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SOIL PROTECTING LAND USE SYSTEM FOR HILLY-UNDULATING LANDSCAPE

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Abstract

The research data presented in this paper were obtained on the hilly-undulating relief of the Žemaičiai upland (Western Lithuania), where prevail loamy sand and clay loam Eutric Albeluvisols. The field experiments evaluating water erosion rates under four different land management systems on the slopes of different gradient had been carried out since 1982. The main results evaluating water erosion rates, plant productivity and changes of physical soil properties had been published in Lithuania and internationally. Extent of soil erosion on the slopes of different gradient and soil organic matter content on differently eroded soil are considered as indicators of soil quality on the hilly-undulating farmland's landscape. Results of investigations permit us to modulate different erosion-resisting land management systems enabling to localize and stabilize erosion processes on the most erosion sensitive areas in the landscape and improving the ecological conditions in the vulnerable Baltic coastal zone. Large scale of erosion-resisting crop rotations and perennial grasses for long-term use for fields of varying gradient and soil texture are presented in this publication. This indicates the possibility how to reorganize fields and landscape structures to limit runoff and erosion, enabling rehabilitation of land degradation. Matching specific soil tillage operations with intensity of fertilization permits further retardation of soil erosion intensity.

Key words: Eutric Albeluvisols, hilly-undulating landscape, soil erosion, soil protection, soil rehabilitation.

Introduction

The extent and severity of erosion on European soils has markedly increased over the last fifty years, particularly on arable land. Unfortunately, soil conservation in Europe has not generally received sufficient attention, until recently /Soil, 2006; Fullen et al., 2006/. Set-aside is a scheme designed to provide farmers with a subsidy to leave land uncultivated and, in doing so, act as a possible soil conservation measure /Chisci, 1994, Fullen, 1998/. In the prevailing economic climate, it is feasible that steep to moderate slopes with erodible soils, and other vulnerable parts of fields (i.e. depressions, minor dry valleys and land adjacent to water courses), be put into non-rotational set-aside /MAFF, 1998; Environment Agency, 2001/. This could decrease erosion rates and potentially increase soil organic matter content, with concomitant decreases in soil erodibility.

In the U.K. in 1995, the Moorland Scheme (MS) was launched with the objective of protecting and improving the upland moorland environment. In 1998, the Arable Stewardship Pilot Scheme (ASPS) was created to assess alternative arable management options for conserving and enhancing farmland biodiversity /Ecoscope Applied..., 2003/.

In Lithuania, erosion-resisting recommendations for land users were prepared on the base of investigations of Lithuanian Institute of Agriculture. The results of investigations were discussed at the scientific conferences and workshops, and were propagated and disseminated by scientific /Jankauskas, Jankauskienė, 2004; 2005/ and by popular publications.

Soil erosion processes are partially responsible for CO_2 concentrations in the atmosphere leading to increase in 'greenhouse effect'. Global CO_2 concentrations are increasing, therefore it is useful to study these changes in terms of carbon ‘sources’, ‘sinks’ and ‘pools’ /Batjes, 1996, Lal, 2002; 2003/. The rate of global CO_2 emissions increased from 1.64 Gt of carbon per year (1 Gegaton or Gt = 10^9 t) to 8.05 Gt C per year between 1950–2000. The sources relate mainly to fossil fuel combustion, cement manufacturing, land use change and deforestation. The total amount of carbon in the soil ‘pool’ is ~2300 Gt C: in organic (1550 Gt C) and inorganic 750 Gt C). Both of these are much greater than the pools in either the atmosphere (770 Gt C) or in all living organisms (610 Gt C). The current CO_2 ‘sink’ in terrestrial ecosystems (vegetation and soils) is ~2.0 Gt C per year, while the oceanic sink absorbs ~2.7 Gt C per year. Therefore, if carbon can be taken from the atmosphere, a small increase in the soil organic pool (0.1–0.2 % per year) could counteract the current increase in CO_2 content of the atmosphere (~1.5 parts per million by volume per year) /Batjes, 1996, Lal, 2002; 2003; Fullen, Catt, 2004/. Considerable amount of organic carbon (SOC) can be sequestered into soils, as carbon is an integral part of soil organic matter (SOM). SOC constitutes ~58% of SOM (USDA, 1996). The potential to sequester atmospheric carbon within the soil store is a growing paradigm in soil science. The consensus is that carbon sequestration is not a panacea to global warming, but sequestration would form a valuable contribution and allow extra time while solutions to the problems are sought /Fullen, Catt, 2004/.

The main aims of our investigations were: 1) to prepare simple strategy for stabilization of soil erosion and for improving the ecological conditions in the vulnerable Baltic coastal zone; 2) to evaluate the potential for soil conservation on eroded undulating land; 3) to advise land users and policy makers for rural development in relation to environmental protection; and 4) to distribute results of investigations for possible implementation in other temperate climatic zones promoting international co-operation in the development of erosion-resisting agro-environmental systems. Results from first and second crop rotations (1983–1994) have been reported and from third crop rotation (1983–2000) by /Jankauskas, Jankauskienė, 1996 a,b,c; 2000; 2003a; 2003c; Jankauskas, 2003; Jankauskas et al., 2004/.

