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SOIL CARBON, NITROGEN AND PHOSPHORUS DISTRIBUTION IN GRASSLAND SYSTEMS, IMPORTANT FOR LANDSCAPE AND ENVIRONMENT

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Abstract. The accumulation of organic carbon (SOC), nitrogen (N) and phosphorus (P) in the soils of protected areas and agrarian lands in Central Lithuania was assessed. Wood pasture is recognised as an important but now scarce element of the historic environment still evident in the current landscape. Soil pH was lower in the surviving wood pasture compared to the pasture under restoration, and pH of the old semi-natural pasture and organically grown legume sward soils was close to neutral. The highest SOC content was accumulated in the meadows of pre-mainland section of floodplain of the Nevėžis. It was more than 5 times as high as that in agrarian land grown with swards, and higher than that accumulated in semi-natural pasture and wood pasture. Soils of the protected areas of pre-mainland section were characterized by the largest amount of N. Soils of semi-natural pasture, affected by agricultural management, and meadows of pre-mainland section were found to be the highest in the total P content. Due to the differences in agricultural management, diverse plant communities are developing in the central section of floodplain of the middle reaches of the Nevėžis.

Keywords: landscape management**,** soil, soil organic carbon, nitrogen, phosphorus, soil pH, pasture, protected areas.

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Introduction

The establishment of the Natura 2000 Network is one of the main actions undertaken at the European level to contribute to the maintenance of biodiversity (Bartula *et al.* 2011). 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. Recognizing the extent of soil resources degradation and associated environmental and social risks in Europe, the European Commission proposed a Thematic Strategy for Soil Protection (EC 2006). In the Strategy, human activities, such as inadequate agricultural and forestry practices, tourism, urban and industrial sprawl and construction works are named as the main impacting factors that prevent the soil from performing its services to society and ecosystems on required levels.

The main functions of the soil – biomass production, biodiversity pool, source of raw materials, storing, filtering and transforming nutrients, substances and water, physical and cultural environment for humans, are directly dependent on carbon pool. Soil organic matter (SOM), of which the main constituent is soil organic carbon (SOC), has been increasingly considered as an indicator of soil quality, one of the components of biosphere sustainability and stability (Slepetiene, Slepetys 2005). SOM as well as SOC compounds play a vital role for soil organisms, their diversity, and plant nutrition. Moreover, they improve water regime, aggregate stability and decrease erosion. Carbon (C) plays a key role in the global C

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cycle – while about 8 Pg of anthropogenic C is emitted into the atmosphere, almost 2 Pg of C is sequestered in SOM annually (Lal 2004, 2011). This underlines the importance of SOM and SOC in relation to climate change. Contemporary agricultural development is increasingly focused on economical, effective, sustainable systems that allow reduction of use of various resources, protect the environment, maintain sustainable landscape, and provide safe and high quality food to consumers. Policy changes in European agriculture are now creating an environment that should encourage greater adoption of legume-based grazing systems. However, this represents a fundamental modification to forage-based systems of livestock production, necessitating a move towards greater extensification and more attention to the management of fodder resources and livestock in both time and space (Rochon *et al.* 2004). Land use affects the ability of surface soils to sequester organic carbon and their contribution to mitigation of the greenhouse effect.

Various publications suggest that land use affects SOC. The conversion of native ecosystems to agriculture almost invariably results in a net loss of soil C (Davidson, Jansens 2006; Smith 2008). Grassland soils present the richest biodiversity, before forests and cropped or urban lands. 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. SOC is the largest C reservoir in many terrestrial ecosystems including grasslands, savannas, boreal forests, tundra, some temperate forests, and cultivated systems, comprising as much as 98% of ecosystem C stocks in some systems (Smith 2004, 2008). Within 25–50 years the storage of C sequestration was 30–60 Pg (Jones, Donnelly 2004; Smith 2008). Grassland soils contain significant amounts of C because grasses transfer a large proportion of their products of photosynthesis belowground (Baker *et al.* 2007). Guo and Gifford (2002) demonstrated that conversion from crop to pasture leads to large increases in SOC of up to nearly 30%, although this was very dependent on soil depth, the topsoil being more active in sequestering C after land-use change. It was stated that the conversion of natural to agricultural ecosystems usually causes depletion of 50 to 75% of the previous soil carbon pool (http://ec.europa.eu/environment/soil/pdf). Within rural lands, soil biodiversity tends to decrease SOC with the increasing intensification of farming practices. However, not all soil management practices have a negative impact on soil biodiversity and related services. While in general, chemical treatments and tillage aimed at improving soil fertility trade off with soil carbon storage and decontamination services, in contrast mulching, composting and crop rotations all contribute to improved soil structure, water transfer and carbon storage.

