CHANGES OF SOIL ORGANIC CARBON AND MOBILE HUMIC ACIDS IN RESPONSE TO DIFFERENT AGRICULTURAL MANAGEMENT

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ABSTRACT. *Field and laboratory investigations were done at the Lithuanian Institute of Agriculture (LIA) and Joniskelis Research Station of LIA, Lithuania. The aim of the study was to compare the soil organic carbon (SOC) as well as carbon of mobile humic acids (MHA) contents in the differently used agricultural soils. The data of SOC and MHA investigated in four different field experiments are discussed in this article. In the Experiment 1 the study investigated two soil tillage systems: conventional and sustainable (factor A) and crop rotations with different structure of winter crops (0−100%) (factor B) on a Endocalcari-Endohypogleyic Cambisol at the Joniskelis Research Station of LIA. The field Experiment 2 compared the influence of long-term legume swards on SOC and MHA in an Epicalcari-Endohypogleic Cambisol. In the Experiment 3 the treatments of factor A involved 7 different swards and the treatments of factor B of this experiment involved frequent and less frequent grazing. Five pasture fertilisation treatments* P_0K_0; $P_{60}K_0$; $P_{60}K_{30}$; $P_{60}K_{60}$; $P_{60}K_{90}$ *were investigated in the Experiment 4 in an Epicalcari-Endohypogleic Cambisol in a long term field experiment. SOC content was determined by Tyurin method. MHA was determined according to the Ponomariova–Plotnikova method. Different agricultural management affected changes in SOC and MHA. MHA fraction in Cambisol can be considered as one of the sensitive indicators of SOM changes in the agricultural environment.*

Keywords: *soil organic carbon, mobile humic acids, agriculture, management, sustainable tillage, grassland, pasture, Cambisol, fertilization.*

Introduction

Soil, which is a complex and continuously developing part of many ecosystems, including grassland, plays an especially important role in the protection of natural environment and use of its resources. One of the major sources of soil organic carbon (SOC) is plant residues, the highest content of which is left in the soil by perennial grasses, especially legumes. Soil C and N sequestration potential can be enhanced by utilization of management practices such as conservation tillage and intensive cropping systems. Impacts of tillage on soil organic matter (SOM) in surface soils have been well documented, but results vary due to soil type, cropping systems, residue management, and climate (Paustian *et al.*, 1997).

Some experimental findings suggest that in grazed swards the build up of (SOC) is higher than that in cut swards and that, in general, the accumulation of carbon is higher at higher mineral nitrogen fertilisation. Using legume/grass swards and improving the use of grazed swards one can also expect satisfactory productivity of swards and C accumulation in the soil. The data on organic carbon accumulation in the soil at different management of legume/grass swards are scarce. The floristic diversity and productivity of long-term Lithuanian pasture ecosystem is closely related to management practices and environmental factors. Annual inputs of organic matter are greater in grasslands than in other agricultural soils. Grass leys supply two to three times more organic matter to soil than annual crops such as cereals (Lægreid *et al.*, 1999). In pasture ecosystem the organic matter and livestock excreta accumulate in the topsoil and take part in the processes of mineralization and humification there (Gutauskas, Slepetienė, 2000).

Agricultural policies in the EU are enhancing the increase of biodiversity in all ecosystems including the pastures. The higher biodiversity at the organic pastures was a result of the extensive farming situation, in terms of low farm mineral inputs (Baars, 2002). Proper well-replicated networks of grassland biodiversity management experiments are urgently needed at the national and European levels. Using the scientific knowledge on evolution and ecology of grassland biodiversity, effective grassland farming and biodiversity conservation can be integrated (Pärtel, 2005).

