# I skyrius. ŽEMDIRBYSTĖ

# Chapter 1. CROP AND SOIL MANAGEMENT

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## THE IMPACT OF SOIL MANAGEMENT ON SURFACE RUNOFF, SOIL ORGANIC MATTER CONTENT AND SOIL HYDROLOGICAL PROPERTIES ON THE UNDULATING LANDSCAPE OF WESTERN LITHUANIA

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### Abstract

The main objective of this paper is to summarise long-term experimental data on sediment transport, soil organic matter (SOM) losses caused by water erosion and soil moisture potential.

Results showed that 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. Erosion-preventive cropping systems (grass-grain crop rotations and long-term perennial grasses) significantly increased SOM/SOC when maintained for ≥12 years. Greatest erosion damage occurred in the ploughing treatments (7.25 t $ha^{-1}$ $yr^{-1}$). When deep autumn ploughing (CT) was replaced by deep cultivation with a heavy cultivator ($RT_{chisel}$), soil losses through erosion were 3.1 times as lesser. Soil losses under $RT_{autumn}$ and $RT_{spring}$ were 8.9 times less compared to CT and 2.9 times less compared to $RT_{chisel}$. Soil moisture retention characteristics (free water content and field moisture capacity) were higher (in the 5–10 cm layer $R^2 = 0.77^*$ and in the 15–20 cm layer $R^2 = 0.74^*$) in the soil with a higher content SOM (i.e. on the foot of the slope). On the *slope* amounts of fissures, transmission pores and residual (<0.6 μm) pores were similar, while amount of storage pores was higher under shallow ploughing than under deep ploughing. On the *foot* of the slope amount of fissures, transmission pores and storage pores were higher in shallow ploughing compared to deep ploughing, while content of residual pores was higher under deep ploughing than shallow ploughing. Soil at the foot-slope was able to transmit more of water than soil at the slope position at 1 h and 24 h measurement intervals. Relationships between soil macro-porosity and saturated hydraulic conductivity were fitted and presented. The hydraulic conductivity of arable layer on the foot of slope position after 1 h of measurement is rapid, and on the slope it is moderately rapid.

Key words: erosion-preventive crop rotations, water erosion, tillage, soil organic mater, soil moisture potential.

## Introduction

Soil erosion is a hazard associated with ecology and especially with agriculture. It is important for long-term effects on soil productivity and sustainable land use. Erosion control is now a necessity in almost every country of the world under every type of land use /Morgan, 2006/. The parent material, soil texture, relief, rainfall, wind velocity and plant cover are natural factors influencing erosion rates /Jozefaciuk C., Jozefaciuk A., 1996; Morgan, 2006/.

About 52 % of Lithuania has a hilly-rolling relief, where the soil is erodible /Kudaba, 1983/. We have investigated soil erosion processes on the Žemaičiai Uplands (Western Lithuania). The last glacier (about 12,000 years ago) left a thin layer of erodible glacial clay loam moraine on the old surface. There are long moderately and strongly sloping hills in the central part and short gently sloping and densely grouped hills in the outskirts of the Uplands. Annual precipitation is 800–858 mm in the central part of the Žemaičiai Uplands and 750–800 mm in the lower parts. About 17 % of Lithuania's agricultural land is eroded, increasing to 43–58 % in the undulating regions. Fully vegetated wasteland and perennial grasses lead to very sharp reductions in soil loss /Jankauskas et al., 2004/. Erosion extent and amount of eroded soil organic mater (SOM) depends on annual rainfall, slope gradient and soil management intensity /Li, Lindstrom, 2001/.

Jankauskas et al. (2007) revealed that soil loses on very severely eroded Eutric Albeluvisols on the undulating topography of the Žemaičiai Uplands were a combined result of natural and accelerated (tillage, water and wind) erosion. The strongest correlation was between erosion severity and slope steepness. Tillage has been identified as the main cause of accelerated soil (tillage and water) erosion on arable slopes. Numerous reports revealed that tillage creates favourable conditions for erosion and may be the primary cause of erosion /Švedas, 1974; Jankauskas, 1996, Feiza, 1997 a, b; Li, Lindstrom, 2001; Heckrath et al., 2005; White, 2006/. Other studies predicate that tillage intensity has significant effects on soil physical properties and soil moisture potential /Brady, 1974; Lal, Shukla, 2004; Feiza et al., 2004, White, 2006/. To develop a soil management system suitable for local agro-environmental conditions is vital on the undulating land of Lithuania. The erosion-resisting capability of perennial grasses and winter grains /Jankauskas, 1996; Morgan, 2006/, and reduced tillage systems /Arshad et al., 1997/ allowed the opportunity to design field experiments and to develop an erosion control system for the erodible soils of Lithuania.

Soil organic carbon (SOC) is an important quality indicator on eroded soils and is composed of a wide range of compounds that decompose at different rates, depending on their chemistry, soil temperature and moisture, biota, soil minerals and aggregation /Paul, Clark, 1996/. Plant residues in agricultural soils do not represent a large storage pool; however, their management influences water penetration, wind and water erosion and the formation of soil OM, thus affecting long term soil fertility and C storage.

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 and conservation tillage. Most of these techniques have also proved effective in preventing erosion, increasing fertility and enhancing soil biodiversity /Lal, 2002, 2003/. Soil erosion affects soil fertility. The natural fertility of Dystric Albeluvisols on the Žemaičiai Uplands during an 8-year period of investigation decreased by 21.7, 39.7 and 62.4 % on slightly, moderately and severely eroded slopes, respectively, in turn causing the deterioration of soil physico-chemical properties /Jankauskas, Fullen, 2002/.

