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IMPACT OF AGRO-ENVIRONMENTAL SYSTEMS ON SOIL EROSION PROCESSES AND SOIL PROPERTIES ON HILLY LANDSCAPE IN WESTERN LITHUANIA

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Abstract. The objective of this study was to evaluate the impact of different land use systems on soil erosion rates, surface evolution processes and physico-chemical properties on a moraine hilly topography in Lithuania. The soil of the experimental site is Bathihypogleyi – Eutric Albeluvisols (ABe–gld–w) whose texture is a sandy loam. After a 27-year use of different land conservation systems, three critical slope segments (slightly eroded, active erosion and accumulation) were formed. Soil physical properties of the soil texture and particle sizes distribution were examined. Chemical properties analysed for were soil pH, available phosphorus (P) and potassium (K), soil organic carbon (SOC) and total nitrogen (N). We estimated the variation in thickness of the soil Ap horizon and soil physico-chemical properties prone to a sustained erosion process. During the study period (2010–2012) water erosion occurred under the grain–grass and grass–grain crop rotations, at rates of 1.38 and 0.11 m^3 ha^{-1} yr^{-1}, respectively. Soil exhumed due to erosion from elevated positions accumulated in the slope bottom. As a result, topographic transfiguration of hills and changes in soil properties occurred. However, the accumulation segments of slopes had significantly higher silt/clay ratios and SOC content. In the active erosion segments a lighter soil texture and lower soil pH were recorded. Only long-term grassland completely stopped soil erosion effects; therefore geomorphologic change and degradation of hills was estimated there as minimal.

Keywords: erosion processes, hilly landscape, long–term land use, crop rotations, transects, slope segments, soil losses.

Introduction

Soil erosion is a natural process, but its rate has been increased by human activities. Soil erosion is one of the most relevant agro-environmental processes in slope areas. In the EU, over 150 million hectares of soil are affected by erosion (Bucur *et al.* 2011) and implementation of appropriate measures at the European scale has been estimated to cost ~€9.3 billion per year (Kuhlmann *et al.* 2010). Unfortunately, until recently soil conservation in Europe has generally not received sufficient attention (Boardman, Evans 2006).

Numerous studies have shown that many soil properties are related to slope gradient and to the particular position of soil on slopes (Birkeland 1984; Zirlewagen, von Wilpert 2010). Conacher and Dalrymple (1977) discussed soil-slope relations in considerable detail and proposed a nine-unit landsurface model based on process and response. They found strong relationships between the spatial distribution of soils and topography. They also assumed that summits are a point of maximum erosion. However, it is sufficient to use a simple five-unit (i.e. summit, shoulder, backslope, toeslope and footslope) model based on slope form, because in reality not all hillslope elements necessarily exist along any given hillslope (Birkeland 1984; Thompson *et al.* 2012).

Olson *et al.* (2002) and Jankauskas (2012) indicated that soil erosion causes irreversible processes in chemical properties of soil along hillslopes by thinning the Ap thickness. The major expenses related to soil erosion in a farm are from the soil nutrients, productivity and quality restoration (Bucur *et al.* 2011; Lal 2001). Erosion has a marked impact on soil physico-chemical properties (Maetens *et al.* 2012; Cerdan *et al.* 2010; Šurda *et al.* 2007) and increase a cost of soil conservation measures in agricultural areas characterised by hilly topography (Leyva *et al.* 2007).

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Vegetation cover reduces runoff and nutrient losses (Morgan 2007). In addition, generic soil quality under vegetative cover is improved with a larger amount of plant roots reinforcing the soil body to resist to erosion and nutrients leaching (Kinderienė *et al.* 2013). Several studies have indicated that application of suitable cropping systems (crop rotations) significant mitigates land degradation in sloping areas (Jankauskas 2012; Cerdan *et al.* 2010).

Soil erosion on the hilly agricultural landscape is a complex phenomenon, involving land degradation in Lithuania (Jankauskas 2012). Soil erosion is the most intensive factor of Lithuanian relief transformation, given that the estimated volume of all deposits re-deposited by erosion reaches 47.6 million m^3 sediments per year (Česnulevičius 2011). The depth of denudation reaches ≤0.5 mm^{-1} yr^{-1} (Česnulevičius 2011), thus in conformity with Dėnas *et al.* (2006) varies from 0.12–3.5 mm^{-1} yr^{-1}, with maximum values in uplands and river valleys, respectively. The main problems requiring agro-environmental land management measures in Lithuanian uplands are the degradation degree of fields by erosion, deterioration of soil structure and compaction. Seventeen per cent of Lithuania's agricultural land is eroded with levels of ≤43–58% in hilly regions (Lietuvos dirvožemiai 2001). Surface runoff generation and soil erosion in the Žemaičiai Uplands mostly depend on the erodible glacial parent material, precipitation intensity, land use and cover condition.