SOM and humic substances are important indicators of soil fertility as they are involved in the stabilization of soil aggregates and binding of metals and anthropogenic organic chemicals (Donisa *et al.*, 2003). Their stability and turnover rates are important factors in interpreting the effects of agricultural and land use changes on soil system dynamics and carbon cycling (Spaccini *et al.*, 2006). Sometimes changes in SOC due to management practices are difficult to investigate while these changes occur slowly, are relatively small compared to the vast SOC pool size, and vary both spatially and temporally (Russell *et al.*, 2004; Purakayastha *et al.*, 2008). In various research works it is documented that some of the soil C fractions are more sensitive to management practices than the total SOC (Campbell *et al.*, 1997). There is not so much evidence on the changes in mobile humic acids (MHA), which being influenced by the management practices, can be considered as indicarors of the changes occurring in the soil. These soil C fractions may serve as indicators of future changes in total SOC that are presently undetectable. There is a lack of data on SOC changes obtained in precision field experiments, and especially the long-term experiments. This gap should be filled.

The purpose of our study was to determine the contents of SOC and MHA accumulated in the differently used agricultural soil: to compare soil properties using conventional and sustainable tillage, the performance of long-term grass/white clover/forbs swards under grazing management; to evaluate the effect of different PK fertilisation rates on accumulation of SOC and MHA in long-time scale; to study soil properties of ecologically grown mono- and multi-component long-term legume swards.

Materials and methods

A field Experiment 1 was established on a glacio-lacustrine clay loam on silty clay *Endocalcari-Endohypogleyic Cambisol* at the Joniskelis Research Station of the Lithuanian Institute of Agriculture (LIA) situated in the northern part of the Central Lithuania's lowland. The study investigated two soil tillage systems: conventional and sustainable and crop rotations with different structures: 0, 25, 50, 75 and 100% of winter crops in a crop rotation. The parent material is glaciolacustrine clay. Clay particles (< 0.002 mm) in the A_a horizon (0−30^{0}cm) constitute 27.0%, in the B_1 horizon (52−76 cm) 51.6%, in the C_1 horizon (77−105 cm) 10.7%, and in the C_2 horizon (106−135 cm) 11.0%. Before the experiment, soil pH (KCl 1M, w/v 1:2.5) was 6.6-6.8; available phosphorus (P_2O_5) 154 mg kg^{-1} and available potassium (K_2O) determined by the Egner-Riem-Domingo (A-L) method 304 mg kg^{-1}. Soil samples were collected from 0−15 and 15−25 cm depths.

The field Experiment 2 compared the influence of long-term legume swards on soil humic substances in an *Epicalcari-Endohypogleic Cambisol* with clay content of 11.9%, silt 34.2% and sand 53.9% in Akademija, near Kedainiai. Before the experiment, plough-layer's pH (KCl 1M, w/v 1:2.5) was 7.0; available phosphorus (P_2O_5) determined by Egner-Riem-Domingo (A-L) method: 128 mg kg^{-1}; and available potassium (K_2O) 211 mg kg^{-1}. Soil samples were collected from 0−10, 10−20 and 20−30 cm depths with 6−8 boreholes per replicated plot. In both Experiments 1 and 2, the soil of three field replicates was investigated in the laboratory. Experiment 2 explored the effects of seven swards grown for 5 years under ecological management on the accumulation of humic substances in different soil layers. No fertilizers or pesticides were used. The following long-lived swards and their mixtures were investigated: *Galega orientalis; Medicago sativa; Onobrychis viciifolia; galega/Medicago/Festulolium; Galega/ Onobrychis/Festulolium; Galega/Medicago/T. Pratense/ Festuloilium; Galega/T. Repens/Onobrychis/ Festulolium.* The experiment was laid out as a randomized complete block with four replications.

A bi-factorial field trial was established in 1998 on an *Epicalcari-Endohipogleic Cambisol* in Akademija, central part of Lithuania (Experiment 3). The treatments of factor A involved 7 different swards consisting of *Trifolium repens* L., *Medicago varia* Mart., *Lolium perenne* L., *Poa pratensis* L., *Festulolium*. The treatments of factor B involved frequent (F) and less frequent (LF) grazing (with 6 or 5 grazing per season respectively). The content of SOC and MHA was determined in the soil of pasture swards in the third year of use at the 0−25 cm layer.