## Materials and methods

The study formed part of an expanded programme of field and laboratory experiments. The research data were obtained from the Kaltinenai Research Station during 1981–2000 and 1995–2000. The station is located on the Western part of Lithuania on the Southern-Central Žemaičiai Uplands (55°34'N, 22°29'E). Field experiments were performed on eroded Eutric Albeluvisol sandy loam /Soil map of the world, 1994/.

***I. Effect of sustainable and environment-friendly plant growing systems on surface runoff and SOM on the undulating relief of the temperate climate zone.*** Since 1982, three long-term field experiments were conducted on slopes of 2–5° (slightly eroded), 5–10° (moderately eroded) and 10–14° (strongly eroded). The mean agro-chemical properties of the Ap horizons (0–20 cm) before the field experiments show that the topsoil was slightly acid, P-deficient, medium rich in K and contained varying SOM contents (Table 1). The highest percentage of SOM was found on the less eroded 2–5° slope and the lowest value was detected on the 10–14° slopes.

Four six-course crop rotations were compared. These were: a) The field crop rotation: 1: winter rye (*Secale cereale* L.), 2: potatoes (*Solanum tuberosum* L.), 3–4: spring barley (*Hordeum vulgaris* L.), 5–6: mixture of clover-timothy (CT) (*Trifolium pratense* L. – *Phelum pratense* L.); b) The grain-grass crop rotation: 1: winter rye, 2–4: spring barley, 5–6: mixture of clover-timothy; c) The grass-grain I crop rotation: 1: winter rye, 2: spring barley, 3–6: mixture of clover-timothy; d) The grass-grain II crop rotation: 1 winter rye, 2: spring barley, 3–6: mixture of orchard grass – red fescue (OF) (*Dactylis glomerata* L. – *Festuca rubra* L.).

***Table 1.*** Soil characteristic of the 0–20 cm layer at experiments established in 1981 (n = 32)

***1 lentelė.*** *Dirvožemio 20 cm sluoksnio charakteristika įrengiant bandymus 1981 m. (n = 32)*

| Slope inclination (degrees) *Šlaito nuolydis (laipsniais)* | $pH_{KCl}$ | Hydrolytic acidity *Hidrolizinis rūgštumas* cmol(+)kg$^{-1}$ | Exchangeable bases *Bazingumas* | Available elements *Judrieji elementai* (mg kg$^{-1}$) | | SOM *Dirvožemio organinė medžiaga* (%) |
|---|---|---|---|---|---|---|
| | | | | P | K | |
| 2–5 | 5.8 | 20.1 | 119 | 49.8 | 146.1 | 2.85 |
| 5–10 | 5.3 | 24.5 | 94 | 18.3 | 127.0 | 2.20 |
| 10–14 | 5.8 | 16.7 | 96 | 29.7 | 131.2 | 2.08 |

A multi-species mixture of perennial grasses for long-term use (sod-forming grasses) has been grown on 10–14° slopes, instead of the field crop rotation, as root crops are not recommended in Lithuania on slopes >10° /Švedas, 1974; Jankauskas, 1996/. The grass mixture consisted of 20 % each of common timothy, red fescue, white clover (*Trifolium repens* L.), smooth-stalked meadow grass (*Poa pratensis* L.) and birdsfoot trefoil (*Lotus corniculatus* L). Some crop rotations, as periodically rotated agri-phytocenoses, were located in the same sites during the 18-year period (three six-course crop rotations); therefore, they can be considered as different land use systems.

***II. Tillage influence on surface runoff and SOM in the undulating landscape.*** Three tillage field trials were set up on the slope, top of the hill and foot of the hill in July 1995. The weakly eroded slope was 70 m long and had an inclination of 6°. Crop rotation: 1) winter wheat (*Triticum aestivum* L.*);* 2) spring barley; 3) oats (*Avena sativa* L.); 4) spring barley (*Hordeum vulgaris* L.); 5) ley: red clover + timothy (*Trifolium pratense* L. – *Phleum pratense* L.). Table 2 presents soil characteristics of the site. Field experiments consisted of four replicates. Table 3 shows the design of investigated tillage systems.

***Table 2.*** Soil characteristics of 0–20 cm layer at experiments establishment in 1995 (n = 48)
***2 lentelė.*** *Dirvožemio 20 cm sluoksnio charakteristika įrengiant bandymus 1995 m. (n = 48)*

| Landscape position *Reljefas* | Available P (A-L) *Judrusis P (A-L)* (mg kg$^{-1}$) | Available K (A-L) *Judrusis P (A-L)* (mg kg$^{-1}$) | SOM *Dirvožemio organinė medžiaga* (%) | $pH_{KCl}$ |
|---|---|---|---|---|
| Slope / *Šlaitas* | 18 | 133 | 2.13 | 5.3 |
| Foot / *Pašlaitė* | 19 | 112 | 3.73 | 5.5 |