The aim of investigations is to study the long–term land use impact of soil erosion in several slope positions, surface evolution processes and soil properties in different agro–environmental systems located on hilly landscape in Western Lithuania.

1. Material and methods

1.1. Study site

The erodible ground moraine material, abundance and intensity of precipitation have created favourable natural conditions for erosion of parent materials by water in the Žemaičiai Uplands (Kudaba 1983). Sandy clay loams and sandy loams Gleyic Albeluvisols and Luvisols prevail in the upland (Lietuvos dirvožemiai 2001). The mean and maximum elevations in the Žemaičiai Uplands are 119.0 and 234.6 m a.s.l., respectively. The topography of Kaltinėnai catchment area consists of large and steeply dissected hills (≥8–12°) where the average slope length is ≥100 m (Lietuvos dirvožemiai 2001). Major crops cultivated in the catchments are wheat, barley and oats with mean annual yields of 3.75, 4.27 and 2.0 t^{-1} ha^{-1} y^{-1}, respectively.

The Lithuanian climate is conducive to the occurrence of water erosion (Jankauskas 2012). Based on 52-year cumulative precipitation data from the nearest meteorological station based in Laukuva (55°61′N, 22°23′E, 166 m a.s.l.), annual precipitation is estimated to be 837 mm, with summer and autumn dominance. Mean annual precipitation in the area during the study period was 831–966 mm. The mean annual air temperature is estimated to be 6.5 °C (–2.5 °C in January and 17.3 °C in July) (Meteorological bulletin of Laukuva meteorological station 1960–2012).

The study was conducted in the fields of a 27-year long experiment on moraine hilly terrain of the southern–central Žemaičiai Uplands (55°34′N, 22°29′E) in Western Lithuania. Research data were obtained in 2010–2012 on a sandy loam Bathihypogleyi–Eutric Albeluvisol (ABe–gld–w) at the Kaltinėnai Research Station of the Lithuanian Research Centre for Agriculture and Forestry. The catchment area has a maximum elevation of 174.2 m a.s.l. The field experiments investigating water erosion rates under different agro-environmental systems in the sloping area have been carried out since 1983. The field experiments (environmental monitoring) are part of the Core Research Programme of the Global Change and Terrestrial Ecosystem (GCTE) Project, a component of the International Geosphere Biosphere Programme (IGBP).

1.2. General methodological framework

The formed critical slope segments (slightly eroded, active erosion and accumulation) and sustained erosion processes were investigated on sloping agricultural lands. Indicators used to estimate formed slope segments included estimated transects of Ap horizon thickness and conformity to topographic attributes. In most cases, differences in thickness of the Ap horizon in hilly areas may be due to soil erosion (Lal 1998). The use of transects is well known in field research (Gillison, Brewer 1985). Nine downslope transects (three replicates within each study plot) 98 m in length were set up along the northern slope with a width of 3.60 m; the relative elevation of slope transects ranged between 13.64–15.02 m.

Based on the spatial heterogeneity of Ap horizon thickness, the studied transects were divided into three slope segments on each study field. Relative flat summit form-unit of slope is called slightly eroded segment and it could serve as a control site due to very weak soil erosion. Meanwhile, the shoulder (under the long-term grassland) and backslope form-units (under the grain-grass and grass-grain crop rotations) served as a strongly eroding site and was entitled as active erosion segments. Finally, the footslope form–unit acted as accumulation segment because all sediment, induced down by the throughflow of water, is trapped in this topographic low.

1.3. Agro-environmental systems and field measurements

The erosion preventive agro-environmental systems (crop rotations) were developed for a 6-course (years). In this study we represent results obtained during 3-course (years). More detailed descriptions and explanations of crop rotations are given in Jankauskas *et al.* (2009). The three crop rotations of the long-term field experiment were compared:

The grain-grass crop rotation (containing 33% grasses and 67% cereal grains): winter rye (*Secale cereale* L.) (in 2010); spring barley (*Hordeum vulgare* L.) (during 2011–2012).

