch crops incorporated alone or with straw increased the content of humic acids bound with calcium (C_{HA2}). The fraction of conditionally stable humic acids bound with clay particles (C_{HA3}) declined in the treatments where only the biomass of catch crops had been incorporated compared with its status before trial establishment. This was determined by higher contents of mobile humic acids and free fulvic acids that formed due to nitrogen-rich plant above-ground biomass incorporation into the soil. Having incorporated catch crops biomass together with straw, C_{HA3} fraction tended to increase or remained unaltered as it had been before the trial establishment. Inappreciable reduction in the total fulvic acids content and an increase in humic acids content, compared with their status before trial establishment, determined positive changes in the main humus quality indicators – C_{HA}:C_{FA} ratio and degree of humification; which were the most marked having incorporated red clover biomass together with straw into the soil. Mineral nitrogen N_{45} incorporation together with straw increased soil organic matter mineralization rate and determined a reduction in humic acids content.

4. Conclusions

1. Biomass of catch crops (red clover, white clover mixture with Italian ryegrass, white mustard) incorporated for greeen manure increased the soil organic matter (4.48–5.63 t ha^{-1} DM) and nitrogen resource. Experimental data suggest that narrow carbon to nitrogen ratio (C:N) was in the aboveground biomass of red clover (12.5), wide – in straw (109).

2. In the first year nitrogen-rich, readily mineralising biomass of all catch crop incorporated into the soil markedly increased (0.08–0.21 C g kg^{-1}) mobile humic acids content compared with the check treatment. Conditionally stable humic acids fractions C_{HA2} and C_{HA3} formed more intensively in the second year of effect of measures applied. The agricultural practices used in combination with straw increased the content of humic acids bound with calcium and bound with soil clay particles. In the first year of effect of the measures applied, the most intensive (4.35–4.38%) humification processes (accumulation of humic acids C_{HA}) occurred in the soil having incorporated biomass of various catch crops, in the second year – having incorporated catch crop biomass in combination with straw (4.25–4.40%).

3. In the first year, the total content of humic substances ($\Sigma C_{HA} + \Sigma C_{FA}$) was significantly dependent upon straw and cover crops, in the second upon only straw. The highest contents of humic substances were identified in the soil where straw had been applied with biomass of white mustard.

4. Inappreciable reduction in the total fulvic acids content and an increase in humic acids content, determined positive changes in the main humus quality indicators – C_{HA}:C_{FA} ratio and degree of humification, which were the most marked (0.98 and 31.1% respectively) having incorporated red clover biomass together with straw into the soil.

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APLINKOSAUGOS PRIEMONIŲ TAIKYMAS AGRARINĖS PASKIRTIES SUNKAUS PRIEMOLIO RUDŽEMIUOSE

A. Arlauskienė, S. Maikštėnienė, A. Šlepetienė

Santrauka

Lietuvos žemdirbystės instituto (LŽI) Joniškėlio bandymų stotyje 2004–2006 m. atlikti tyrimai, kurių tikslas buvo nustatyti našiame agrarinės paskirties sunkaus priemolio glėjiškame rudžemyje (*Endocalcari-Endohypogleic Cambisol*, *CM-n-w-can*) tarpiniuose pasėliuose augintų įvairių biologinių rūšių augalų – raudonųjų dobilų (*Trifolium pratense* L.), baltųjų dobilų (*Trifolium repens* L.) mišinio su gausiažiedėmis svidrėmis (*Lolium multiflorum* Lamk.) bei baltųjų garstyčių (*Sinapis alba* L.) biomasės ir paprastųjų kviečių (*Triticum aestivum* L.) šiaudų, įterptų į dirvožemį, įtaką humuso kokybei. Įterpus vien tarpinių pasėlių biomasę ar kartu su šiaudais, pirmaisiais metais judriųjų huminių rūgščių (C_{HR1}) kiekis, palyginti su buvusiu prieš bandymą, padidėjo 0,024–0,061 % C. Didėjant judriųjų huminių rūgščių kiekiui, didėjo ir agresyviųjų bei laisvųjų fulvinių rūgščių kiekis (atitinkamai $r = 0{,}80$, $p < 0{,}01$; $r = 0{,}85$, $p < 0{,}01$). Santykinai patvarios huminių rūgščių (C_{HR2}, C_{HR3}) frakcijos intensyviau formavosi antraisiais taikytų priemonių poveikio metais. Pupinių šeimos augalų biomasė, įterpta viena ar su šiaudais, didino huminių rūgščių junginio su kalciu (C_{HR2}) kiekį. Įterpus tarpinių pasėlių biomasę kartu su šiaudais, huminių rūgščių C_{HR3} frakcija tendencingai didėjo ar prilygo buvusiai prieš bandymą. Suminio fulvinių rūgščių kiekio nežymus sumažėjimas ir huminių rūgščių kiekio padidėjimas, palyginti su duomenimis prieš bandymą, lėmė teigiamus pagrindinių humuso kokybės rodiklių – C_{HR}:C_{FR} santykio ir humifikacijos laipsnio pokyčius; jie ryškiausi buvo į dirvožemį įterpus raudonųjų dobilų fitomasės kartu su šiaudais. Patręšus mineralinėmis azoto trąšomis N_{45} kartu su šiaudais, didėjo dirvožemio organinių medžiagų mineralizacijos intensyvumas ir sumažėjo huminių rūgščių.