***Table 3.*** Experimental design of the field trials
***3 lentelė.*** *Lauko bandymų tyrimų schema*

| Treatment abbreviation *Varianto santrumpa* | Tillage systems (Factor A) / *Žemės dirbimo sistemos (veiksnys A)* | |
|---|---|---|
| | Primary soil tillage *Pagrindinis žemės dirbimas* | Presowing soil tillage *Priešsėjinis žemės dirbimas* |
| CT | Deep ploughing<br>*Gilus arimas (22 cm)* | Cultivation 8 cm + harrowing 5 cm<br>*Kultivavimas + akėjimas* |
| $RT_{chisel}$ | Glyphosate + chiselling<br>*Glifosatas + čizeliavimas (20 cm)* | Cultivation 8 cm + harrowing 5 cm<br>*Kultivavimas + akėjimas* |
| $RT_{autumn}$ | Glyphosate, no-tillage<br>*Glifosatas, nedirbta* | Harrowing with a narrow tine rotary harrow<br>*Akėjimas peilinėmis akėčiomis (6 cm)* |
| $RT_{spring}$ | No-tillage / *Nedirbta* | Glyphosate + harrowing with a narrow tine rotary harrow / *Akėjimas peilinėmis akėčiomis (6 cm)* |

### *III. Deep and shallow ploughing effect on soil water properties and degree of risk of erosion.*

Covering field and laboratory experiments of soil physical properties in deep ploughed and shallow ploughed plots were carried out in 1996. Soil water potential, pore size distribution, soil water conductivity and air permeability were investigated.

Undisturbed core samples were taken with steel cylinders (internal diameter 7.0 cm, height 5.0 cm) from 5–10 and 15–20 cm soil depth in two replicates from shallow and deep ploughed treatments at two landscape positions (i.e. shoulder and foot of the slope).

Saturated hydraulic conductivity of the soil was determined by the constant head method at +20 °C temperatures with an interval of 1 and 24 h between measurements /Klute, Dirksen, 1986/.

An equivalent pore-size distribution for different tension levels (pF 0.7, 1.0, 1.5, 1.7, 2.0, 2.5, 2.8, 3.0, 3.7 and 4.2) was calculated as described by S. Andersson and P. Wiklert (1972) as follows:

$$\mathrm{D} = \frac{30}{h}$$

Where: D – diameter of pores in cm; h - suction level in cm (water column) and 30 – the constant.

For SOM determination, each sample was analyzed by Tyurin titrimetric method. This method is a wet combustion method, where SOM is oxidized by 0.2 M potassium dichromate solution with sulphuric acid and heated at boiling point for precisely 5 min. After oxidation, excess dichromate is determined by titration with ammonium ferrous sulphate (Mohr's salt solution) and SOM calculated by multiplying the SOC content by the alteration factor f = 1.724 /Aleksandrova, Naidenova, 1976/.

Soil runoff was measured with aluminium stationary collectors.

## Results and discussion

### *I. Effect of sustainable and environment-friendly crop systems on surface runoff and SOM on the undulating relief of the temperate climate zone.*

***Surface runoff.*** The erosion-protection capability of different crops varied widely. Mean soil losses (1983–2000) under winter rye were 3.2, 6.7 and 8.6 $m^3$ $ha^{-1}$ $yr^{-1}$ and under spring barley 9.0, 19.1 and 27.1 $m^3$ $ha^{-1}$ $yr^{-1}$ from slopes of 2–5°, 5–10° and 10–14°, respectively. Perennial grasses prevented erosion almost completely; with only a small soil loss from the grass-grain I crop rotation due to a poor red clover cover in 1992. Potatoes had the least erosion-preventive capability with soil losses from slopes of 2–5° and 5–10° being 8.7 times higher than under winter rye and 3.1 times higher than under spring barely. The highest soil losses appeared during the first crop rotation (1983–1988) and the least during the third crop rotation (1995–2000). Erosion strongly depended on rainfall intensity when cultivated soil had not been covered by plant cover.

The highest soil losses (6.4–20.5 $m^3$ $ha^{-1}$ $yr^{-1}$) occurred under the field crop rotation (Table 4). The lower losses (4.9–15.9 $m^3$ $ha^{-1}$ $yr^{-1}$) were measured under the grain-grass crop rotation and least (1.6–4.7 $m^3$ $ha^{-1}$ $yr^{-1}$) were registered under the grass-grain crop rotations that contained four fields of perennial grasses. There were no significant differences in soil losses between the grass-grain I and II crop rotations. The largest mean soil loss (11.4 m$^3$ ha$^{-1}$ yr$^{-1}$) occurred at the 10–14° slopes and it decreased on gentler slopes, losing a mean of 7.9 m$^3$ ha$^{-1}$ yr$^{-1}$ from the 5–10° slope and 3.6 m$^3$ ha$^{-1}$ yr$^{-1}$ from the 2–5° slope.

***Table 4.*** Influence of different crop rotations on water erosion rates
***4 lentelė.*** *Skirtingų rotacijų įtaka vandens erozijai*