The long-term grassland: multi–species mixture of perennial grasses which contribute to soil humus formation. This grass mixture consisted of 20% each of common timothy (*Phelum pratense* L.), red fescue *(Festuca rubra* L.), white clover (*Trifolium repens* L.), Kentucky bluegrass (*Poa pratensis* L.) and birdsfoot trefoil (*Lotus corniculatus* L.) (during the period 2010–2012). Multi-species mixtures of perennial grasses for long-term use as sod–forming grasses.

The grass-grain crop rotation (containing 67% grasses and 33% cereal grains): winter rye (*Secale cereale* L.) (in 2010); spring barley (*Hordeum vulgare* L.), undercrop of cocksfoot and red fescue mixture (*Dactylis glomerata* L. – *Festuca rubra* L.) (in 2011), and one year of red clover and timothy mixture (*Trifolium pratense* L. – *Phleum pratense* L.) (in 2012).

The topographic attributes (elevations, distances and angles) of study fields (Fig. 1) were measured using precision geometrical land levelling methods (equipment Zeiss Ni002®), providing measurement accuracy of ±0.03 m, according to Kriaučiūnaitė–Neklejonovienė *et al.* (2008).

The topographic measurements showed the slope inclination of each experimental field to be 8.0° (17.8%) (the grain-grass crop rotation), 8.9° (19.8%) (the long-term grassland) and 8.7° (19.3%) (the grass-grain crop rotation) (Table 1). Data of soil erosion rate for the period 1983–2009 was obtained by Jankauskas (2012).

Table 1. Experimental agro-environmental plots description

Variables	Grain-grass crop rotation	Long-term grassland	Grass-grain crop rotation
Altitude range (m)	170.54–156.91	171.05–156.02	171.73–157.06
Slope gradient (°)	8.0	8.9	8.7
Slope length (m)	98	98	98
Slope width (m)	3.60	3.60	3.60
Aspect	north	north	north
Textural class	Sandy loam	Sandy loam	Sandy loam
Soil erosion rate (m^3 ha^{-1} yr^{-1})			
2010–2012	1.38	0	0.11
1983–2009	15.88	0.01	4.69

1.4. Soil laboratory analyses

Soil samples (~500 g) were taken annually from topsoil (200 mm) using a sterile soil corer. The samples were taken randomly from the studied slope segments across the slope. Three soil samples per slope segment were collected considering the entire slope. A total of 27 composite soil samples were collected for determination of soil properties. Soil samples were examined for textural class, particle size (sand 2000–63 μm; silt 63–2 μm and clay <2 μm) distribution and chemical properties (soil pH_{KCl}, available phosphorus (P) and potassium (K), soil organic carbon (SOC) and total nitrogen (N)). Soil particle size distribution was established at the Agrochemical Research Laboratory of the LRCAF using the particle-size analysis method (ISO 11277: 2009). Soil pH