In the Experiment 4 long-term trials were conducted at the LIA over the period 1993−2002. The experiments have been carried out since 1961. Five fertilisation treatments were investigated: P_0K_0; $P_{60}K_0$; $P_{60}K_{30}$; $P_{60}K_{60}$; $P_{60}K_{90}$. The experimental soil is *Epicalcari-Endohypogleic Cambisol*. Each treatment of the field trial had four replicates. Experimental pastures were grazed 3−4 times per season on a rotational basis with a herd of dairy cows. Before each grazing cycle, the plots in the pasture were cut to a grazing height.

Analytical methods. SOC content was determined by Tyurin method modified by Nikitin (1999). Mobile humic acids (MHA) are free or weakly bound with clay minerals fraction. According to the Ponomariova–Plotnikova method mobile humic substances were extracted by 0.1M NaOH solution (room temperature) at a soil–solution ratio of 1:20 and separated into humic and fulvic acid fractions by acidifying the extract to pH 1.3–1.5 using 0.5M H_2SO_4 at 68–70^{0}C and after following MHA's were separated by filtering (Ponomareva, Plotnikova, 1980). Carbon of mobile humic acids (MHA) was determined spectrophotometrically using Carry 50.

Results

Data on the SOC and MHA investigations of differently used agricultural soils are presented in this work. Our findings suggest that sustainable soil tillage system affected organic carbon accumulation in the soil (Table 1). Sustainable soil tillage significantly increased SOC content both in the topsoil and subsoil compared with conventional tillage. In the conventional tillage system the content of SOC accumulated in the topsoil (0−15 cm) was from 11.5−11.9 g kg^{-1} in the crop rotation with 0−50% of winter crops to 12.2 g kg^{-1} in the crop rotation with 75−100% of winter crops. In the sustainable soil tillage system, SOC content was significantly higher in the topsoil (0−15 cm) from 13.1−13.2 g kg^{-1} (0−50% of winter crops in the crop rotation) to 13.7 g kg^{-1} (100% of winter crops in the crop rotation). The highest SOC content was in the sustainable soil tillage system, having increased the share of cereals in the crop rotation structure to 100%. Similar regularities were identified in the 15−25 cm layer. These results demonstrate also the role of wintering crops in SOM and SOC conservation.

Table 1. The influence of soil tillage systems and proportion of winter crops in the crop rotation on the content of SOC (g kg^{-1}). Mean data from 2004−2006

Proportion of winter crops, % (A)	Depth (cm)	Soil tillage system (B)	
		Conventional	Sustainable
0	0–15	11.9	13.2
	15–25	11.0	11.8
25	0–15	11.5	13.1
	15–25	11.5	12.8
50	0–15	11.8	13.1
	15–25	11.5	12.5
75	0– 15	12.2	13.1
	15–25	12.2	12.0
100	0–15	12.2	13.7
	15–25	12.2	13.2
Mean across tillage (B)	0–15	11.9	13.2
	15–25	11.7	12.5
LSD_{05}		0–15 cm	15–25 cm
A		0.42	1.0
B		0.21	0.50
AB		0.63	1.5

The data presented in Figure 1 and Figure 2 show the variation of humified carbon representing by mobile humic acids (MHA) in 0−15 cm and 15−25 cm soil layers. It was found that increasing the area of longer vegetation wintering crops and applying sustainable tillage in the heavy soil had a positive influence on the MHA. The data show a significant increase in these MHA in the crop rotation with winter crops in both soil layers similar to trends in the SOC content. Compared with conventional tillage (CT), sustainable tillage (ST) significantly increased MHA content in topsoil (0−15 cm) from 0.68 to 0.85 g kg^{-1}. An increase in the share of winter crops in the crop rotation to 100% strengthened this effect and the highest content of MHA was identified here.