Materials and Methods

The main form of soil erosion on the arable land in Lithuania is tillage erosion. Water and wind erosion occurs on arable slopes and wind erosion occurs on the Baltic

Sea coast and on the large areas of peaty-/sandy-soils on arable land, too /Jankauskas, Jankauskienė, 2003c/. Some 51.9 % of Lithuania's terrains are on the hilly-undulating relief, where soil is vulnerable for erosion processes.

Research data were obtained from the Kaltinenai Research Station of the Lithuanian Institute of Agriculture (KRS of LIA). Dystric Albeluvisols (ABd) prevail in this region of Lithuania; however, soils become Eutric Albeluvisols (ABe) due to intensive periodical liming, when lime changes the properties of both Ap and deeper soil horizons. Study sites A, B and C are on slopes of 2–5°, 5–10° and 10–14°, respectively.

Field experiments were performed on eroded Eutric Albeluvisol sandy loams /IUSS working group..., 2006/. Soil was differentially eroded along the slopes, being slightly eroded on 2–5° slopes, moderately eroded on 5–10° slopes and strongly eroded on 10–14° slopes, with colluvial deposits on basal slopes. Soil erosion was mainly caused by tillage and water erosion under continuous intensive cropping. The agro-chemical properties of Ap horizons (0–20 cm) before field experiments show that topsoil was slightly acid, P-deficient, medium rich in K and contained varying soil organic matter (SOM) contents (Table 1). The highest percentage of SOM was on less eroded 2–5° slopes and the least on 10–14° slopes. For historical reasons, soil analytical techniques were mainly former Soviet procedures /Jankauskas, Fullen, 2002/. Therefore analytical results differ from those generated by currently internationally-accepted protocols /USDA Chemical analysis..., 1996/, but are consistent with former Soviet protocols /Jankauskas, Jankauskienė, 2003a/. Suggestions how to transfer functions between Soviet and international systems were published on the base of international project /Booth et al., 2003; Jankauskas et al., 2006/.

Table 1. Mean chemical soil properties of the arable (Ap) horizon (0–20 cm) before field experiments in 1981

1 lentelė. *Agrocheminės dirvožemio ariamojo sluoksnio (Ap) savybės (0–20 cm) 1981 m. prieš bandymų įrengimą*

Study sites *Tyrimų fonai*	Steepness of slope *Šlaito statumas*	pH_{KCl} *pH_{KCl}*	Available elements *Judrūs elementai* (mg kg^{-1}) P	K	Exchangeable bases *Bazių suma* (cmol(+)kg^{-1})	Organic matter *Organinės medžiagos* (g kg^{-1})
A	2-5°	5.8	49.8	146.1	119	28.5
B	5-10°	5.3	18.3	127.0	94	22.0
C	10-14°	5.8	29.7	131.2	96	20.8

Mean annual precipitation in Lithuania is 626 mm, with ~858 mm on the central Žemaičiai Uplands and 750–800 mm on the upland fringe. Annual precipitation during the study period was 635–1075 mm. Plots were deep-ploughed (where need), usually in September, and were bare until spring. Total runoff and erosion from bare soil was measured before the following spring cultivation (usually in mid-April). Plot runoff and erosion were measured on a regular basis, up to weekly during erosive rains, after sowing. Measurements were taken from spring sowing (typically late April or early May) to mid-June for cereals and late August for potatoes.

Long-term field experimental data were collected on the slopes of 2–5°, 5–10° and 10–14° since 1983. Four crop rotations were compared (Fig. 1), specifically:

a) The field crop rotation, containing 17 % tillage crops (potato), 33 % grasses and 50 % cereal grains: 1: winter rye (*Secale cereale L.*), 2: potatoes (*Solanum tuberosum L.*), 3–4: spring barley (*Hordeum vulgare L.*), 5–6: mixture of clover-timothy (CT) (*Trifolium pratense L.-Phelum pratense L.*);

b) The grain-grass crop rotation, containing 33 % grasses and 67 % cereal grains: 1: winter rye, 2–4: spring barley, 5–6: CT;

c) The grass-grain I crop rotation, containing 67 % grasses and 33 %cereal grains: 1: winter rye, 2: spring barley, 3–6: CT);

d) The grass-grain II crop rotation, containing 67 % grasses and 33 % cereal grains: 1 winter rye, 2: spring barley, 3–6: mixture of orchard grass-red fescue (OF) (*Dactylis glomerata L.-Festuca rubra L.*).