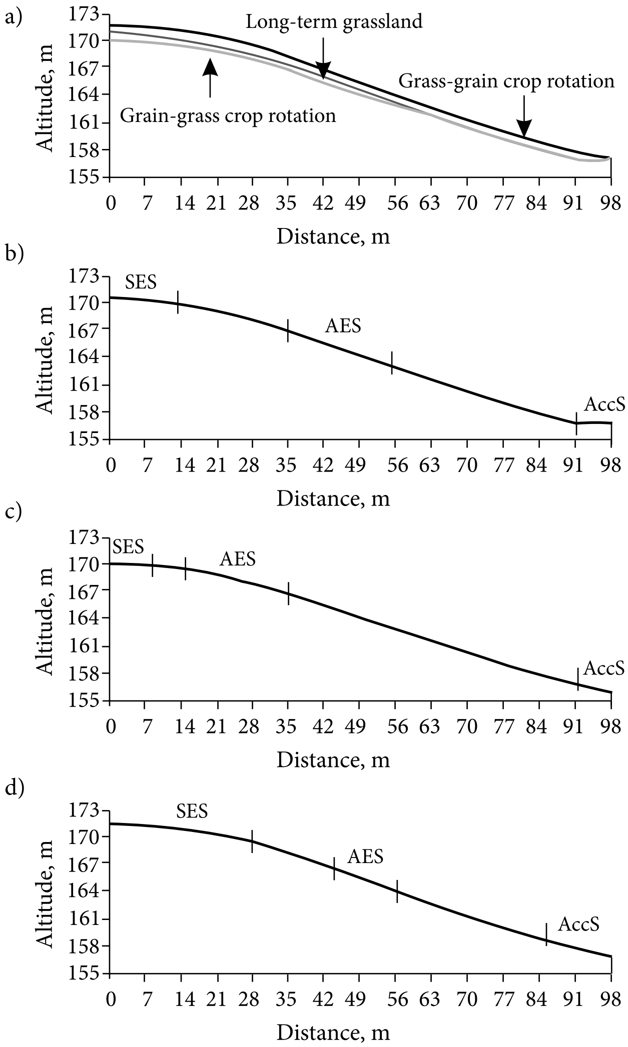

Fig. 1. The localization and topographical attributes of the slope segments: transects in the experimental sites under: a) all agro-environmental systems, b) the grain-grass crop rotation, c) long–term grassland, and d) grass-grain crop rotation. Abbreviations: SES – Slightly eroded segment; AES – Active erosion segment; AccS – Accumulation segment.

was determined in 1 M KCl soil sample extracts using a calibrated digital pH meter (ISO 10390: 1994), mobile P_2O_5 and K_2O extracted using the A–L method (available P and K were extracted with ammonium acetate–lactate solution, pH 3.7, ratio 1:20) (GOST 26208-91: 1993). SOC content was determined by the Tyurin dichromate–oxidation method (Nikitin 1999; ISO 14235: 1998) and total N by the Kjeldahl method (ISO 11261: 1995). The silt/clay ratio, an index of soil weathering, was calculating according to FAO (1988).

1.5. Assessment of water erosion

Water erosion rates on environmental monitoring site were assessed by measuring the length and cross–sectional area of rills, to calculate soil loss volume (Chambers *et al.* 2000; Jankauskas *et al.* 2008). Lost soil volume was calculated using the formula (1):

$$x = [(\Sigma l_1 p_1 + \Sigma l_2 p_2 + ... \Sigma l_n p_n) : n] : y, \quad (1)$$

where: x – volume of erosion rills (m^{-3} ha^{-1}); l, l_1, … l_n – rill depth (cm^{-1}); p, p_1, … p_n – rill width (cm^{-1}, accuracy ±0.1 cm^{-1}; n – number of rills on the measured plot width; y – measured plot width (m^{-1}), and Σ – sum of performed measurements from selected 1 m length segments located at equal distances on the experimental plot.

Methods of rill volume measurements may be performed relatively well in areas where rill erosion represents the dominant sediment source (Govers, Poesen 1988; Vanmaercke *et al.* 2012). Plot runoff and erosion were measured on a regular basis, up to weekly after rainfall and sowing. Measurements were taken from spring sowing (typically late April or early May) to mid-June for cereals. During the research period 72 rill volume measurements were performed.

1.6. Statistical analysis

One-way analysis of variance (ANOVA) was used to estimate significance of differences at $P \leq 0.05$ between treatment means using Fisher's LSD test and correlations among soil properties were determined using Pearson correlation coefficients on a significance levels of $p \leq 0.05$ using the statistical programme STAT ENG from the software package *Selekcija* (Tarakanovas, Raudonius 2003).

2. Results

2.1. Plot topography change and soil texture

Variations in the soil Ap layer thickness and soil properties prone to long-term erosion process are potentially indicative of the relative effects of both accelerated (human induced) and natural erosion. In experimental fields, measurements of Ap layer thickness showed a great variation under various erosion preventive agro–environmental systems by slope segments (Table 2).

Under the influence of erosive processes on cultivated study plots higher soil weathering and thinner Ap horizon at a higher altitude was observed, therefore as after-effect the thicker accumulation segments were determinate as well. The silt/clay ratios were highest in the accumulation segments under all crop rotations.

Soil texture was classified as sandy loamy in all agro-environmental systems and slope segments. The results showed a strong correlation between sand and silt contents ($r = -0.95$, $p \leq 0.05$, $n = 27$) under the grain–grass crop rotation. However, sand content under the long-term grassland strongly correlated with clay and silt contents ($r = -0.85$–0.86, $p \leq 0.05$, $n = 27$). Sand and clay particles under the grass–grain crop rotation were significantly correlated ($r = -0.96$, $p \leq 0.05$, $n = 27$).