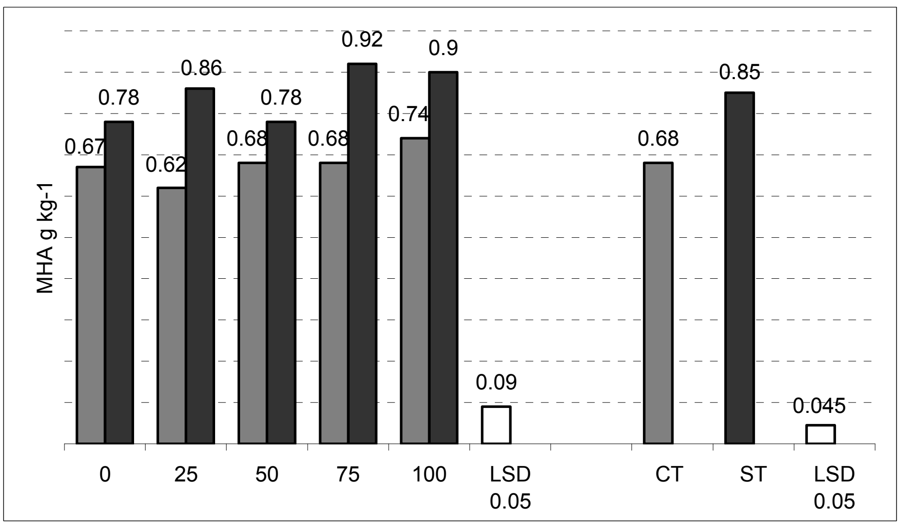

Figure 1. Effect of soil tillage systems and proportion of winter crops in the crop rotation on the MHA in 0−15 cm soil layer. CT-conventional tillage; ST-sustainable tillage.

Statistically significant topsoil increases in MHA were obtained in the crop rotation with 100% winter crops, compared with the rotation composed solely of spring crops. MHA was 3.0−6.0% of SOC using the conventional tillage, and 2.0 to 4.0% using sustainable tillage. While in the sustainable tillage MHA content (% in the soil) increased compared to conventional tillage, but in the sustainable tillage it seems that SOC content increased due to an accumulation of more stable SOC fractions.

Pastures, meadows and leys in Lithuania cover about 1 million hectares and account for over one third of the total agricultural land. Besides forest ecosystems, grassland ecosystems make up one of the largest areas in Lithuania, like in many European countries. Therefore these ecosystems are also extremely important from the environmental viewpoint and it is vital to know them. Nonetheless there are few researchers involved in this area, and particularly in the research into carbon accumulation and transformation processes. The data show, that the soil under long-lived swards after 5 years of cultivation was rich in SOC: in all soil layers 0−10, 10−20, 20−30 cm the SOC content had mean values of 15.1, 14.1 and 11.7 g kg^{-1}, respectively. Multi-component swards (throughout the 0−30 cm layer) tended to increase SOCs content more than mono-component swards (Table 2).