Rapid land use changes are still occurring today, towards increased urbanisation and intensification of agriculture, but also towards forest growth. Soil biodiversity can only respond slowly to land-use changes, so that ecosystem services under the new land uses may remain sub-optimal for a long time (e.g. reduced decomposition of SOM). Land conversion from grassland or forest to cropland resulted in rapid loss of soil carbon, which indirectly enhances global warming. It may also reduce the water regulation capacity of soils and their ability to withstand pests and contamination. The current urbanisation and enlargement of cities creates cold spots of soil ecosystem services, and one of the challenges is to free soils in urban environments, for example by semi-opening pavement, green roofs and by avoiding excessive soil sealing and a much stronger focus on the reuse of land, e.g. abandoned industrial sites (brownfield development).

Sustained soil use, application of recommended soil management practices in agrarian lands can reduce CO_2 emissions into the atmosphere and can make a positive impact on the food safety, water and environment quality at the same time. Lithuanian researchers have extensively investigated the influence of tillage, fertilization and cultivation of various crops on SOM and humus (Slepetiene, Slepetys 2005; Marcinkonis 2007; Tripolskaja *et al.* 2012). Recently, more attention in research has been given to carbon compounds transformations in agricultural soils (Liaudanskienė *et al.* 2011). This is in line with the new trends in global research, since increasingly more investigations and quantitative determinations of carbon flows are performed in order to reduce the negative impact of human activity on the environment. The potential possibilities of agrarian land-use to mitigate climate change by carbon sequestration in soils was studied in the US (Morgan *et al.* 2009), and carbon compounds response to natural systems' use changes was investigated (Krull *et al.* 2003).

Agrarian and forest soils are comprehensively investigated in Lithuania, but there is no detailed comparison with the soils of protected areas (Lietuvos dirvožemiai 2001). Our research attempts to investigate and to compare the changes of carbon, nitrogen and phosphorus, the main elements of organic matter, in different natural ecosystems. Consequently, the obtained data are important theoretically, and can be practically applied in the scientific evaluation of both carbon sequestration and soil quality.

The objective of this research is to determine soil organic carbon, nitrogen, and phosphorus quantities and their ratios in the EU protected areas and agrarian lands covered with grasses in Central Lithuania.

1. Materials and methods

1.1. Details of experimental site and soil sampling

The soils of EU protected areas (Natura 2000) and Krekenava regional park (reserve of middle reaches of the Nevėžis), and also agrarian lands overgrown with grasses were investigated in this research. A detailed description is given in Table 1. Soil samples of protected areas and agricultural soils were collected in 2012 from the 0–10, 10–20 and 20–30 cm depths with 6 boreholes per replicated plot. Three replicates of protected areas and agricultural soils were investigated, and 72 representative soil samples were taken in selected areas. The vegetation was recorded using the Braun-Blanquet scale (1964). Plant communities were evaluated according to the national classification (Balevičienė *et al.* 1998). Latin names of plants are provided in accordance with botanical names' digest (Gudžinskas 1999).

EU's network of protected areas Natura 2000 was developed to preserve and restore habitats of European importance under natural habitats, wild flora and fauna Directive 92/43/EEC. One of these habitats is Fenoscandian wooded pastures 9070, which are rapidly disappearing throughout Lithuania. Forests with fragments of natural meadows in Klamputė area are in the C XI Nevėžis moraine plain according to physical geographical classification of Lithuania, and occupy an area of 12 hectares. According to the current state, the wood pasture area was divided into northern and southern parts. The southern part of the area has preserved the vegetation structure and species composition typical of the Fennoscandian wood pastures. Single old oaks (*Quercus robur* L.), large hawthorn (*Crategus sp*.) shrubs, including intrusive herbaceous plant communities grow there. The northern part of the area is overgrown with a dense forest, which has replaced the previous Fennoscandian wood pastures. The meadow herbaceous plants have been superseded by the species inherent to forest plant communities. The fact that this area has been used as a pasture before can be judged by the deployment of the isolated old trees (*Quercus robur* L.*, Tilia cordata* Mill.*, Fraxinus exelsior* L.*).* Tree crowns were matted, and growing stock closeness was 95% against the clearance. *Picea abies* (L., H. Karst) is quite widespread here. Plants specific to acidic soils and tolerant of shade can grow in this area. These are *Oxalis acetosella* L.*,* mosses *Eurhynchium angustirete* (Broth., T. J. Kop.), *Pleurozium schreberi* (Brid, Mitt), and others, calcium-loving plants are almost nonexistent. It will be interesting to observe the changes taking place in vegetation and soil pH after introduction of livestock grazing in the area, since young trees and firs non-specific to Fenoscandian wood pasture habitats have been cut down. Only old trees were left, mostly *Quercus robur* L., *Fraxinus excelsior* L., *Ulmus minor* Mill, *Tilia cordata* Mill.