Reikšminiai žodžiai: glėjiškas rudžemis, tarpiniai pasėliai, šiaudai, huminės ir fulvinės rūgštys.

ПРИМЕНЕНИЕ МЕР ДЛЯ ОХРАНЫ ОКРУЖАЮЩЕЙ СРЕДЫ НА ТЯЖЕЛОСУГЛИНИСТЫХ БУРОЗЕМАХ АГРАРНОГО НАЗНАЧЕНИЯ

А. Арлаускене, С. Майкштенене, А. Шлепетене

Резюме

В 2004–2006 гг. на Йонишкельской станции Литовского института земледелия (ЛИЗ) проводились исследования, целью которых было определить влияние биомассы выращиваемых в промежуточных посевах культур – клевера красного (*Trifolium pratense* L.), смеси клевера белого (*Trifolium repens* L.) и райграса однолетнего (*Lolium multiflorum* Lamk.), горчицы белой (*Sinapis alba* L.) и соломы пшеницы обыкновенной (*Triticum aestivum* L.) на качественный состав гумуса тяжелосуглинистого бурозема. Внесение в почву биомассы промежуточных культур или внесение их совместно с соломой пшеницы в первый год увеличило количество подвижных гуминовых кислот ($C_{ГК1}$) на 10,7–28,0% по сравнению с их исходным количеством перед закладкой опыта. С увеличением количества подвижных $C_{ГК1}$ увеличивалось также количество фракций «агрессивных» и свободных фульвокислот (соответственно $r = 0,80$, $p < 0,01$; $r = 0,85$, $p < 0,01$). Относительно стабильные фракции гуминовых кислот ($C_{ГК2}$ и $C_{ГК3}$) интенсивнее формировались на второй год после действия исследуемых агротехнических приемов. Внесение биомассы бобовых культур в сочетании с соломой или без нее увеличило количество связанных с кальцием гуминовых кислот ($C_{ГК2}$). При внесении биомассы промежуточных растений совместно с соломой формирование $C_{ГК3}$ увеличивалось и было аналогично их количеству перед закладкой опыта. Незначительное снижение содержания в почве фульвокислот и увеличение количества гуминовых кислот, по сравнению с начальным уровнем до закладки опыта, определило положительные изменения основных показателей качества гумуса – соотношения $C_{ГК}$:$C_{ФК}$ и степени гумификации. Более значительными они были при внесении фитомассы клевера красного совместно с соломой. Внесение минерального азота (N_{45}) вместе с соломой увеличивало интенсивность минерализации органического вещества почвы и снижало количество гуминовых кислот.

Ключевые слова: глееватый бурозем, промежуточные посевы, солома, гуминовые и фульвокислоты.

Aušra ARLAUSKIENĖ. Dr, senior research worker at the Joniškėlis Experimental Station of the Lithuanian Institute of Agriculture (LIA). Main research areas: soil ecology, biodiversity plant productivity Publications: author of over 40 research papers, co-author of monograph “Sustainable Agriculture on Productive Soils” (in Lithuanian). Membership: Lithuanian Soil Science Society at the Department of Agriculture and Forestry in Lithuanian Academy of Science, Nordic Association of Agricultural Scientists (NJS), International Soil Tillage Research Organisation (ISTRO).

Stanislava MAIKŠTĖNIENĖ. Dr, senior research worker and director of the Joniškėlis Experimental Station of the Lithuanian Institute of Agriculture. Doctor of Biomedical Sciences (agronomy) received in 1982. Publications: author of more than 80 research papers in soil tillage and management, organic matter of soil, humic substances, ecology and soil productivity. Membership of: Nordic Association of Agricultural Scientists (NJS), International Soil Tillage Research Organisation (ISTRO) and Lithuanian Soil Science Society at the Department of Agriculture and Forestry in Lithuanian Academy of Science and European Weed Research Society (EWRS). Member of Joint Methodological Commision and of Board of the Lithuanian Institute of Agriculture. Research interests: organic matter of soil, ecology and sustainable agriculture.

Alvyra ŠLEPETIENĖ. Dr (HP), Head of Chemical Research Laboratory since 2004, a senior research worker at the Lithuanian Institute of Agriculture (LIA) (http://www.lzi.lt/chem_lab). Doctor of Biomedical Sciences (agronomy) received in 1997. Publications: author of more than 60 research papers in soil tillage and management, analytical and bioanalytical chemistry, organic matter, humic substances, ecology and environment studies. Membership of professional bodies: Nordic Association of Agricultural Scientists; Nordic – Baltic chapter of International Humic Substances Society; International Soil Tillage Research Organisation (ISTRO), Member of Joint Methodological Commission and Board of the Lithuanian Institute of Agriculture. Research interests: soil chemistry, humic substances, food quality.