Table 2. Topography and soil properties of the slope segments in the different agro–environmental systems after 27-years of study

Variables	Grain-grass crop rotation			Long-term grassland			Grass-grain crop rotation		
	SES	AES	AccS	SES	AES	AccS	SES	AES	AccS
Topography									
Gradient (°)	3.3	10.9	0.8	3.5	13.8	8.5	5.5	7.4	7.3
Length (m)	14	21	7	8.9	17.3	7	28	13	12.8
Area (m^{-2})	50.40	75.60	25.20	32.04	62.28	25.20	100.80	46.80	46.08
Soil properties									
Ap horizon thickness (cm)	18.3±4.26	14.6±0.84	75.7±4.72	25.3±2.17	23.3±0.68	46.3±2.26	21.4±2.53	18.8±0.59	63.7±2.11
Sand (%)	69.6±1.11	64.5±0.39	62.7±1.23	70.3±2.85	60.9±0.35	65.2±0.29	66.2±0.59	65.2±2.18	69.5±0.36
Silt (%)	16.0±0.44	19.7±0.50	22.6±0.73	16.1±1.50	20.8±0.46	21.2±0.09	18.5±0.49	18.8±0.67	19.1±0.23
Clay (%)	14.2±0.82	15.8±0.13	14.7±0.55	13.6±1.43	18.3±0.81	13.6±0.27	15.3±0.09	16.0±1.51	11.4±0.23
Silt/clay ratio (%)	1.15	1.25	1.55	1.20	1.14	1.60	1.21	1.21	1.70

Abbreviations: SES – Slightly eroded segment; AES – Active erosion segment; AccS – Accumulation segment.
Mean ± standard error.

The silt/clay ratio varied from 1.14–1.25% on slightly eroded and active erosion segments to 1.55–1.70% in accumulation segments (Fig. 2).

The correlation between silt/clay ratios and Ap thickness values showed that under all crop rotations the active erosion segments have lighter soil textures than the other segments ($r = 0.93$, $p \leq 0.05$, $n = 27$).

2.2. Soil chemical properties

The results showed that under all crop rotations the active erosion segments had significantly ($P \leq 0.05$) lower soil pH compared with other segments. Slope gradient values were correlated negatively with soil pH values ($r = -0.68$, $p \leq 0.05$, $n = 27$). Mean soil pH ranged from 5.8–6.5. The lowest soil pH was established under the grain-grass crop rotation and long-term grassland in active erosion segments, where relatively acidic soils prevailed.

It was found that under all crop rotations accumulation segments had significantly ($P \leq 0.05$) higher SOC content compared with the other slope segments. The SOC under the grain–grass crop rotation varied from 0.85% in the slightly eroded segment to 0.93 and 1.25% in the active erosion and accumulation segments, respectively. The SOC under the long-term grassland and grass-grain crop rotations was higher in the slightly eroded segment and lower under the grain-grass crop rotation (decrease 38%