It is likely that due to the soil properties and other edaphic conditions, *Quercus robur* L., *Malus sylvestris* (L.) Mill and old shrubs have survived in the northern part of Klamputė: *Crategus rhipidophylla* a Gand, *Coryllus avelana* L. and *Euonymus europeus* L. The coverage with trees and shrubs accounted for 40% before the start of wood pasture restoration. Meadow flora was abundant in the glades with many herbaceous plant species, including *Prunella vulgaris L., Ranunculus polyanthemos L., Succisa pratensis Moench, Veronica chamaedrys L., V.officinalis L., Alchemilla* sp, *Dactylis glomerata* L., *Geum rivale* L., *Agrostis capillaris* L., *Agrimonia euatoria* L., *Galium boreale* L., *G. molugo* L., *G. album* Mill., *Phleum pratense* L. var. *nodossum*, *Pimpinella major* (L.) Huds, *Filipendula vulgaris* Moench, *Briza media* L, *Trifolium montanum* L. A total of 69 were species growing in meadows (Table 1).

The sward in Valinava pasture was sown in 1946. The pasture sward was not renewed up to present day in the paddock occupying area of 2.1 ha where the soil samples were taken. This is one of the oldest pastures in Lithuania. Currently there is formed medium early sward with white clover. This sward contains little addition of early maturity grass *Alopecurus pratensis.* For many years the sward has been used for grazing and forage, but currently, since the cattle for pasturing is no longer, this sward is only cut for silage making.

Fodder galega is grown in ecological crop rotation, in certified area. Estonian variety '*Gale*' was sown at a seed rate of 30 kg ha^{-1} with a cover crop of spring barley in 2001. Fodder galega did not receive any fertilization, and no chemicals were used. During the first 5 years when crop was used for forage, fodder galega was cut two times per season: the first cut of galega was taken at the beginning of mass flowering (end of May–beginning of June), and the second cut was taken at the end of vegetation (end of October). Over the last 7 years galega crop occupying area of 1.1 ha is used for seed.

The landscape reserve of the middle reaches of the Nevėžis, occupying area of 366 ha, is part of Krekenava Regional Park, and is already included in the list Natura 2000. The soil samples were taken in four representative places in the alluvial grassland with an area of 4.2 ha near Dembava, Panevėžys district. This is representative alluvial grassland with clearly expressed riverside, central and pre-mainland sections. The vegetation typical for natural grassland is survived here. We attempted to relate soil chemical parameters to the flora and vegetation composition in our investigation. The Cl. *Molinio-Arrhenatheretea elatioris* R. Tx. 1937 and Ass. *Molinietum caeruleae* W. Koch 1926 communities (*Molinia coerulea* (L.) Moench, *Selinum carvifolia* (L.) L., *Inula salicina* L., *Potentilla erecta* (L.) Raeusch., *Ophioglossum vulgatum* L. (Table 1) were formed in the lower part of pre-mainland section, where one soil sample was taken. Two soil samples were taken in the central section of floodplain of Nevėžis. Water floods the central section of the floodplain irregularly. The following steppe grassland communities have formed there: Cl. *Festuco-Brometea erecti* ass. *Pulsatillo-Phleetum phleoidis* Passarge 1959 (Balevičienė *et al.* 1998). These communities are more common in warm areas and calcareous soils. A community with a similar species composition is being formed in the former arable land. The soil pH in the respective soil layers, in both meadow and former arable land was very similar due to deep ploughing of the light textured soil. Steppe grasslands begin to form, *Phleum phleoides* (L.) H. Karst and tansy *Tanacetum vulgare* L. overgrowths predominate