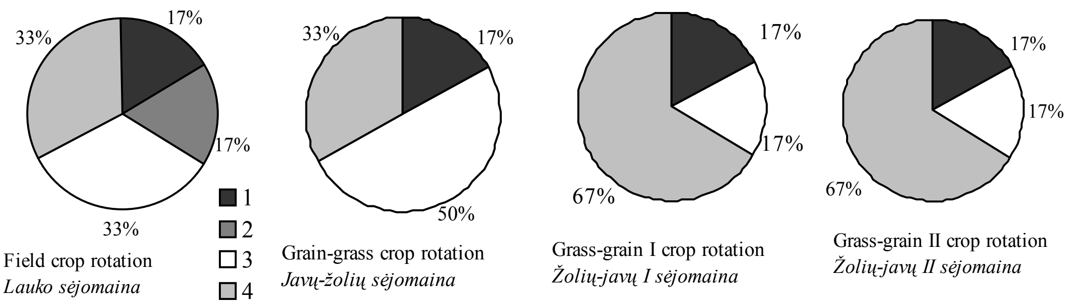

Figure 1. Structure of investigated crop rotations % (1. Winter rye. 2. Potašo. 3. Spring barley. 4. Perennial grass mixtures (clover-timothy (I) or orchard grass- red fescue (II))
1 paveikslas. *Tyrinėtų sėjomainų sudėtis % (1. Žieminiai rugiai. 2. Bulvės. 3. Vasariniai miežiai. 4. Daugiamečių žolių mišiniai (dobilų ir motiejukų (I) ar šunažolių ir raudonųjų eraičinų (II))*

Multi-species mixtures of perennial grasses for long-term use as sod-forming grasses g) were grown on 10–14° slopes instead of field crop rotation. The grass mixture consisted of 20 % each of common timothy, red fescue, white clover (*Trifolium repens L.*), Kentucky bluegrass (*Poa pratensis L.*) and birdsfoot trefoil (*Lotus corniculatus L.*). The grass ley replaced the field crop rotation, as tilled crops are not recommended in Lithuania on slopes >10° /Jankauskas, 1996/.

The significance of differences between treatment means was determined using Fisher's LSD_{05} /Tarakanovas, Raudonius, 2003/. The statistical correlation-regression analysis was done using computer programs ANOVA, STAT, SPLIT-PLOT from the package SELKCIJA and IRRISTAT /Tarakanovas, Raudonius, 2003/.

Results and discussion

The arable soils are eroded by tillage operations, water, and wind on the hilly-rolling relief. The natural fertility of the soil on the slightly, moderately and severely eroded slopes of Žemaičiai upland in Lithuania has decreased by 21.7, 39.7 and 62.4 % /Jankauskas, Jankauskienė, 2004/ comparing with the field crop rotation. This was due to soil degradation under influence of erosion processes: the bulk density and the percentage of clay-silt and clay fractions increased, while the total porosity and water field capacity decreased on the eroded topsoil. The strong acidity of the E, EB and B1t horizons, and the increased acidity throughout the soil profile are characteristic features of Dystric Albeluvisols /Jankauskas, 1996; Jankauskas et al., 2007/.

Measured water erosion rates on the arable slopes were: 3.17–8.6 m^3 ha^{-1} yr^{-1} under winter rye, 9.01–27.09 m^3 ha^{-1} yr^{-1} under spring barley and 24.2–87.12 m^3 ha^{-1} yr^{-1} under potatoes according to results of 18 years field experiments. Perennial grasses completely prevented water erosion. The mean water erosion rates under the field crop rotation varied from 6.43 m^3 ha^{-1} yr^{-1} to 20.5 m^3 ha^{-1} yr^{-1} on the slopes of 2–5°, 5–10° and 10–14°. The erosion-preventive grass-grain crop rotations (>50 % grass) decreased soil losses on arable slopes of 2–5°, 5–10° and 10–14° by 74.7–79.5 %, while the grain-grass crop rotation (<50 % grass) decreased rates by 22.7–24.2 %, compared with the field crop rotation /Jankauskas et al., 2004/. Water erosion rates increased with increasing of slope inclination. They were 9.9, 23.4 and 32.2 Mg ha^{-1} yr^{-1} on the slopes of 2–5°, 5–10° and 10–14° accordingly under the field crop rotation; 7.5, 18.0 and 24.9 Mg ha^{-1} yr^{-1} under the grain-grass crop rotation or 2.5, 4.8 and 7.3 Mg ha^{-1} yr^{-1} under the grass-grain crop rotation. Water erosion rates varied in dependence of soil texture: the smallest soil losses (0.45–3.59 Mg ha^{-1} y^{-1}) were from the slope having the heaviest soil texture i.e. silty clay loam; somewhat higher soil losses (0.65–6.29 Mg ha^{-1} y^{-1}) were from the slope with the silt loam on the silty clay soil, and the highest water erosion rates (4.38–29.38 Mg ha^{-1} y^{-1}) were from the slope with the lightest soil texture: silt loam on the loamy sand /Jankauskas, Jankauskienė, 2003b/.

Evaluation role of soil organic matter (SOM) to soil degradation by erosion and formation strategies for soil carbon sequestration is one of most important requirements of soil protection strategy. SOM accumulation is a slow process and considerably slower than the decline /Lal et al., 1998/. Fortunately, accumulation can be enhanced by positive farm management techniques, such as permanent grassland, cover crops, conservation tillage (including no-tillage cropping techniques), mulching, green manures and applications of farmyard manure and compost. Most of these techniques have also proved effective in preventing erosion, increasing fertility and enhancing soil biodiversity /Lal, 2002/. Therefore, determination of change in SOM content is possible only by long-term investigations (field experiments, periodical analysis of soil).