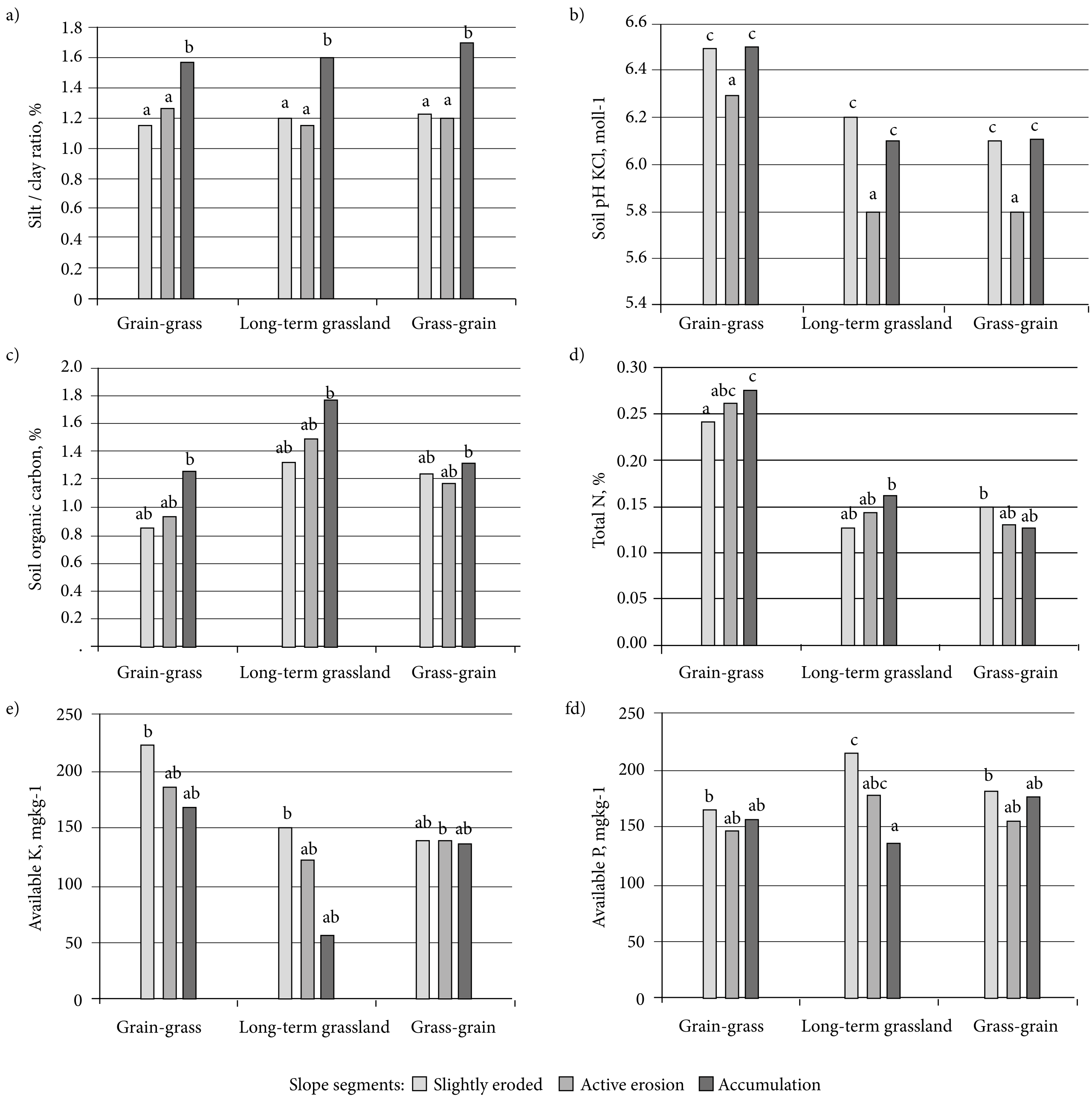

Fig. 2. The comparison of mean values by slope segments under separate crop rotations for: a) Silt/clay ratio, b) Soil pH, c) SOC, d) Total N, e) Available K, and f) Available P. Different letters represent significant differences among treatments at $p \leq 0.05$; $n = 27$

in relative value), respectively. The SOC was generally high under long-term grassland compared to the other crop rotations. Under the grain-grass crop rotation and long-term grassland the slightly eroded segments had less SOC, only under the grass-grain crop rotation there was recorded lower SOC in the active erosion segment.

Analysis of total *N* showed that the upper mean (0.28%) was obtained under the grain-grass crop rotation in the accumulation segment, the lower (0.13%) under the grass-grain crop rotation in the accumulation segment. Under the grass-grain crop rotation there was identified significantly ($P \leq 0.05$) lower total N content than under other crop rotations.

Under all crop rotations was observed significant ($P \leq 0.05$) differences between slope segments with higher available *P* in slightly eroded segments. Under the long–term grassland the accumulation and active erosion segments had 55 and 29% lower means of available P versus slightly eroded segment. The highest concentration of available *K* (139–224 mg kg^{-1}) under all crop rotations was in slightly eroded segments; the least mean (57 mg kg^{-1}) was under the long-term grassland in the accumulation segment. The higher ($P \leq 0.05$) available K was estimated under the grain-grass crop rotation and long-term grassland in the slightly eroded segments. Significantly ($P \leq 0.05$) lower available K was determined under the grass-grain crop rotation in slightly eroded and accumulation segments.

2.3. Soil erosion rate under the crop rotations

Rill erosion prevailed in the study fields. The streams of water runoff developed small and large rills on slopes. In this form of erosion, soil and particles displaced by water were intensively separated and sorted. The soil erosion rate during three-year experimental period was estimated under the grain-grass and grass-grain crop rotations of 1.38 and 0.11 m^3 ha^{-1} yr^{-1}, respectively. Tillage erosion was a dominant process of soil redistribution. However, even the grass-grain crop rotation could not completely prevent soil erosion. Only long-term grassland prevented water erosion where there was no evidence of rilling.