Table 1. Site characteristics, Central Lithuania, 2012

Site	Soil	Vegetation type
Protected area of Natura 2000, Klamputė, Kėdainiai district		
– surviving wood pasture, the southern part (55°17′39.85″N, 23°53′18.37″E; the altitude of the site is 53 m above sea level)	Endocalcari-Endohypergleyic Cambisols	The typical structure and species composition of Fennoscandian wooded pastures 9070 has survived: Quercus robur L., Fraxinus excelsior L., Tilia cordata Mill, Prunella vulgaris L., Ranunculus polyanthemos L., Succisa pratensis Moench, Veronica chamaedrys L., V.officinalis L.
– wood pasture under restoration, the northern part (55°17′42.16″N, 23°53′20.80″E; the altitude of the site is 53 m above sea level)	Endocalcari-Endohypergleyic Cambisols	The mixed forest vegetation had established before clearing. Few meadow plant species have survived. Tree crowns were matted and closeness of trees reached 95%. Picea abies species was abundant here.
Old semi-natural Valinava pasture, Kėdainiai district. The study was conducted in an experimental plot established in a 66-year-old pasture used since 1946. (55°22′48.66″N, 23°51′58.42″E; the altitude of the site is 60 m above sea level)	Endocalcari-Endohypogleyic Cambisols	Currently predominant species: Festuca rubra L., Dactylis glomerata L., Phleum pratensis L., Alopecurus pratensis L., Elytrigija repens (L.) Desv. Ex Nevski, Taraxachum officinale F. H. Wigg., etc.
Sown long-lived sward, Akademija, Kėdainiai district. Fodder galega was sown in organic crop rotation in 2001. (55°23′57.15″N, 23°51′54.69″E; the altitude of the site is 64 m above sea level)	Endocalcari-Endohypogleyic Cambisols	Although pure galega was initially sown, Dactylis glomerata, Festuca pratensis Huds., Taraxachum officinale have become established
Protected area of middle reaches of the Nevėžis, the floodplain near Dembava, Panevėžys district. This part of Krekenava Regional park is already included in the list Natura 2000		
– pre-mainland section (55°29′01.63″N, 24°03′25.05″E; the altitude of the site is 31 m above sea level)	Fluvi-Eutric Fluvisols	Molinia meadows 6410 were formed on calcareous, peaty or clayey silt-laden soil (Molinion caeruleae) with typical flora: Molinia coerulea (L.) Moench, Selinum carvifolia (L.) L., Inula salicina L., Potentilla erecta (L.) Raeusch., Ophioglossum vulgatum L.
– central section, meadow (55°28′59.43″N, 24°03′28.54″E; the altitude of the site is 31 m above sea level)	Endohypogleyi-Eutric Fluvisols	Formed semi-natural dry grasslands 6210 and scrubland facies on calcareous substrates (Festuco-Brometalia) with typical species Fragaria viridis Duchesne, Filipendula vulgaris Moench, Medicago falcata L.
– central section, former arable land (55°28′59.43″N, 24°03′28.54″E; the altitude of the site is 31 m above sea level)	Endohypogleyi-Eutric Fluvisols	Steppe grasslands begin to form and there is only narrow spectrum of the species typical of them. Almost mono-dominant overgrowths of Phleum phleoides (L.) H. Karst., Tanacetum vulgare L. predominated, and only single indicators of the following grasslands are observed. Neophyte, such as Oenothera biennis L. rubricaulis Klebe, Silene tatarica (L.) Pers. etc settled.
– riverside section (55°28′57.65″N, 24°03′37.59″E; the altitude of the site is 31 m above sea level)	Endohypogleyi-Eutric Fluvisols	Semi-natural dry grasslands 6210 and scrubland facies are forming on calcareous substrates (Festuco-Brometalia) with typical species Fragaria viridis Duchesne, Filipendula vulgaris Moench, Medicago falcata L. Unlike in central part, species specific to sands occur here: Sedum acre L., Festuca trachyphyla (Hack.) Krajina, Thymus pulegioides L.

there. Neophytes such as *Oenothera biennis* L., *rubricaulis Kleb*., and *Silene tatarica* (L.) Pers., etc. become established. The plant communities of sands previously prevailed in the riverside section, but the steppe grassland vegetation has already formed there. Only some species from the former sands' vegetation have survived: *Festuca trachyphylla* (Hack.) *Krajina*, *Thymus pulegioides, Sedum acre* L.

1.2. Analytical methods

All samples were air-dried, visible roots and plant residues were removed manually. Then the samples were crushed, sieved through a 2-mm sieve and homogeneously mixed. For the analyses of soil C, N and P an aliquot of the soil samples was passed through a 0.25-mm sieve. Soil pH was determined in 1 N KCl (soil – solution ratio 1:2.5) using a pH-meter *IONLAB*. SOC content was determined using the Tyurin method modified by Nikitin (Nikitin 1999; Liaudanskienė 2009). This modified method of wet combustion with photometric determination measures organic carbon content according to the potassium dichromate approach using combustion at 160 °C for 30 min. The measurements were performed using the spectrophotometer *Cary 50* (*Varian)* equipped with software, and glucose as a standard at the wavelength of 590 nm. Soil total nitrogen (N) was determined by the Kjeldhal method with photometric measure procedure at the wavelength of 655 nm. Soil total phosphorus (P) content was determined by photometric procedure at the wavelength of 430 nm using the spectrophotometer *Cary 50* (*Varian)* after wet digestion procedure with sulphuric acid.

1.3. Statistical analyses

Experimental data of each variable ($n = 3$) were processed ($P < 0.05$) by the statistical programme *STAT ENG* (Tarakanovas, Raudonius 2003).