| Crop rotations<br>*Augalų sėjomainos* | Soil losses m$^3$ ha$^{-1}$<br>*Dirvožemio nunešimas m$^3$ ha$^{-1}$* | | | | Mean soil losses<br>*Vidutiniškai nunešta dirvožemio* (t ha$^{-1}$)<br>1983–2000 |
|---|---|---|---|---|---|
| | I rotation<br>*I rotacija*<br>1983–1988 | II rotation<br>*II rotacija*<br>1988–1994 | III rotation<br>*III rotacija*<br>1994–2000 | Mean<br>*vidutiniškai*<br>1983–2000 | |
| 2–5° slope / *2–5° šlaitas* | | | | | |
| Field crop rotation<br>*Lauko sėjomaina* | 7.99 | 8.45 | 2.73 | 6.43 | 9.90 |
| Grain-grass crop rotation<br>*Javų-žolių sėjomaina* | 6.81 | 5.62 | 2.16 | 4.88 | 7.52 |
| Grass-grain I crop rotation<br>*Žolių-javų sėjomaina I* | 1.39 | 2.36 | 1.08 | 1.61 | 2.48 |
| Grass-grain II crop rotation<br>*Žolių-javų sėjomaina II* | 1.35 | 2.32 | 1.20 | 1.63 | 2.51 |
| LSD$_{05}$ / $R_{05}$ | 1.34 | 1.03 | 0.19 | 0.57 | 0.88 |
| 5–10° slope / *5–10° šlaitas* | | | | | |
| Field crop rotation<br>*Lauko sėjomaina* | 24.13 | 14.91 | 4.16 | 14.53 | 23.39 |
| Grain-grass crop rotation<br>*Javų-žolių sėjomaina* | 19.84 | 10.80 | 2.57 | 11.16 | 17.97 |
| Grass-grain I crop rotation<br>*Žolių-javų sėjomaina I* | 5.82 | 1.80 | 1.17 | 3.03 | 4.88 |
| Grass-grain II crop rotation<br>*Žolių-javų sėjomaina II* | 5.49 | 1.86 | 1.15 | 2.93 | 4.72 |
| LSD$_{05}$ / $R_{05}$ | 2.84 | 2.13 | 0.35 | 1.18 | 1.90 |
| 10–14° slope / *10–14° šlaitas* | | | | | |
| Field crop rotation<br>*Lauko sėjomaina* | 0(35.61)* | 0(21.030* | 0(4.47)* | 0(20.50)* | 0(32.19)* |
| Grain-grass crop rotation<br>*Javų-žolių sėjomaina* | 29.56 | 14.78 | 3.07 | 15.88 | 24.93 |
| Grass-grain I crop rotation<br>*Žolių-javų sėjomaina I* | 8.08 | 3.98 | 1.52 | 4.61 | 7.24 |
| Grass-grain II crop rotation<br>*Žolių-javų sėjomaina II* | 8.71 | 3.62 | 1.49 | 4.69 | 7.36 |
| LSD$_{05}$ / $R_{05}$ | 2.50 | 1.37 | 0.41 | 0.92 | 1.44 |

Note: * On the 10–14° slope potatoes were not grown. The data were calculated by a group comparison method

*Pastaba: 10–14° šlaite bulvės nebuvo auginamos. Duomenys apskaičiuoti grupių palyginimo metodu*

However, even the grass-grain crop rotations could not completely suppress soil erosion. The average annual rates of soil loss due to water erosion were 4.61–4.69 m$^3$ ha$^{-1}$ on slopes >10$^{o}$, 2.93–3.03 m$^3$ ha$^{-1}$ on slopes of 5–10$^{o}$ and 1.61–1.63 m$^3$ ha$^{-1}$ on slopes of 2–5$^{o}$. Therefore, only grass-grain crop rotations can be considered as environmentally friendly land use systems on slopes ≤ 5$^{o}$. Soil losses are not tolerable under other land use systems or on slopes > 5$^{o}$.

***Table 5.*** SOM content under diffrent crop rotations
***5 lentelė.*** *Dirvožemio organinės medžiagos kiekis skirtingose sėjomainose*

| Crop rotations<br>*Augalų sėjomainos* | SOM (%) / *Dirvožemio organinė medžiaga* (%) | | |
|---|---|---|---|
| | After I rotation<br>*Po I rotacijos*<br>1988 | After II rotation<br>*Po II rotacijos*<br>1994 | After III rotation<br>*Po III rotacijos*<br>2000 |
| 2–5$^{o}$ slope / *2–5$^{o}$ šlaitas* | | | |
| Field crop rotation / *Lauko sėjomaina* | 3.47a* | 2.73a,b | 2.64a |
| Grain-grass crop rotation<br>*Javų-žolių sėjomaina* | 3.46a | 2.54a | 2.99b |
| Grass-grain I crop rotation<br>*Žolių-javų sėjomaina I* | 3.08a | 3.65b | 3.39c |
| Grass-grain II crop rotation<br>*Žolių-javų sėjomaina II* | 3.23a | 3.47b | 3.46c |
| LSD$_{05}$ / $R_{05}$ | 0.412 | 0.301 | 0.284 |
| 5–10$^{o}$ slope / *5–10$^{o}$ šlaitas* | | | |
| Field crop rotation / *Lauko sėjomaina* | 2.52a | 2.37a | 2.17a |
| Grain-grass crop rotation<br>*Javų-žolių sėjomaina* | 2.47a | 2.35a | 2.01a |
| Grass-grain I crop rotation<br>*Žolių-javų sėjomaina I* | 2.48a | 2.27a | 2.75 b |
| Grass-grain II crop rotation<br>*Žolių-javų sėjomaina II* | 2.41a | 2.31a | 2.67b |
| LSD$_{05}$ / $R_{05}$ | 0.287 | 0.169 | 0.1.64 |
| 10–14$^{o}$ slope / *10–14$^{o}$ šlaitas* | | | |
| Perennial grasses** / *Daugiametės žolės* ** | 2.49a** | 2.59b** | 2.51b** |
| Grain-grass crop rotation<br>*Javų-žolių sėjomaina* | 2.42a | 2.24a | 1.99a |
| Grass-grain I crop rotation<br>*Žolių-javų sėjomaina I* | 2.71b | 2.47b | 2.45b |
| Grass-grain II crop rotation<br>*Žolių-javų sėjomaina II* | 2.50a | 2.39a | 2.43b |
| LSD$_{05}$ / $R_{05}$ | 0.232 | 0.221 | 0.328 |