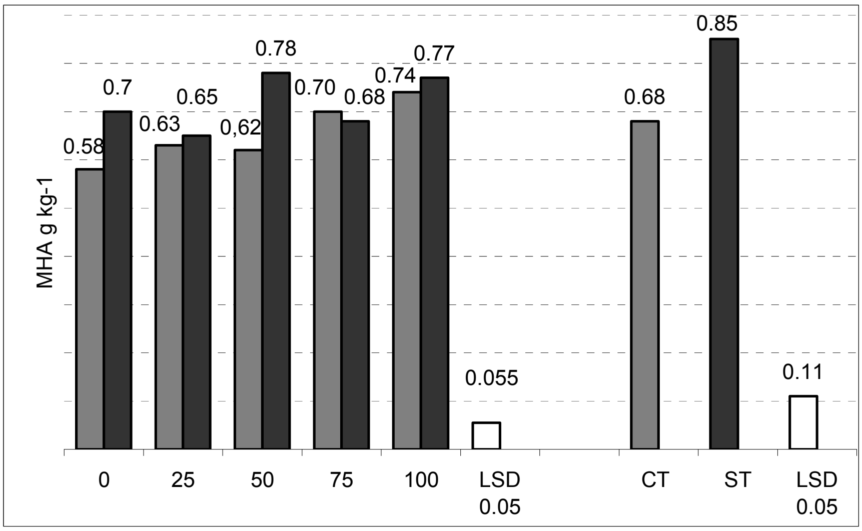

Figure 2. Effect of soil tillage systems and proportion of winter crops in the crop rotation on the MHA in 15−25cm soil layer. CT-conventional tillage; ST-sustainable tillage.

Table 2. The influence of grass species on the content of SOC (g kg^{-1}) in soil. Mean data from five year sward

Grass (factor A)	Soil depth (factor B) (cm)			Mean across all depths
	0−10	10−20	20−30	
Galega orientalis	14.4	14.2	11.5	13.4
Medicago sativa	15.1	13.8	12.1	13.7
Onobrychis viciifolia	15.3	13.9	12.1	13.8
Galega/Medicago/Festulolium	15.2	14.8	12.3	14.1
Galega/Onobrychis/Festulolium	15.0	14.5	11.3	13.6
Galega/Medicago/T. pratense /Festulolium	15.5	13.9	11.3	13.6
Galega/T. repens /Onobrychis/Festulolium	15.5	13.9	11.5	13.6
Mean across grasses	15.1	14.1	11.7	
LSD_{05}				
A	0.63			
B	0.37			
AB	1.16			

Notes: Galega orientalis 100%; 2. *Medicago sativa* 100%; 3.*Onobrychis viciifolia* 100%; 4. *Galega orientalis* 40%, *Medicago sativa* 40%, *Festulolium* 20%; 5. *Galega orientalis* 40%, *Onobrychis viciifolia* 40%, *Festulolium* 20%; 6. *Galega orientalis* 40%, *Medicago sativa* 20%, *Trifolium pratense* 20%, *Festulolium* 20%; 7. *Galega orientalis* 40%, *Trifolium repens* 20%, *Onobrychis viciifolia* 20%, *Festulolium* 20%.

MHA accumulation in the soil depended on swards and their mixtures' biological characteristics. The highest amount of MHA accumulated in the soil under four-component sward (Figure 3). The use of mono- and multi-component swards during the 5 year experimental period determined significant increases in MHA. Compared with the 2001 data, the content of MHA increased more than two-fold. In the four-component sward (*Galega/T. repens/Onobrychis/Festulolium)* the 0−30 cm soil layer had more MHA, compared with mono-sward (*Galega orientalis)*. MHA content in the 0−10 cm and 10−20 cm soil layer was 2.0 to 3.0% of the SOC, and the deeper layer (20−30 cm) only 2.0%. This reflects more intensive humification and SOM transformation processes occurring in the top layer of grassland soil.

At the Experiment 3 a trend was observed that a higher content of organic carbon was accumulated in the soil under frequently grazing of swards (Table 3).