2. Results and discussion

Lithuanian agrarian landscape is the consequence of the former forested landscape, which for thousands of years has been cultivated and used for agricultural purposes, particularly for grazing and haymaking. The archaic agricultural period covered a much longer history period than the current time of the modern land-use. Forested pastures and wooded meadows are habitats which significantly decreased or almost disappeared. The patches of these habitats, once numerous in Lithuania, have survived in the central part of the Kėdainiai district, in moraine plain landscape. This area falls within local Smilga and Smilgaitis landscape Reserve. The following area of EU importance was identified as protected habitats Fennoscandian wooded pastures 9070. This type of habitats remind of very distant past, even before the emergence of agriculture and livestock production they existed supported by herds of large wild herbivores – bisons, nobles, tarpans. Later these pastures became prevalent when people started to extensively graze their livestock in the forests and their edges. After World War II, the wooded pastures were rapidly disappearing because of the ban on grazing in forests and land large-scale land reclamation. These wood pastures overgrew with forest and the former diversity of pasture vegetation declined.

Forests with fragments of natural meadows in Klamputė area are in the C XI Nevėžis moraine plain according to physical geographical classification of Lithuania. The current Klamputė forest area was previously wood pasture. Due to the changes in farming methods the community successions take place, and forest communities are formed from the wood pastures (Table 1). This type of habitat has recently become extremely rare in Lithuania. One of the tasks of nature protection is to preserve these pastures, and to restore the abandoned ones. Klamputė is one of the areas where restoration of habitats is being carried out. Klamputė area is included in the wood pastures remediation plan because its individual fragments corresponded to the structure inherent to this habitat. In 2011, restoration of the habitat in Klamputė area was launched. Young trees and those non-specifics to the habitat were cut down during the winter. The grass was mown in 2012. It is planned to acquire cattle which will be grazed on the restored wood pastures in the future. Restoration success will depend on their rational use. The Dubysa Regional park administration is in charge of the restoration work of Klamputė wood pasture habitat. Soil composition has not been studied until now therefore it is very important research object.

The assessment of soil chemical composition and the investigation of condition of protected and newly formed areas, unique in historical and natural approach, are very important. In Lithuania, like in other countries, there is little research on the preservation processes of organic carbon, the key element of organic matter, and other macronutrients in differently-aged protected areas and no comparison with agrarian land. Soil pH is often hypothesized to be a major factor regulating organic matter turnover and inorganic nitrogen production in agricultural soils (Kemmitt *et al.* 2006; Prach *et al.* 2007). Forest soils are more acidic than the analogous arable soils. For example, it was reported by Paripovic (2011), which in the two study areas the pH values in the pine forest ranged from 4.5 to 5.8. In only two measurements exceeded pH 6, which was in 2 and 3 year-old pastures converted from pine forest at the Tokoroa study area. In our research, we established that soil pH values in the surviving wood pasture were higher compared to those in wood pasture under restoration, in the 0–10, 10–20 and 20–30 cm soil layers they were 5.91, 5.82, 6.53 and 5.02, 4.93, 5.39, respectively (Fig. 1).

The acidity of the soil layer 20–30 cm of surviving wood pasture was low. It is therefore evident that soil pH enabled the wood pasture habitat to persist longer in the northern part of the area. Most of the plants growing there are calcium-loving. The forest ecosystem became established more rapidly in the northern part of the area with a lower pH value, especially after spruces began to grow, because spruce needle debris tends to acidify the soil. Soil acidification created conducive conditions to shade-loving plants. In both surviving wood pastures and those under restoration, the trend in distribution of pH values in different soil layers was similar; however, they differed in values. The soil of wood pastures under restoration is acidic (pH = 4.93–5.39) and more typical of forest. The soil in the old semi-natural Valinava pasture in the 0–30 cm layer was close to neutral. The pH of grassland and arable soil ranges from 5.8 to 5.9 and from 6.8 to 6.9 respectively, and is suitable for growing grasses and legumes and other agricultural plants. Soil pH differences between individual soil layers are not considerable there. The floodplain meadows of protected area of the middle reaches of the Nevėžis differ in acidity, which increases from pre-mainland to riverside section. A lot of silt is bank up from the slopes to the pre-mainland section due to erosion, and the lightest silt particles settled here. Moreover, the pre-mainland section of river floodplain is often springy. Eventually, the process of neutral or weakly acidic peat formation can begin due to an excess humidity (Lietuvos dirvožemiai 2001). In the past it was arable land in the belt of central section, where natural Cl. *Festuco-Brometea erecti* are formed now. The soil of natural meadow is slightly more acid than that of former arable land there. A negligible influence of ploughing is observed, since the differences between pH values in the 0–10 and 10–20 cm soil layers of the former plough layer reduced compared with the former untilled meadow. The riverside section is from several to several tens of meters in width. Heavy coarse sediments as leaching sand and sandy loam settle here, and thus the riverside rise formed. The following sands have a little of light silt particles, they do not have calcareous layer, so they are more acidic (pH = 5.19–5.67) than that of central section. The riverside section is the highest compared with the river surface, sand and fine gravel dominate in the soil. It is flooded only in certain years. The soil is quickly-drying, and the topsoil layer is quite acidic, which creates favourable conditions for nutrients leaching. The former sand meadows in the riverside section are now overgrown with vegetation typical of steppe meadows, because the riverside section is hardly ever flooded, and sand does not accumulate here. Sand vegetation may form after the high floods. The indicator species of steppe meadows can become established because the pH values are lower in deeper soil layers and there is no competition with plants requiring more fertile soils. The vegetation of riverside section is poorer not only due to increased soil acidity and aridity, but also due to light soil texture resulting from historical formation of Nevėžis floodplain. Therefore psamophytes are more common here (Table 1).