The results of SOM content changes in long-term field experiments at the KRS of LIA illustrate multiple influences of land use systems on SOM dynamics (Table 2). Firstly, the variety of crops as constituents of the rotation can differentially affect C sequestration processes /Jankauskas, 1996; Lal et al., 1998/. Secondly, different land use systems require different intensities of soil tillage. Consequently, more intense soil tillage stimulates more SOM mineralization, which releases more C from the soil store to the atmosphere /Lal, 1999/. Thirdly, there were different soil losses due to water erosion under different land use systems: the highest losses were under the field crop rotation and the lowest were under grass-grain crop rotations /Jankauskas, Jankauskienė, 2003a; Jankauskas et al., 2004/. The higher soil losses lead to higher losses of SOM. Furthermore, different land uses influence C sequestration by changing soil physical properties, such as dry bulk density, total soil porosity and moisture field capacity. At KRS, the erosion-preventive grass-grain crop rotations and long-term perennial grasses significantly increased total porosity and moisture field capacity /Jankauskas, Jankauskienė, 1999/.

Table 2. Mean SOM contents under different land use systems
2 lentelė. *Skirtingo žemės naudojimo įtaka dirvožemio organinės medžiagos kiekiui*

Crop rotations *Sėjomainos*	SOM (%) after the crop rotations (c.r.): *Dirvožemio organinės medžiagos % po sėjomainų (sm.):*		
	1988, after 1st c.r. *po I sm.*	1994, after 2nd c.r. *po II sm.*	2000, after 3rd c.r. *po III sm.*
2–5° slope / *2–5° šlaitas*			
a) Field / *Lauko*	3.47a*	2.73a,b	2.64a
b) Grain-grass *Javų-žolių*	3.46a	2.54a	2.99b
c) Grass-grain I *Žolių-javų I*	3.08a	3.65b	3.39c
d) Grass-grain II *Žolių- javų II*	3.23a	3.47b	3.46c
LSD_{05} / R_{05}	0.412	0.301	0.284
5–10° slope / *5–10° šlaitas*			
a) Field / *Lauko*	2.52a	2.37a	2.17a
b) Grain-grass *Javų-žolių*	2.47a	2.35a	2.01a
c) Grass-grain I *Žolių-javų I*	2.48a	2.27a	2.75 b
d) Grass-grain II *Žolių- javų II*	2.41a	2.31a	2.67b
LSD_{05} / R_{05}	0.287	0.169	0.1.64
10–14° slope / *10–14° šlaitas*			
g) Grasses** / *Žolės***	2.49a**	2.59b**	2.51b**
b) Grain-grass *Javų-žolių*	2.42a	2.24a	1.99a
c) Grass-grain I *Žolių-javų I*	2.71b	2.47b	2.45b
d) Grass-grain II *Žolių- javų II*	2.50a	2.39a	2.43b
LSD_{05} / R_{05}	0.232	0.221	0.328

* Values with the same letter subscript are not significantly (LSD_{05}) different. g)
Skirtumai tarp rodiklių su vienodomis raidėmis yra nepatikimi (R_{05})
** The sod-forming perennial grasses were grown instead of the field crop rotation on the 10–14° slope
10–14° šlaite ilgaamžės daugiametės žolės augintos vietoje lauko sėjomainos

There were small changes in % SOM after both the first and even the second crop rotation (Table 2). However, differences in % SOM became more evident after the third crop rotation in 2000. Significantly higher SOM values were found under the grass-grain crop rotations on the 2–5° and 5–10° slopes compared with the field crop rotation, and under the sod-forming perennial grasses on the 10–14° slope compared with the grain-grass crop rotation. The results demonstrate that sod-forming perennial grasses on the 10–14° and grass-grain crop rotations on the 2–5° and 5–10° slopes enable rehabilitation of land degradation.

Comparable results were found at the Hilton Experimental Site, Shropshire, UK. Conversion of 10 erosion plots from bare arable to grass ley set-aside reversed the trend of declining SOM contents, which then significantly increased, especially in the first four years. Mean soil organic content (0–5 cm depth) significantly (LSD_{001}) increased from 2.04 % by weight (S.D. 0.45, n = 50 samples) in April 1991 to 3.11 % (S.D. 0.68, n = 50 samples) in April 2001, compared with permanent grassland values of ~4.5%. Soil erodibility after six years of set-aside (sampling date 24/04/97) was determined using a drip-screen rainfall simulator. Soil aggregate stability was higher on the grassed soils, compared with set-aside and bare arable soils. Despite no significant (LSD_{05}) differences between grassland and set-aside soils, both these treatments were significantly (LSD_{001}) greater than bare soils /Foster et al., 2000; Fullen et al., 2002/.

Generally, higher soil losses promote greater SOM loss. Furthermore, various land use systems influence erosion rates and changes in soil physical properties. Erosion-preventive grass-grain crop rotations and perennial grasses for long-term use significantly increased SOM on 2–5° and 5–10° slopes, compared to field crop rotations. Sod-forming perennial grasses significantly increased SOM on 10–14° slopes compared with the grain-grass crop rotation (Fig. 2).