3. Discussion

The erosion-preventive agro-environmental systems developed over a 27-year period, tillage practice and influence of annual rainfall indicate important impacts on land degradation processes on the moraine hilly terrain in Western Lithuania. Soil was differentially eroded along the slopes. Soil erosion was mainly caused by tillage and water under continuous intensive cropping. Variations in the Ap thickness and soil properties prone to erosion are potentially indicative of the relative **effects** of both accelerated and natural erosion. Thinner Ap horizons not only reflect soil erosion rates. Soil compaction by agricultural machinery may also play a significant role. The results from this study suggested that transects of Ap thickness and the same agro–chemical soil properties can be successfully adapted determining critical slope segments.

The silt content was a very meaningful indicator of the extent of soil erosion along the slope. Eroded soil occurred in accumulation segments on footslope considering to increased silt quantity. Bronick and Lal (2004) observed that on sloping soils erosion tends to preferentially remove light particles, including silts. Grasses exhibit high resistance to soil erosion and sediment accumulation, while cereals perform poorly in this respect (Račinskas 1990). Actually, when soil erosion occurs, silt particles are suspended in surface water and are transported downslope, thus leaving coarser material at the top slope positions (Halim *et al.* 2007). Previous studies (Morgan 2007; Aksoy, Kavvas 2005) have also reported that eroded materials are enriched by silt sized particles relative to the original soil where the erosion event commenced. Bronick and Lal (2004) reported that elevation influences the rate of weathering in soils. Sand content under the grain-grass crop rotation decreased with decreasing elevation, while the silt increased with decreasing elevation. Clay content was significantly higher in active erosion segments. Silt content under the long-term grassland increased with decreasing elevation. It was found, that more weathered soils (e.g. in active erosion segments) contained more clay than less weathered ones. Where the rills eroded through the topsoil, there was a marked reduction in SOC, from 2.4–3.9 to <0.9%. Clay content was reduced from 7–9 to 3–4%. The fraction 0.002–0.1 mm (silt+very fine sand) increased from 84–90 to about 92%. Especially the reduction in SOC makes the soil more erodible and gives a sudden decrease in the resistance to erosion when concentrated water flows into the layer with a high silt and sand content.

Higher silt/clay ratios in accumulation segments compared with others can be explained by their lower locality on slopes, where silt particles can be washed out by runoff and might be deposited in the topographic low (Zachar 1982; Øygarden 2003). Thus, silts, as SOC, were probably eroded, which occurred at more severe rates on the higher elevation segments. Similar results were obtained in Nordic countries on silt loam and clay loam soil. Silt is very vulnerable to water erosion, since it is small and has low resistance to both cohesion and friction (Ulen *et al.* 2012; Bechmann 2012). Combined with a high silt/sand content, more severe rilling and ephemeral gullies develop (Øygarden 2003).

Nutrient dynamics are closely linked to soil movement by tillage (Ni, Zhang 2007). Soil pH could become one of very sensitive and suitable criteria for identifying critical slope segments on moraine hilly terrain in agricultural areas affected by erosion. This could be because eroding soils are exhuming calcareous subsoils. Variations of soil pH and SOC changes prone to the erosion process and are potentially indicative of the relative extent of erosion along the slopes. Soil pH and SOC strongly correlated ($r = 0.81$, $p \le 0.05$, $n = 27$). We also estimated a positive correlation ($r = 0.80$, $p \le 0.05$, $n = 27$) between soil pH and total N within each slope segment.

Apparently, the accumulation segments in all agro-environmental systems showed higher SOC contents than in other vulnerable erosion headland segments. In general, the SOC of slightly eroded and active erosion segments were redistributed and deposited in the accumulation segments. These differences may be due to finest soil particles and SOC translocation caused by tillage and water erosion from upper to lower parts of the slope. As confirmation, significant correlation ($r = 0.50$, $p \le 0.05$, $n = 27$) between the SOC and silt contents was indicated. Fullen *et al.* (2006) and Jankauskas *et al.* (2009) also reported that silt can play an important role in influencing SOC storage. The higher SOC content under long–term grassland compared to the grain–grass and grass–grain crop rotations are impacted by differences in soil erosion, vegetation cover, biomass return and it provides evidence of effective SOC sequestration in soil.