Results of laboratory analyses showed that quantity of SOC, the basic element of soil organic matter, accumulated in soils of protected areas and agricultural lands was very different (Fig. 2).

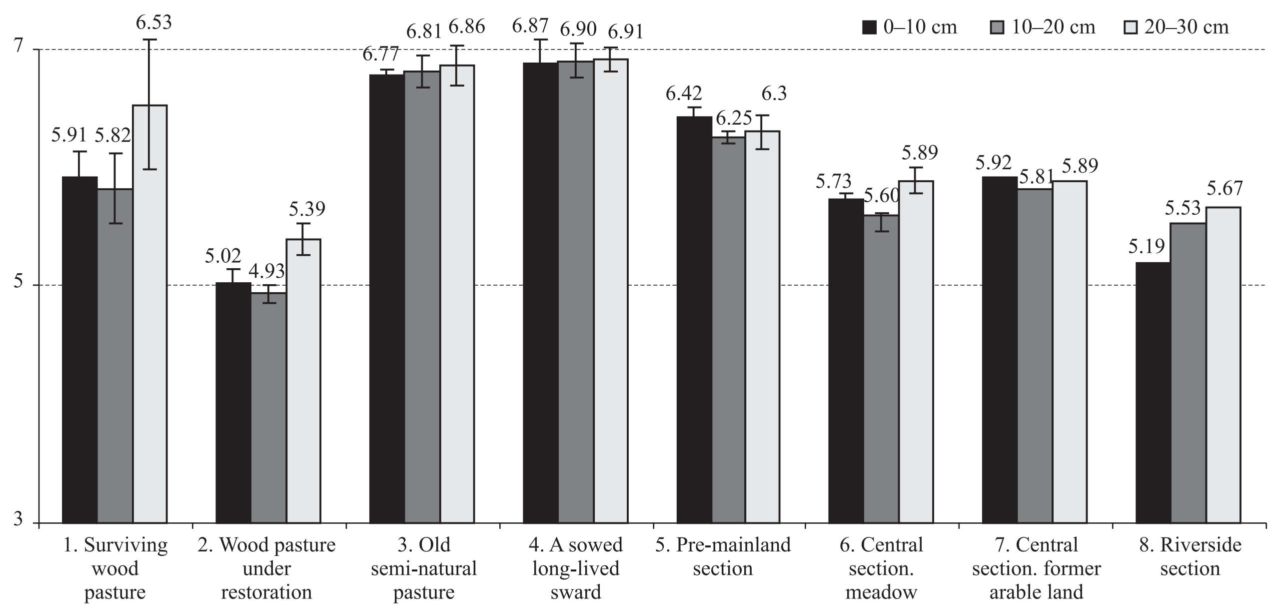

Fig. 1. The pH values in different layers of soil (0–10, 10–20 and 20–30 cm), 2012
Note: vertical bars indicate standard error of means, $n = 3$.

The largest amounts of SOC were accumulated in the soils of meadows of pre-mainland section. The peat-formation processes had already started here, and SOC content was more than 5-fold higher than that in arable land and also higher compared with long-lived systems of Valinava semi-natural pasture and wood pasture. The SOC content in surface soil layer of pre-mainland section is 8.31%, in the 10–20 cm layer 4.72%, and in the 20–30 cm layer – 1.79% of SOC. Many findings suggest that conversion from forest to pasture is followed by decreased SOM in the soil (Parfitt *et al.* 2003; de Oliveira *et al.* 2008; Steffens *et al.* 2008). However, some findings showed a significant increase in soil organic matter in the first 5 years after conversion from plantation forest to dairy pasture (Hedley *et al.* 2009). In our research, the SOC content in the soil of agricultural land (*Galega orientalis* Lam.) was 1.65% in the 0–10 cm layer, 1.26% in the 10–20 cm and 0.99% in the 20–30 cm soil layer.