Analysing complex hilly-rolling relief of Lithuanian Uplands, we found different conditions for water erosion on the arable slopes with different inclination and containing different soil texture. The most vulnerable to the water erosion were terrains having light soil texture on the steep slopes, however, the cover crops determined water erosion rates on the different soil and relief conditions. Therefore, the main attributes of the proposed land conservation and sustainable land-use system were the careful selection of optimum erosion-preventive agri-phytocenoses (sod-forming perennial grasses or erosion-preventive crop rotations) with high erosion-resisting capabilities. These systems would vary in response to slope and soil conditions. Such ecosystems assist erosion control and thus the ecological stability of the undulating topography, being as main component for soil protection strategy at undulating relief of Temperate Climate zone.

The erosion prevention grouping of erodible hilly-undulating terrain contains 5 groups of relief depending on slopes' gradient and texture of soil (Table 3). The requirements for picking out of groups and recommended soil conservation measures were formed using research data from field experiments. Group I includes the highly erodible soils that are on slopes <10°, having sandy, loamy sand or gravel textures (light soils) or on slopes <15° with loamy or clay textures (heavy soils). We suggest planting trees on such slopes increasing woodland and biodiversity enabling to accumulate CO_2 and to decrease greenhouse effect.

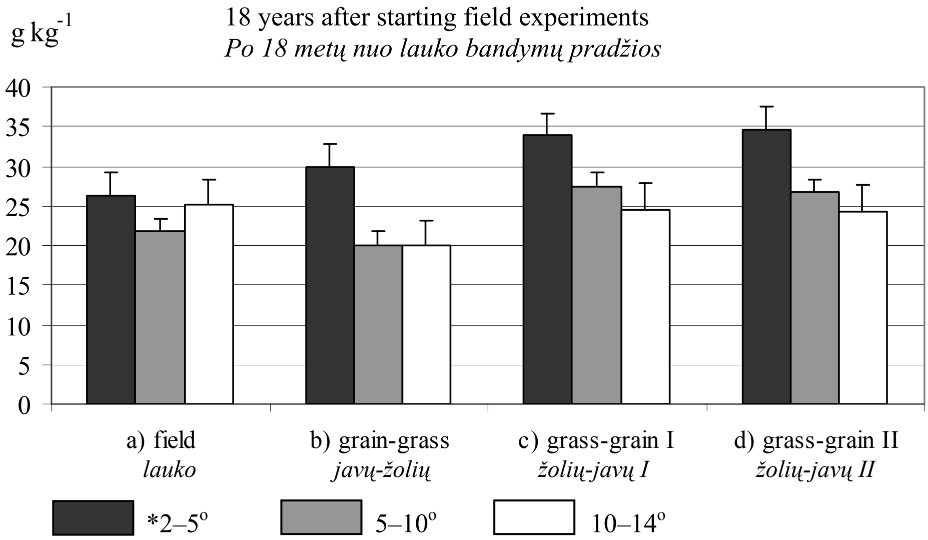

Figure 2. SOM contents (g kg^{-1}) under different land use systems 18 years after starting field experiments. * The sod-forming perennial grasses were grown instead of the field crop rotation on the 10–14° slope

2 paveikslas. *Dirvožemio organinės medžiagos kiekis (g kg^{-1}) 18 metų po bandymo įrengimo.* 10–14° šlaite ilgaamžės daugiametės žolės augintos vietoje lauko sėjomainos*

Table 3. Grouping of erodible terrain for better erosion control and erosion-resisting measures

3 lentelė. *Erozingos teritorijos grupavimas geresniam dirvožemio ardymo kontroliavimui ir antierozinės priemonės*

Group *Grupė*	Soil texture* *Dirvožemio granuliometrinė sudėtis**		Type of land use *Žemė-nauda*	Requirements for group formation *Grupės išskyrimo reikalavimai*	Recommended erosion-resisting measures *Rekomenduojamos antierozinės priemonės*
	S, LS, G	L, C			
1	2	3	4	5	6
I	< 10°	< 15°	Wood-land *Miškas*	To pick out slopes over 10° and 15°. Slopes over 10° of heavy texture and over 5° of light texture are unsuitable for land reclamation *Išskirti statesnius kaip 10° ir 15° šlaitus. Nemelioruoti statesnių kaip 10° sunkios ir 5° lengvos granuliometrinės sudėties dirvožemio šlaitų*	To plant trees or shrubs, to tend carefully perennial grasses *Apsodinti mišku. Kol jis paaugs, puoselėti žolinę augaliją*