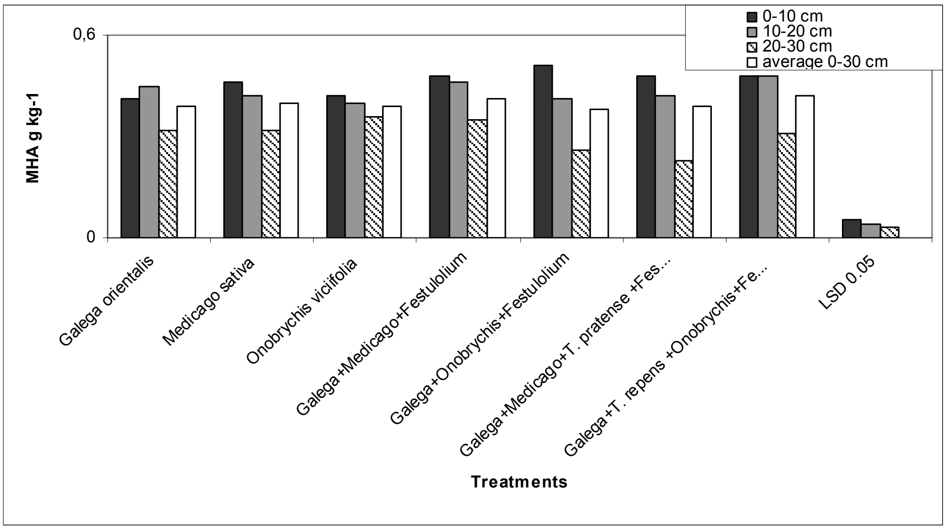

Figure 3. The effect of grass species on the MHA in different soil layers. Mean data from five year sward

1. Galega orientalis 100%; 2. *Medicago sativa* 100%; 3.*Onobrychis viciifolia* 100%; 4. *Galega orientalis* 40%, *Medicago sativa* 40%, *Festulolium* 20%; 5. *Galega orientalis* 40%, *Onobrychis viciifolia* 40%, *Festulolium* 20%; 6. *Galega orientalis* 40%, *Medicago sativa* 20%, *Trifolium pratense* 20%, *Festulolium* 20%; 7. *Galega orientalis* 40%, *Trifolium repens* 20%, *Onobrychis viciifolia* 20%, *Festulolium* 20%.

Table 3. Organic carbon accumulation in the soil under grazed swards, Akademija, 2002

Treatment	SOC g kg^{-1}	
	F	LF
Trifolium repens/Lolium perenne	19.8	17.7
Trifolium repens/Poa pratensis/Lolium perenne/	17.1	17.7
Medicago sativa/Poa pratensis/Lolium perenne/	18.0	17.8
Medicago sativa/ Trifolium repens/ Lolium perenne	19.1	18.5
Lolium perenne N_0	18.4	17.7
Lolium perenne N_{240}	17.4	17.0
Trifolium repens//Lolium perenne/Festuliolium	17.9	17.3

N_0 – without mineral fertilisers; N_{240} – fertilisation rate 240 kg ha^{-1}; F – grasses grazed frequently; LF – less frequently

Figure 4 shows that the highest MHA content in the soil accumulated under sward a mixture consisting of legume *Trifolium repens* and grasses grazed frequently (1.38– 1.47 g kg^{-1}) and in other investigated sward mixtures the opposite trends were determined. MHA content in the 0–25 cm soil layer was 6.0 to 8.0% of the SOC. This shows intensive humification and SOM transformation processes occurring in the top layer of soil under different F or LF grazed pasture swards.