Table 2 shows that grassland soils of pre-mainland section of middle reaches of the Nevėžis were characterized by the largest amount of nitrogen in the 0–10 cm layer – 5.76, 10–20 cm – 4.05, and in 20–30 cm layer 2.13 g kg^{-1} compared to old Valinava pasture: 3.53, 2.32 and 1.35 g kg^{-1} respectively. Semi-natural Valinava pasture, affected by grazing livestock manure and mineral fertilizers, as well as pre-mainland section of middle reaches of the Nevėžis were found to be richest in the total phosphorus content: 0.67, 0.54 and 0.42 g kg^{-1} . Such accumulation of both elements in Valinava pasture resulted from soil management for agricultural purposes livestock grazing (manure) and mineral fertilizer application.

The C/N ratio is an important indicator of soil quality and microbial activity. This ratio of agricultural soils in Lithuania usually ranges from 12 to 14; however it may decrease up to 4 depending on the land-use (Marcinkonis 2007). The C/N ratio of the organic residues added to the soil influences the rate of organic matter decomposition and these results in the release (mineralization) or immobilization of soil nitrogen. In our research, the C/N ratio of soil varied from 7.6 (the central section meadow 20–30 cm soil layer) up to 14.6 (Klamputė wood pasture upper 0–10 cm soil layer). The C/P ratio was much higher compared to C/N ratio, and varied from 21.2–22.0 (the central section 20–30 cm soil layer) up to 124.3 (the pre-mainland section upper 0–10 cm soil layer).

The determination of SOC, nitrogen, phosphorus amounts and their relationships is important for sustainable use of soil, conservation of landscape resources and surface water, as well as assessment of climate impacts.

Conclusions

Scientifically valuable tendencies in the soils of wood pasture recognised as an important but now scarce element of the historic environment as well as protected areas of Natura 2000 and long-lived grassland systems were determined in this research. The new data obtained in the experiment can be used for the soil carbon and other macronutrients stock inventories, as well as prediction opportunities for soil conservation, sustainability, and protection against degradation.

1. The data show that soil pH values of the surviving wood pasture is higher than that of the wood pasture

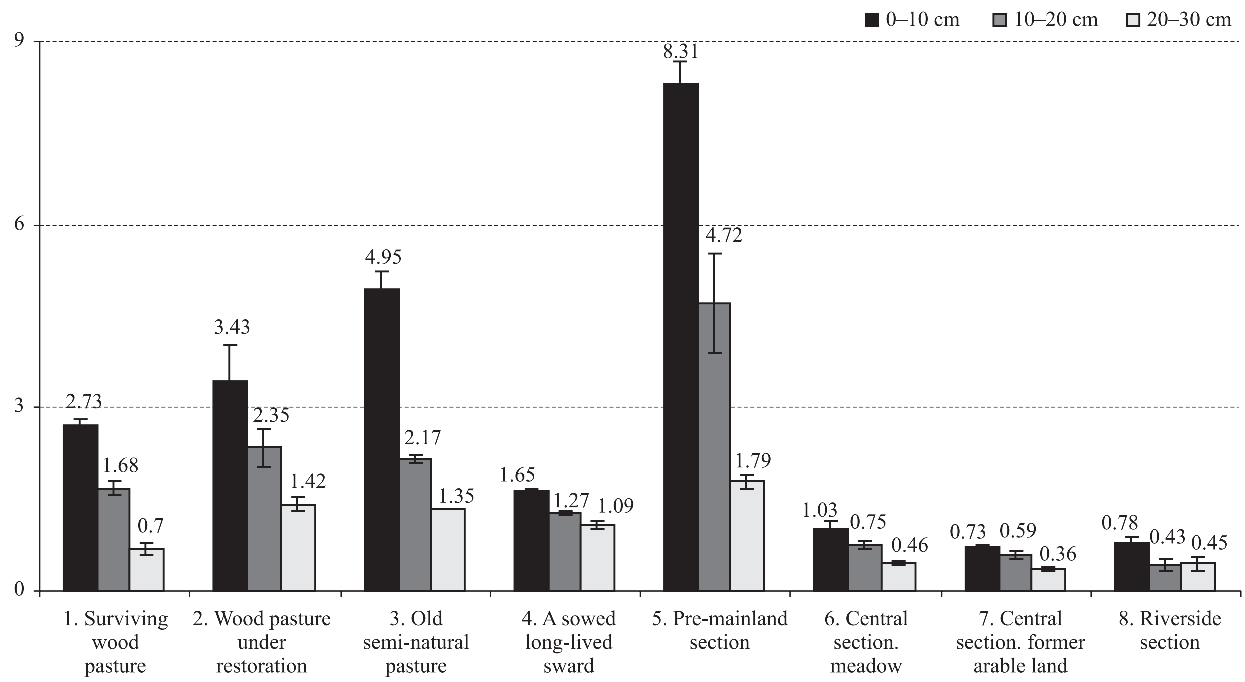

Fig. 2. SOC content (%) in different layers of soil (0–10, 10–20 and 20–30 cm), 2012
Note: vertical bars indicate standard error of means, $n = 3$.