Table 3 continued
3 lentelės tęsinys

1	2	3	4	5	6
II	7–10^{o}	10–15^{o}	Grass-land *Žoly-nai*	Along with the indicated slopes to annex the inconvenient for tillage, more plain arable plots and to establish the pasture or grassland. *Prie nurodyto statumo šlaitų prijungti lygesnius, nepatogius dirbimui ariamos žemės plotus ir įrengti kalvų ganyklas ar pievas*	To plant perennial grasses for long-term use. To renovate it by mixture of another composition. Cover crop must be annual grasses *Apželdinti ilgaamžėmis daugiametėmis žolėmis. Prireikus, atnaujinti kitos sudėties žolių mišiniu. Antsėlis – vienametės žolės*
III	5–7^{o}	7–10^{o}	Arable land or grass-land *Ariama arba žolės*	Similar to IInd group, only indicated plots must be suitable form for tillage *Kaip II grupėje tik išskirtas masyvas turi būti žemės dirbimui parankios formos*	To put into practice the erosion-preventive grass-grain crop rotation. To apply erosion-preventive tillage means *Diegti antierozinę žolių-javų sėjomainą ir antierozines agropriemones*
IV	2–5^{o}	3–7^{o}	Arable land *Ariama žemė*	Similar to IIIrd group, only 10 % of light soil slopes up to 7^{o} can be annexed. *Kaip III grupėje. Leistina įtraukti iki 10 % statesnių (iki 7^{o}) lengvos granuliometrinės sudėties dirvožemio šlaitų*	To put into practice the erosion-preventive grain-grass crop rotation. To apply erosion-preventive tillage means. To avoid growing of tillage crops and flax. *Diegti antierozinę javų- žolių sėjomainą. Taikyti antierozines agropriemones, vengti kaupiamųjų ir linų*
V	Up to 2^{o} *Iki 2^{o}*	Up to 3^{o} Iki 3^{o}	Arable land *Ariama žemė*	Plains, suitable for tillage practice, these remained after forming groups I–V. *Į kitas grupes neįtraukti apylygių laukų dirbimui parankios formos masyvai*	Use intensive field crop rotations. On the slopes of 2–3^{o}, apply soil conserving tillage practices. *Diegti intensyvias lygių laukų sėjomainas, o 2–3^{o} šlaituose taikyti antierozines agropriemones*

* S – sand / *smėlis*, LS – loamy sand / *priesmėlis*, G – gravel / žvyras, L – loam / priemolis, C – clay / molis

Growing long-term perennial grasses was recommended (Table 4) on the light soils with prevailing 7–10^{o} slopes and heavy soils with 10–15^{o} slopes, and on surrounding soil that is unsuitable for any other exploitation (group II). Because, the perennial grasses provide full protection from soil erosion, even on the 10–15^{o} slopes, the grass mixtures with a high percentage (90 %) of common alfalfa *(Medicago sativa* L.) were recommended for hilly pastures, if soils were suitable for growing alfalfa. The annual average yield was 6.12 Mg ha^{-1} dry matter or 0.92 Mg ha^{-1} digestible protein. However, the majority of soils on the Žemaičiai Upland are not suitable for growing alfalfa due to excess soil acidity and a high percentage of waterlogged subsoil.

Therefore, grass mixtures of high fertility for early, medium and late hay making or grazing were established. The annual average productivity of the most fertile hay meadow mixture during a 6-year period was 7.9–9.2 Mg ha^{-1} dry matter. The productivity of the pastureland was 5.6–7.1 Mg ha^{-1}. The productivity of these grass mixtures did not decrease during a 6-year period, indicating that the duration of these grass mixtures might be longer /Norgailienė, Zableckienė, 1994/. These long-term perennial grass mixtures can be used for grasslands on the areas in Group II with erodible terrain.

Table 4. The erosion-resisting crop rotations for the fields of IInd group (see Table 3)
4 lentelė. *Antierozinės sėjomainos II grupės laukams (3 lentelė)*

I. Not less than 80 % grasses *I. Žolių ne mažiau kaip 80 %*	II. Not less than 74 % grasses *II. Žolių ne mažiau kaip 74 %*	III. Not less than 67 % grasses *III. Žolių ne mažiau kaip 67 %*
1. Winter grains or spring barley *Žieminiai javai ar vasariniai miežiai*	1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*
2. Perennial grasses *Daugiametės žolės*	2. Spring barley *Vasariniai miežiai*	2. Spring barley *Vasariniai miežiai*
3. Perennial grasses *Daugiametės žolės*	3. Perennial grasses *Daugiametės žolės*	3. Perennial grasses *Daugiametės žolės*
4. Perennial grasses *Daugiametės žolės*	4. Perennial grasses *Daugiametės žolės*	4. Perennial grasses *Daugiametės žolės*
5. Perennial grasses *Daugiametės žolės*	5. Perennial grasses *Daugiametės žolės*	5. Perennial grasses *Daugiametės žolės*
	6. Perennial grasses *Daugiametės žolės*	6. Perennial grasses *Daugiametės žolės*
	7. Perennial grasses *Daugiametės žolės*	

IV. Not less than 63 % grasses *IV. Žolių ne mažiau kaip 63 %*	V. Not less than 63 % grasses *V. Žolių ne mažiau kaip 63 %*	VI. Not less than 60 % grasses *VI. Žolių ne mažiau kaip 60 %*
1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*
2. Winter grains *Žieminiai javai*	2. Spring barley *Vasariniai miežiai*	2. Spring barley *Vasariniai miežiai*
3. Spring barley *Vasariniai miežiai*	3. Spring barley *Vasariniai miežiai*	3. Perennial grasses *Daugiametės žolės*
4. Perennial grasses *Daugiametės žolės*	4. Perennial grasses *Daugiametės žolės*	4. Perennial grasses *Daugiametės žolės*
5. Perennial grasses *Daugiametės žolės*	5. Perennial grasses *Daugiametės žolės*	5. Perennial grasses *Daugiametės žolės*
6. Perennial grasses *Daugiametės žolės*	6. Perennial grasses *Daugiametės žolės*	
7. Perennial grasses *Daugiametės žolės*	7. Perennial grasses *Daugiametės žolės*	
8. Perennial grasses *Daugiametės žolės*	*8.* Perennial grasses *Daugiametės žolės*	

We suggested soil conserving grass-grain crop rotations, including 50–80 % of perennial grasses (Table 5), for soils in Group III on 5–7^{o} slopes with light soils and on 7–10^{o} slopes with heavy soils. These slopes should be arranged into fields suitable for tillage.