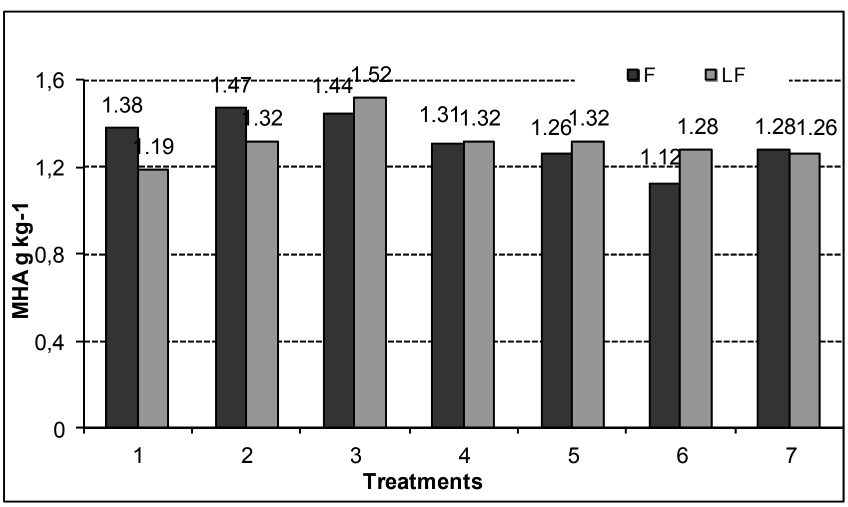

Figure 4. MHA accumulation in the 0−25 cm layer of different swards. F-frequent, LF-less frequent grazing.

1. Trifolium repens/Lolium perenne; 2. Trifolium repens/Poa pratensis/Lolium perenne; 3. Medicago sativa/Poa pratensis/Lolium perenne; 4. Medicago sativa/Trifolium repens/Lolium perenne; 5. Lolium perenne N_0; 6. Lolium perenne N_{240}; 7. Trifolium repens/Lolium perenne/festulolium

At the Experiment 4 long-term (40 years) grazing management of multi-component grass/legume/forbs swards maintained natural soil fertility and in the long run improved its quality parameters. The application of the inorganic PK fertiliser on the background of grazing had a strong and stable effect on the processes SOC and MHA accumulation in the soil (Table 4).

SOC content in the 0−10 cm layer was 3 times as high as that in the 20−30 cm layer. Yet, in the deep 30−50 cm layer relatively high contents of SOC were established and they were markedly higher than those in similarly managed soils under crop rotations. The MHA content in the soil (0−30 cm layer) applied with PK fertilisers increased by 8 % to twice (Figure 5). This reflects very intensive SOM transformation processes occurring in the long term pasture soil fertilized by inorganic PK.

Table 4. Distribution of SOC content in different layers of soil of the 40 year-old pasture

Treatment	Soil layer (cm)			
	0−10	10−20	20−30	30−50
	SOC g kg^{-1}			
P_0 K_0	28.8	15.4	9.74	3.49
P_{60} K_0	32.9	16.5	9.16	3.56
P_{60} K_{30}	34.3	17.7	10.2	3.91
P_{60} K_{60}	34.7	18.4	11.5	4.09
P_{60} K_{90}	35.7	19.3	12.4	4.28
LSD_{05}	2.70	1.98	2.72	1.33

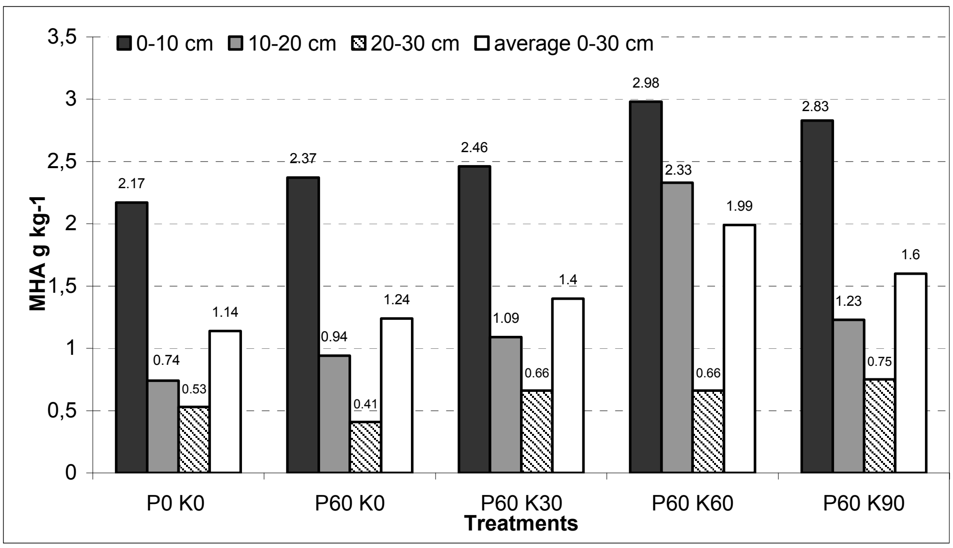

Figure 5. MHA content in different layers (0−10, 10−20, 20−30 cm) of soil in a long term (40 years) pasture