Table 2. The soil variables of protected areas and agricultural lands, 2012

Site description	Soil layer, cm	N (g kg^{-1})	P (g kg^{-1})	C/N	C/P
Protected area of Natura 2000, Klamputė, Kėdainiai district					
– surviving wood pasture, southern part	0–10	2.58±0.18	0.46±0.03	10.6	59.5
	10–20	1.76±0.15	0.41±0.04	9.6	40.9
	20–30	0.82±0.06	0.35±0.03	8.4	19.8
–wood pasture under restoration, northern part	0–10	2.34±0.12	0.35±0.03	14.6	102.7
	10–20	1.67±0.25	0.32±0.03	14.5	75.1
	20–30	1.24±0.07	0.29±0.02	11.4	49.4
Old semi-natural pasture Valinava	0–10	3.53±0.20	0.67±0.03	14.0	73.8
	10–20	2.32±0.04	0.54±0.02	9.4	40.0
	20–30	1.35±0.06	0.42±0.01	10.5	32.2
Sown long-lived sward of Galega orientalis Lam	0–10	1.69±0.01	0.43±0.03	9.7	38.7
	10–20	1.37±0.06	0.39±0.02	9.2	32.9
	20–30	1.13±0.08	0.38±0.03	9.7	28.8
Protected area of middle reaches of the Nevėžis, the floodplain near Dembava, Panevėžys district. This part of Krekenava Regional park is already included in the list of Natura 2000					
– pre-mainland section	0–10	5.76±0.38	0.67±0.05	14.3	124.3
	10–20	4.05±0.54	0.58±0.06	11.5	80.8
	20–30	2.13±0.27	0.48±0.05	8.6	37.2
– central section, meadow	0–10	1.14±0.07	0.32±0.01	9.1	32.9
	10–20	0.85±0.02	0.28±0.01	8.8	29.0
	20–30	0.62±0.04	0.23±0.02	7.6	21.2
– central section, former arable land	0–10	0.75±0.04	0.23±0.02	9.7	31.2
	10–20	0.62±0.03	0.20±0.01	9.5	29.8
	20–30	0.44±0.02	0.17±0.01	8.3	22.0
– riverside section	0–10	0.78±0.08	0.18±0.02	10.0	44.4
	10–20	0.48±0.07	0.17±0.01	8.7	25.0
	20–30	0.49±0.08	0.20±0.01	8.8	22.4

under restoration, in the 0–10, 10–20 and 20–30 cm soil layers it was 5.91, 5.82, 6.53 and 5.02, 4.93, 5.39, respectively. The soil pH of the Valinava semi-natural pasture (66 y. old) was close to neutral. Similar pH values were in the soil of organically grown legume sward *Galega orientalis* Lam.

2. In the pre-mainland section of middle reaches of the Nevėžis the SOC content was more than 5-fold higher than that in arable land and also higher compared with long-lived systems of Valinava semi-natural pasture and wood pasture Klampute.

3. Grassland soils of pre-mainland section of middle reaches of the Nevėžis were characterized by the largest amount of nitrogen in the 0–10 cm layer 5.76, in the 10–20 cm layer 4.05, and in the 20–30 cm layer 2.13 g kg^{-1} compared to the old pasture Valinava: 3.53, 2.32 and 1.35 g kg^{-1} , respectively. Semi-natural pasture Valinava, affected by manure from grazing livestock and mineral fertilizers, as well as pre-mainland section of middle reaches of the Nevėžis were found to be richest in the total phosphorus content. The nitrogen content in the soil of organically grown sward *Galega orientalis* Lam. increased due to nitrogen fixation by legumes; despite the fact that neither mineral nor organic nitrogen fertilisers were applied.

4. The soil of surviving wood pasture was richer in nitrogen and had a narrower C/N and C/P ratio than wood pasture under restoration. The C/N and C/P ratios were much higher in the 0–10 cm soil layer of the pre-mainland section suggesting that the soil of this section is more resistant to mineralization processes as compared to other treatments of the middle reaches of the Nevėžis.

5. Although diverse plant communities are developing in the central section of the middle reaches of Nevėžis due to the differences in agricultural management, some soil chemical characteristics slightly differ.

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