Table 5. The erosion-resisting crop rotations for the fields of IIIrd group (see Table 3)
5 lentelė. *Antierozinės sėjomainos III grupės laukams (3 lentelė)*

I. Not less than 57 % grasses *I. Žolių ne mažiau kaip 57 %*	II. Not less than 57 % grasses *II. Žolių ne mažiau kaip 57 %*	III. Not less than 50 % grasses *III. Žolių ne mažiau kaip 50 %*
1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*
2. Winter grains *Žieminiai javai*	2. Spring barley *Vasariniai miežiai*	2. Spring barley *Vasariniai miežiai*
3. Spring barley *Vasariniai miežiai*	3. Spring barley *Vasariniai miežiai*	3. Spring barley *Vasariniai miežiai*
4. Perennial grasses *Daugiametės žolės*	Perennial grasses *Daugiametės žolės*	4. Perennial grasses *Daugiametės žolės*
5. Perennial grasses *Daugiametės žolės*	5. Perennial grasses *Daugiametės žolės*	5. Perennial grasses *Daugiametės žolės*
6. Perennial grasses *Daugiametės žolės*	6. Perennial grasses *Daugiametės žolės*	6. Perennial grasses *Daugiametės žolės*
7. Perennial grasses *Daugiametės žolės*	7. Perennial grasses *Daugiametės žolės*	

IV. Not less than 50 % grasses *IV. Žolių ne mažiau kaip 50 %*	V. Not less than 43 % grasses *V. Žolių ne mažiau kaip 43 %*	VI. Not less than 40 % grasses *VI. Žolių ne mažiau kaip 40 %*
1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*
2. Cereal grains with legumes *Varpiniai ir ankštiniai javai*	2. Cereal grains with legumes *Varpiniai ir ankštiniai javai*	2. Cereal grains with legumes *Varpiniai ir ankštiniai javai*
3. Spring barley *Vasariniai miežiai*	3. Cereal grains *Varpiniai javai*	3. Spring barley *Vasariniai miežiai*
4. Perennial grasses *Daugiametės žolės*	4. Spring barley *Vasariniai miežiai*	5. Perennial grasses *Daugiametės žolės*
5. Perennial grasses *Daugiametės žolės*	5. Perennial grasses *Daugiametės žolės*	6. Perennial grasses *Daugiametės žolės*
6. Perennial grasses *Daugiametės žolės*	6. Perennial grasses *Daugiametės žolės*	
	7. Perennial grasses *Daugiametės žolės*	

Group IV includes 2–5^{o} slopes with light soils and 3–7^{o} slopes with heavy soils, and utilizes soil conserving grain-grass crop rotation, including 33–50 % perennial grasses (Table 6). When growing grain crops, it is important to use soil conservation tillage and fertilizers on the undulating and rolling relief.

Group V includes the remaining fields with flat to gently undulating relief. Common field crop rotations containing row crops can be used on these soils, however we suggest using conservation tillage on 2–3^{o} slopes.

Even grass-grain crop rotations could not completely stabilize soil erosion. The annual rates of soil loss from water erosion under grass-grain crop rotation were 7.2–7.4 Mg ha^{-1} on the 10–14^{o} slope, 4.7–4.9 Mg ha^{-1} on the 5–10^{o} slope, and 2.5 Mg ha^{-1} on the 2–5^{o} slope. Soil losses on the >10^{o} slopes are greater than soil formation rates according to our soil profile depth /Richter, 1997; Fullen, Catt, 2004/. Therefore, we recommended grassing the >10^{o} slopes, and using of conservation tillage and fertilizing-liming the 2–10^{o} slopes as well as the soil conserving crop rotations.

Table 6. The erosion-resisting crop rotations for the fields of IVth group (see Table 3)
6 lentelė. *Antierozinės sėjomainos IV grupės laukams (3 lentelė)*