Discussion

Research results help to look slightly differently at the impact of sustainable soil management methods (grasses and sustainable tillage) on the accumulation of SOC and MHA. One of the major sources of SOC is plant residues, the highest content of which is left in the soil by perennial grasses, especially legumes (Paustian *et al.*, 1997). It was reported earlier, that a large amounts of pasture plant residues and roots were continually contributed to the soil, as well as the near to neutral soil reaction resulted in prevalent humification processes (Gutauskas, Slepetiene, 2000). The newly obtained data of our research show that the content of MHA in a long-term pasture soil depended on PK fertilisation level and increased most in the fertilisation treatment $P_{60}K_{60}$. The data show that the highest amount of SOC and MHA accumulated in the soil that had not been tilled for a long time, compared with arable soils. Although arable soils contain less SOC and MHA, the sustainable tillage applied on them promoted SOC and MHA accumulation. According to SOC and MHA content, the long-term (40 years) pasture soil stratified in different layers (0−10, 10−20 and 20−30 cm). When fertilised with PK up to $P_{60}K_{60}$, SOC content in the 0-10 cm layer was 1.8−2 times higher than in the 10−20 cm layer, and as many as 2.9−3.6 times as high as that in the 20−30 cm layer. MHA content in different soil layers differentiated even more: in the 0−10 cm layer it was up to 2.9 times higher than in the 10−20 cm, and as many as up to 4 times as high as that in the 20−30 cm layer. This shows that MHA more sensitively responds to soil use as pasture when fertilised with PK and eventually forms very active SOC and MHA-rich 0−10 cm top soil layer. MHA accumulation depended also on soil texture. The trial done on a heavy-textured clay loam soil showed the least MHA share compared with lighter-textured soils. MHA makes up a different part in SOC depending also on soil management practices. On the other hand, organic matter transformation processes are influenced by soil specific properties and its texture. Thus, higher content of clay particles in the soil increases MHA sorption and due to the interaction with the soil mineral part, SOM mobility declines which results in lower MHA relative share. Conversely, an increase of the share of fractions of mobile humic acids in the total organic carbon demonstrates a high SOM activity. Our findings on MHA supplement the data obtained by other researchers about the role of certain parts of SOC such as dissolved organic carbon, microbial biomass carbon, particulate organic carbon and others as indicators of changes in SOM pool. We found that MHA fraction in *Cambisol* can also be considered as one of the sensitive indicators of SOM changes in the agricultural environment.

Conclusions

Positive effect of grasses on the accumulation of SOC and MHA was determined. The highest SOC and MHA contents accumulated in the soil that had not been tilled for a long time, compared with arable soils. In grassland soil the SOC and MHA tented to accumulate in the topsoil. The long-term use (40 years) of swards as pastures increased SOC content in the 0−10 cm soil layer by as many as 2−2.5 times. The swards with legumes were found to promote SOC and MHA accumulation whose values depended on the composition of swards. In the four-component sward (*Galega/ Trifolium Repens/ Onobrychis/Festulolium)* the 0−30 cm soil layer had more MHS, compared with monosward (*Galega orientalis)*. A trend was observed that a higher content of organic carbon is accumulated in the soil under less frequent grazing of swards. The content of MHA depended on PK fertilisation level and increased most in the fertilisation treatment $P_{60}K_{60}$. MHA made up a different share in SOC depending on soil agricultural management as well as on the soil itself.

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