Note: Values with the same letter subscript are not significantly ($P<0.05$) different. ** The sod-forming perennial grasses were grown instead of the field crop rotation on the 10–14$^{o}$ slope

*Pastaba: Skaičiai, pažymėti ta pačia raide, rodo statistiškai nepatikimą skirtumą esant tikimybės lygiui ($P<0,05$). ** Velėną formuojančios daugiametės žolės buvo augintos lauko sėjomainoje, 10–14$^{o}$ statumo šlaite*

***SOM on the undulating relief.*** SOM content changes in long-term field trials illustrate multiple influences of land use systems on SOM dynamics (Table 5). The higher soil losses lead to higher SOM losses. There were small changes in % SOM after both the first and even the second crop rotation. 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$^o$ and 5–10$^o$ slopes compared with the field crop rotation, and under the sod-forming perennial grasses on the 10-14$^o$ slope compared with the grain-grass crop rotation.

Analogous results were found in relative SOM contents on the 80 investigated plots (Table 6). SOM content was lower by 11.7, 25.3 and 49.0 %, on the slightly, moderately and severely eroded slopes, respectively, compared with SOM content on adjacent flat land. The decreasing amounts of SOM can be considered a potential source of $CO_2$, thus contributing to atmospheric greenhouse gases. Of course, some lost SOM will contribute to colluvial sediments.

***Table 6.*** Dependence of SOM content on slope gradient and erosion severity on the Žemaičiai Upland

***6 lentelė.*** *Dirvožemio organinės medžiagos kiekio priklausomumas nuo šlaito nuolydžio ir erozijos intensyvumo Žemaičių aukštumoje*

| Relief component<br>*Reljefas* | Degree of soil erosion<br>*Dirvožemio erozijos laipsnis* | SOM content from 80 investigated plots *Vidutinis dirvožemio organinės medžiagos kiekis 80 tirtų plotų* | | |
|---|---|---|---|---|
| | | % | decrease *sumažėjimas* (%) | in relative numbers *santykiniais skaičiais* |
| Flat land / *Lyguma* | Non-eroded / *Neeroduota* | 25.7 | - | 100 |
| 2–5$^o$ slopes / *šlaitai* | Slightly eroded<br>*Silpnai eroduota* | 22.7 | 3.0 | 88.3 |
| 5–10$^o$ slopes / *šlaitai* | Moderately eroded<br>*Vidutiniškai eroduota* | 19.2 | 6.5 | 74.7 |
| 10–14$^o$ slopes / *šlaitai* | Severely eroded<br>*Stipriai eroduota* | 13.1 | 12.6 | 51.0 |
| Foot-slopes / *pašlaitės* | Deposited soil<br>*Užneštas dirvožemis* | 30.9 | - | 120.2 |
| $LSD_{05}$ / $R_{05}$ | | 0.19 | - | - |

Note: 80 investigated plots in the villages of Gineikiai, Burniai (Šilalė District) and Pavandenė (Telšiai District)

*Pastaba: tirta 80 vietų Gineikių, Burnių (Šilalės r.) bei Pavandenės (Telšių r.) kaimuose*

***II. Tillage influence on surface runoff and SOM content***.

Our results suggested that highest runoff and highest soil losses occurred during *autumn-spring* under traditional tillage (CT) – mean annual losses amounted to 6.45 t ha$^{-1}$ of absolutely dry soil. Replacement of CT by $RT_{chisel}$ decreased erosion on average by 3.3 fold compared to CT. Renouncement of primary tillage and use of Glyphosate herbicide in autumn ($RT_{autumn}$) decreased soil losses on average by 10.0 fold compared to CT and on average by 3.0 fold compared to $RT_{chisel}$. After renouncement of primary tillage and use of Glyphosate herbicide in spring ($RT_{spring}$), soil losses were marginally lower compared to $RT_{autumn}$. Soil losses during spring-autumn period were on average 5.6 times less than the autumn-spring period. Tillage influence on soil losses during the spring-autumn period was weaker compared to the influence of autumn-spring period. Mean annual losses were 0.80 t ha$^{-1}$ of absolutely dry soil under CT. This index in the $RT_{chisel}$ was lower on average by 2.0 fold compared to CT; in the $RT_{autumn}$ and $RT_{spring}$ it was less on average by 3.2 fold compared to CT and less on average by 1.6 fold compared to $RT_{chisel}$.

Summarised data (Table 7) from the spring-autumn and autumn-spring seasons suggest that the greatest erosion damage occurred on the ploughed treatments (7.25 t ha$^{-1}$ per year). When deep autumn ploughing was replaced by deep cultivation by a heavy cultivator (chisel), soil losses due to erosion declined 3.1 fold per year. Soil losses under $RT_{autumn}$ and $RT_{spring}$ were 8.9 fold lesser compared to CT and 2.9 fold lesser compared to $RT_{chisel}$.