I. Not less than 38 % grasses *I. Žolių ne mažiau kaip 38 %*	II. Not less than 33 % grasses *II. Žolių ne mažiau kaip 33 %*	III. Not less than 33 % grasses *III. Žolių ne mažiau kaip 33 %*
1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*	1. Winter grains *Žieminiai javai*
2. Cereal grains with legumes *Varpiniai ir ankštiniai javai*	2. Spring grains *Vasariniai javai*	2. Winter grains *Žieminiai javai*
3. Spring barley *Vasariniai miežiai*	3. Cereal grains with legumes *Varpiniai ir ankštiniai javai*	3. Cereal grains with legumes *Varpiniai ir ankštiniai javai*
4. Winter or spring grains *Žieminiai ar vasariniai javai*	4. Spring barley *Vasariniai miežiai*	4. Spring barley *Vasariniai miežiai*
5. Spring barley *Vasariniai miežiai*	5. Perennial grasses *Daugiametės žolės*	5. Perennial grasses *Daugiametės žolės*
6. Perennial grasses *Daugiametės žolės*	6. Perennial grasses *Daugiametės žolės*	6. Perennial grasses *Daugiametės žolės*
7. Perennial grasses *Daugiametės žolės*		
8. Perennial grasses *Daugiametės žolės*		

The deep soil chisel tillage can be used instead of deep mouldboard ploughing, and spraying the stubble with the herbicide Glifosat ($C_3H_8O_5NP$) can be used instead of stubble cultivation and deep ploughing common in the autumn soil tillage system. Soil erosion rates were reduced 2–9 fold by using these measures while productivity remained on the same level /Arlauskas, Feiza, 1996/. Differentiation of nitrogen fertilizer rates on various parts of hilly-rolling upland /Feizienė, 1996/ and matching fertilizer and liming rates to the sensitivity of the crops to soil acidity and erodibility /Jankauskas, 1996/ are also important parts of this erosion control system.

Conclusions

1. The need for soil conserving management system on the hilly-rolling relief increases with increase of slope gradient and with increase of human activities.

2. The soil conserving capability of investigated crop rotations depended on the erosion-resisting capability of constituent crops. Only erosion-preventive grass-grain crop rotations decreased losses of soil due to water erosion on slopes of 2–14^o by 36.8–80.8 % as compared with the field crop rotation.

3. Erosion-preventive cropping systems (grass-grain crop rotations and long-term perennial grasses) significantly increased SOM/SOC when maintained for ≥18 years. Therefore, erosion-preventive crop rotations and other ecosystems assisting erosion control and the ecological stability of the undulating topography can be considered as main component for soil protection strategy at undulating relief.

4. Sod-forming perennial grasses on the 10–14^o and grass-grain crop rotations on the 2–5^o and 5–10^o slopes enable rehabilitation of land degradation.

5. The erosion-resisting tillage and fertilizing-liming intensify an erosion-preventive capability of crops and crop rotations being as additional measures of soil protection strategy.

6. Introduction of optimum management system for soil conservation (sod-forming perennial grasses, soil conserving crop rotations, erosion-resisting soil tillage and fertilizing-liming) assists both soil erosion control and stability of soil degradation on the hilly-rolling relief.

6. The presented results may have wider applicability on the undulating landscapes of the temperate climate zone.

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DIRVOSAUGINĖ KALVOTO-BANGUOTO KRAŠTOVAIZDŽIO ŽEMĖNAUDOS SISTEMA

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Santrauka

Straipsnyje pateikiami mokslinių tyrimų duomenys buvo gauti Žemaičių aukštumos (Vakarų Lietuva) kalvotame-banguotame reljefe, kur vyrauja priesmėlio ir priemolio pasotintieji balkšvažemiai (*Eutric Albeluvisols - ABe*). Vandeninės dirvožemio erozijos tyrimai skirtingo statumo šlaituose, naudojant keturias skirtingas žemės naudojimo sistemas, pradėti 1982 metais. Pagrindiniai tyrimų rezultatai, įvertinantys dirvožemio vandeninės erozijos mastą, dirvožemio savybių pokyčius ir auginamų augalų produktyvumą, buvo plačiai skelbti Lietuvoje ir tarptautiniu mastu. Dirvožemio erozijos mastas skirtingo statumo šlaituose ir dirvožemio organinės medžiagos kiekis skirtingu laipsniu nuardytuose dirvožemiuose yra vertinami kaip kalvoto-banguoto kraštovaizdžio dirvožemio kokybės indikatoriai. Tyrimų rezultatai įgalina modeliuoti skirtingas antierozines žemės naudojimo sistemas, leisiančias lokalizuoti ir stabilizuoti labiausiai erozijai jautrių teritorijų ardymą ir pagerinti lengvai pažeidžiamos Baltijos pakrančių zonos ekologines sąlygas. Pasiūlytas erozingų teritorijų grupavimas atsižvelgiant į šlaitų statumą ir dirvožemio granuliometrinę sudėtį ir tokį grupavimą atitinkančios antierozinės priemonės: dirvožemio ardymą mažinanti pasėlių struktūra (antierozinės sėjomainos ir ilgaamžių žolių mišiniai) glaudžiai siejama su antierozinėmis žemės dirbimo ir pasėlių mitybos priemonėmis. Tuo parodomos galimybės laukų ir kraštovaizdžio struktūrų pertvarkymui, įgalinančiam maksimaliai apriboti vandens nuotėkį, dirvožemio ardymą ir sudaryti sąlygas degraduotų dirvožemių savybėms atstatyti.

Reikšminiai žodžiai: pasotintieji balkšvažemiai, kalvotas-banguotas kraštovaizdis, dirvožemio erozija, dirvožemio apsauga, dirvožemio savybių atstatymas.