Results regarding total N under the grain–grass crop rotation revealed an increasing trend from slightly eroded slope segment, which might be due to their downward movement with surface runoff from top slopes and accumulation on basal slopes. Birkinshaw and Ewen (2000) and Aksoy and Kavvas (2005) have confirmed that on upland areas total *N* is transported with sediments by surface runoff to topographic lows. The difference found in total *N* content by slope segments can be also justified by their difference in SOC content (Dercon *et al*. 2006; Pennock *et al.* 1994). Our investigations established significant correlation bettwen SOC and total *N* under the grain-grass crop rotation ($r = 0.86$, $p \le 0.05$, $n = 9$) and the long-term grassland ($r = 0.79$, $p \le 0.05$, $n = 9$). Only under the grass-grain crop rotation these relationship was not observed. It could be so because under the grass-grain crop rotation, where grasses predominate, the fertilizer of nitrogen on the soil surface is spreading and as a result nitrogen became more mobile and relation with SOC is incoherent. Though under the grain-grass crop rotation the nitrogen in the soil are inserted as well. In general, different soil cover (vegetation), water runoff volume and methods of fertilization have influence to agrochemical properties of soil on eroded and steep slopes. The significant correlative occurrence of total *N* and SOC was confirmed in eroded agricultural fields by Haag and Kaupenjohann (2001).

The soil under the long-term grassland was richest in available *P*. The influence of the SOC explains available *P* retention and supply under this highly vegetated cover. It was estimated that only under the grass-grain crop rotation all slope segments contained sufficient available *P*.

Previous researchers (Brubaker *et al.* 1993; Kinderiene, Karcauskiene 2012) argued that erosion hazard on eroded lands is the main factor of controlling potassium (K) and other soil fertility parameters. Our study data showed an decreasing trend in soil available K down the slopes under grain-grass crop rotation and long-term grassland. Thus, contents of available K under grass-grain crop rotation in all slope segments were similar. According to Jankauskas (2003) due to water erosion on a sandy loam Bathihypogleyi – Eutric Albeluvisols losses of K with soil are 20 kg t^{-1}.

In Europe, soil erosion caused mainly by water and rill erosion affects the largest area (Gobin *et al*. 2004). The upland area is usually considered to have rill erosion (Aksoy, Kavvas 2005). Soil loss due to rill erosion is important processes of soil degradation that cause significant on-site and off-site problems (Montgomery 2007).

In Lithuania vegetation have a great influence on soil erodibility. In the study the anti-erosion agro-environmental system (grass-grain crop rotation) decreased soil losses due to erosion by ninety-two per cent compared with those of the grain-grass crop rotation. This shows the importance of applying soil conservation measures on hilly terrain and agrees with Van Rompaey *et al.* (2001; 2002) idea that the potential for surface runoff and soil erosion is mostly affected by land use and cultivation. The surface of the long-term grassland was not subject to rill erosion. Kinderienė *et al.* (2013) observed that the slopes occupied with permanent grasses, where slightly and moderately eroded Eutric Albeluvisol (AB–e) prevailed, were also resistant to soil erosion. It should be mentioned, that according to data collected in 1983–2000 in the long-term experiments at the Kaltinėnai Experimental Station, under the perennial grasses, winter rye and spring barley the annual soil losses amounted to 0.15, 34.44 and 108.35 $m^3\ ha^{-1}$, respectively (Jankauskas, Jankauskienė 2003). The risk of erosion of agricultural land is an important factor for land abandonment (Koulouri, Giourga 2007; Pointereau *et al.* 2008).

Conclusions

The findings of the current study suggested that after 27-years of use of different erosion preventive agro-environmental systems on moraine hilly landscape, sustained soil erosion resulted in micro-topographic landscape changes. Erosion processes can affect spatial variability of soil particle distribution, thus resulting in soil texture becoming lighter in active erosion and increasing the silt/clay ratios in accumulation segments.

Soil pH was significantly negatively correlated with slope gradient. Thus, soil pH was the lowest in active erosion segments. The highest concentration of available P and K was in slightly eroded segments. Higher SOC content was in the accumulation segments compared with others. The SOC content was generally higher under the long-term grassland.

During the experimental period water erosion occurred under the grain-grass and grass-grain crop rotation fields. The grass-grain crop rotation decreased rill erosion and soil erosion rate by ninety-two per cent compared to grain-grass crop rotation. Only long-term grassland completely stopped soil erosion.

Therefore, our research data relating to slope segments as the critical parts of sustained erosion process and experience of progressive soil conservation practices on the moraine hilly terrain are important for sustainable agricultural development in the temperate climate zone. The observed topographic changes and alterations in soil properties, resulting from land use management, would lead to further land degradation, with negative implications on slope use for agricultural needs.

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