***Table 7.*** Soil, P, K and soil organic mater losses under different tillage systems
***7 lentelė.*** *Dirvožemio, P, K ir organinės medžiagos nuostoliai skirtingo žemės dirbimo sistemose*

| | Mean runoff / *Vidutiniškai nunešta* | | | |
|---|---|---|---|---|
| | Soil / *Dirvožemis* (t ha$^{-1}$ yr$^{-1}$) | P (kg t$^{-1}$ of soil) *P (kg t$^{-1}$ dirvožemio)* | K (kg t$^{-1}$ of soil) *K (kg t$^{-1}$ dirvožemio)* | SOM (kg t$^{-1}$ of soil) *Dirvožemio organinė medžiaga (kg t$^{-1}$ dirvožemio)* |
| CT | 7.25 | 2.93 | 20.67 | 144.07 |
| $RT_{chisel}$ | 2.38 | 0.93 | 5.42 | 45.68 |
| $RT_{autumn}$ | 0.88 | 0.36 | 2.34 | 17.02 |
| $RT_{spring}$ | 0.75 | 0.29 | 1.80 | 12.02 |

### *III. Deep and shallow ploughing effects on soil moisture characteristics. Soil moisture retention*

On the *slope* position, shallow and deep ploughing sustained similar soil moisture retention conditions in the 5–10 cm layer, while deep ploughing tended to increase field capacity (pF 1.7–4.0) in the 15–20 cm soil layer (Fig. 1) where plant available soil moisture content was higher under deep ploughing on average by 2 volume percent units compared to shallow ploughing. Permanent wilting point (wilting point – is defined as the minimum soil moisture at which a plant wilts and can no longer recover its turgidity when placed in a saturated atmosphere for 12 hours) was similar in both soil layers (on average 9 volume percent) and did not significantly depend on tillage depth.

On the *foot of the slope* shallow ploughing caused higher free water content (pF 0.0–1.7) in the 5–10 cm soil layer (Fig. 2). Shallow and deep ploughing sustained similar field moisture capacity in the 5–10 cm layer, while deep ploughing tended to increase this characteristic in 15–20 cm layer where plant available soil moisture content was higher under deep ploughing on average by 3 volume percent units compared to shallow ploughing. Permanent wilting point in the 5–10 cm layer was 9 volume percent under shallow ploughing and 11 volume percent under deep ploughing.

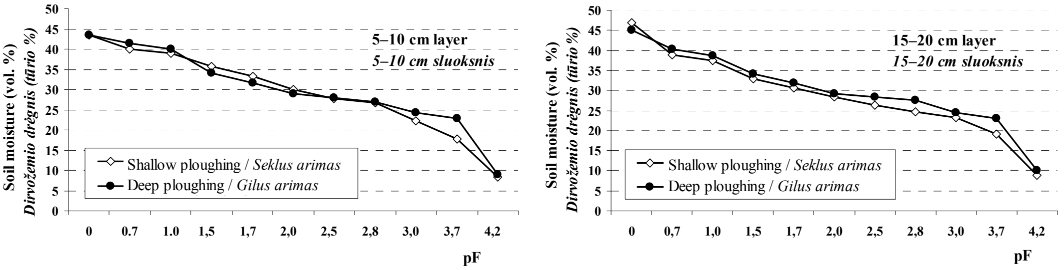

***Figure 1.*** Effect of deep and shallow ploughing on soil water retention curves on the slope

***1 paveikslas.*** *Gilaus ir seklaus arimo įtaka dirvožemio drėgmės potencialui*

According to summarised soil moisture retention results for the whole arable layer, the ploughing depth factor did not significantly affect differences of this soil characteristic on the slope, but soil moisture retention under deep ploughing on the foot of the slope was noticeably higher compared to shallow ploughing.

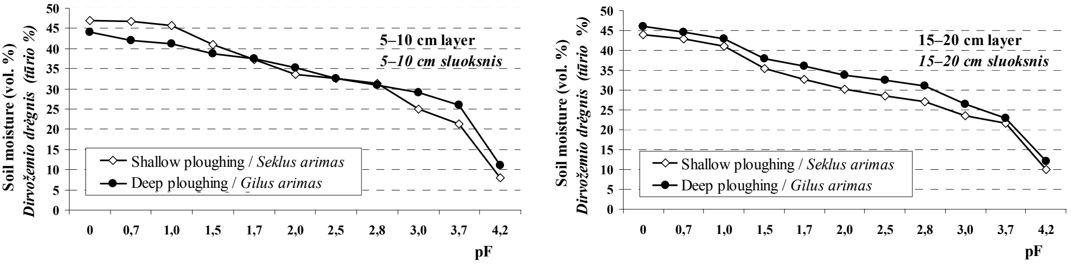

***Figure 2.*** Effect of deep and shallow ploughing on soil water retention curves on the foot of the slope

***2 paveikslas.*** *Gilaus ir seklaus arimo įtaka dirvožemio drėgmės potencialui kalvos pašlaitėje*

There are numerous factors that affect soil moisture characteristics. In addition to pore size distribution, SOM content plays an important role, especially at low suction (or field capacity). Soil wetness at field soil moisture capacity (pF 1.7–4.0) increases with increased SOM content /Brady, 1974; Lal, Shukla, 2004/. Our data revealed that soil moisture retention characteristics (free water content and field capacity) were higher in the soil with higher SOM content, i.e. on the foot of the slope (Fig. 3 and 4).

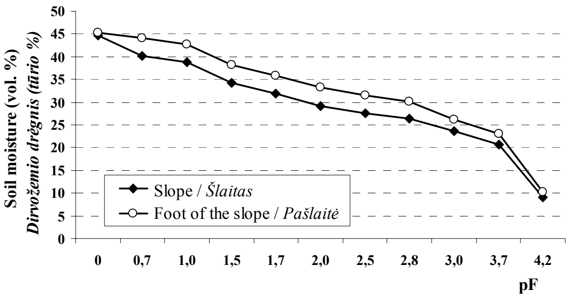

***Figure 3.*** The pF curve of soils of similar texture but with high (foot of the slope) and low (slope) SOM contents
***3 paveikslas.*** *Dirvožemio pF kreivės vienodos granuliometrinės sudėties dirvožemiuose, bet esant dideliam (pašlaitė) ir mažam (šlaitas) organinės medžiagos kiekiui*

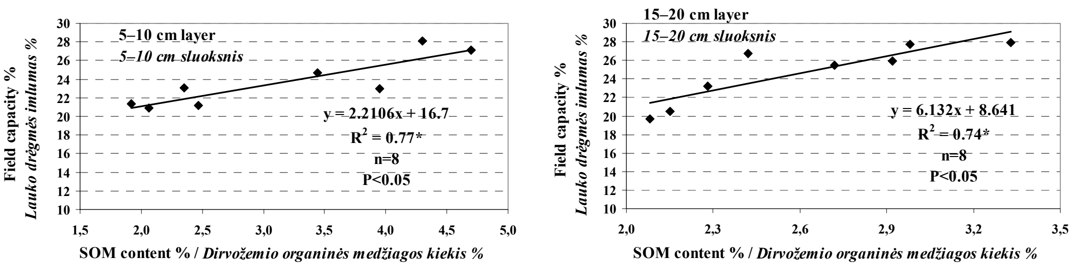

***Figure 4.*** Relationship between field capacity and SOM content at both landscape positions
***4 paveikslas.*** *Tarpusavio priklausomumas tarp dirvožemio lauko drėgmės imlumo ir organinės medžiagos kiekio abiejuose reljefo elementuose*

### *Pore-size distribution*

In this paper the classification of soil porosity in defined size groups is specified according to K. Berglund (1996): macropores (>30 µm; respectively pF ≤ 2.0), mesopores (30–0.2 µm, respectively 2.0 > pF ≤ 4.2) and micropores (< 0.2 µm, respectively pF > 4.2). An attempt to classify pores in regard to their function, rather than just size alone, has been made by D. J. Greenland (1977). He proposed a scheme to describe the functional properties of pore size groups as follows: fissures (> 500 µm), transmission pores (500–50 µm), storage pores (50–0.5 µm) and residual pores (< 0.5 µm). For soil tillage studies it is important to have the information about soil macro-porosity, and especially about the transmission pores from which water drains due to gravity.

Data revealed that *mesopores* monopolized a large portion of total soil porosity of the 5–20 cm layer in both deep and shallow ploughed plots and in all landscape positions (Fig. 5). Theirs amount reached 19.6–19.8 % on the slope and 20.9–23.5 % on the foot of the slope. On average, the volume of *macropores* amounted to 13.6 % on the slope and 14.0 % on the foot. Quantity of macropores on the slope in both deep ploughed and shallow ploughed plots was similar; while on the foot it was highest under shallow ploughing (17.8 %) and least under deep ploughing (10.2 %). The volume of *micropores* was slightly higher on the foot (11.0 %) than on the slope (9.4 %), but ploughing depth had no significant influence on the content of micropores.

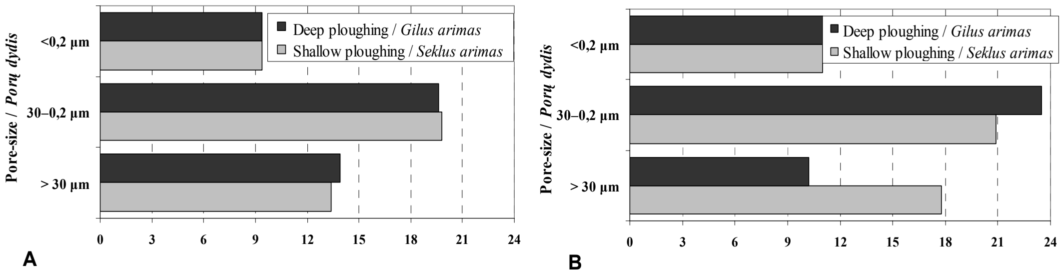

***Figure 5.*** Pore-size distribution in the 5–20 cm soil layer on the slope (A) and on the foot of the slope (B)
***5 paveikslas.*** *Porų pasiskirstymas pagal jų dydį dirvožemio 5–20 cm sluoksnyje šlaite (A) ir pašlaitėje (B)*

More detailed analysis (according to Greenland, 1977) showed that the pores, < 0.6 µm occupied most total soil porosity at both ploughing depths and landscape positions (Table 8).

***Table 8.*** Pore-size distribution in the 5–20 cm soil layer
***8 lentelė.*** *Dirvožemio porų pasiskirstymas 5–20 cm sluoksnyje*

| Tillage<br>*Žemės dirbimas* | Pore-size (µm) and their content (vol. % of total porosity)<br>*Porų skersmuo ir jų kiekis (tūrio %)* | | | | Total porosity (vol. %)<br>*Bendrasis poringumas (tūrio %)* |
|---|---|---|---|---|---|
| | >600 | 600–60 | 60–0.6 | <0.6 | |
| Slope (low SOM content) / *Šlaitas (mažas organinės medžiagos kiekis)* | | | | | |
| Shallow ploughing / *Seklus arimas* | 3.2 | 7.4 | 13.6 | 18.4 | 42.6 |
| Deep ploughing / *Gilus arimas* | 2.1 | 9.2 | 8.8 | 22.9 | 43.0 |
| Foot of the slope (high SOM content) / *Pašlaitė (didelis organinės medžiagos kiekis)* | | | | | |
| Shallow ploughing / *Seklus arimas* | 4.8 | 9.8 | 13.6 | 21.4 | 49.6 |
| Deep ploughing / *Gilus arimas* | 1.4 | 6.6 | 12.3 | 24.4 | 44.7 |

On the *slope* amounts of fissures, transmission pores and the least pores were similar, while the amount of storage pores was higher under shallow ploughing than that for deep ploughing. Nevertheless, both deep and shallow ploughing had no significant influence on total soil porosity on the slope.

On the *foot* of the slope soil total porosity was higher under shallow ploughing compared with deep ploughing. Furthermore, amount of fissures, transmission pores and storage pores there was higher compared to deep ploughing, while the content of residual pores was higher under deep ploughing than for shallow ploughing.

### *Soil saturated hydraulic conductivity*

Soil characteristics to readily permeate and keep water into deeper soil layers are very important, especially on hill slopes. When the water rapidly moves into deeper soil layers there is less likelihood of water erosion. However, on the other hand, a high water permeability of soil is one of the reasons causing rapid leaching of nutrients from the plough layer as well as increasing the threat of environmental pollution.

Soil hydraulic conductivity parameters help to evaluate soil water potential level on undulating relief. According to the international classification /Guidelines for soil description, 1990/ water permeability in the 5–20 cm layer on the foot of the hill one hour after taking measurements could be defined as medium rapid, and on the slope as rapid. Furthermore, the soil property to permeate water, when it has been fully saturated for 24 hours, is a relevant characteristic which defines soil resistance to very difficult conditions. Our tests revealed that on the foot of the hill the soil saturated hydraulic conductivity declined sharply after 24 hours, compared with the water permeability after one hour (Table 9). This is explained by slaking, in the course of which intensively flowing water through the soil breaks down and washes down soil particles and clogs soil pores. Nonetheless, soil water permeability on the foot of the hill remained sufficiently high after 24 hours and was defined as rapid.

Many scientific sources revealed that soil hydraulic conductivity depends on pore size distribution /Brady, 1974; Lal, Shukla, 2004; White, 2006/. Total porosity within soil aggregates and their connectivity with inter-aggregate pore spaces influence the movement and retention of solutes, chemical processes, aeration, erosion and biological activity /Revil, Cathles, 1999/. Consequently, spatial distributions of soil organic carbon, solutes, and microbial communities within aggregates depend on the pore development within aggregates /Chenu et al., 2001/. Tillage enhances the decomposition of soil organic matter and often increases wetting–drying cycles of soils, disrupting soil aggregates in a manner that leads to structural deterioration including reductions in the stability and collapse of intra-aggregate pores /Beare et al., 1994/. Wetting and drying cycles induce hydration pressures within aggregates, causing unstable aggregates to collapse /Ghezzehei, Or, 2003/. Similar forces contribute to the expansion of pores within stable aggregates /Horn et al., 1995/. There is a general concept that tillage decreases aggregate stability by increasing mineralization of organic matter and exposing aggregates to additional raindrop impact energies /Amézketa, 1999; Balesdent et al., 2000/. However, reports of tillage modifications on macro-pore structure and hydraulic properties at the field scale are often contradictory /Heard et al., 1988; Lal, Van Doren, 1990; Coutadeur et al., 2002/ and there are no comparative experimental data on intra-aggregate porosity and associated hydraulic properties modified by tillage. Park Eun-Jin and Smucker (2005) revealed that relationships between porosities and *Ks* imply differences in pore connectivity within aggregates from CT and NT.

***Table 9.*** Soil saturated hydraulic conductivity (*Ks*) under deep and shallow ploughing on the slope and foot of the slope
***9 lentelė.*** *Dirvožemio, prisotinto vandeniu, laidumas (Ks) sekliai ir giliai suarus dirvą šlaite ir pašlaitėje*

| Tillage<br>*Žemės dirbimas* | Soil layer<br>*Dirvožemio sluoksnis* (cm) | After 1 hour / *Po 1 valandos* | | | After 24 hours<br>*Po 24 valandų* | | |
|---|---|---|---|---|---|---|---|
| | | K (cm h$^{-1}$) | log K | *Ks* | K (cm h$^{-1}$) | log K | *Ks* |
| Slope (low SOM content) / *Šlaitas (mažas organinės medžiagos kiekis)* | | | | | | | |
| Shallow ploughing | 5–10 | 1.74 | 0.2296 | 1.70 | 1.17 | 0.0681 | 1.17 |
| *Seklus arimas* | 15–20 | 9.85 | 0.9932 | 9.84 | 2.92 | 0.4616 | 2.89 |
| Deep ploughing | 5–10 | 5.14 | 0.6913 | 4.91 | 2.27 | 0.3378 | 2.18 |
| *Gilus arimas* | 15–20 | 8.68 | 0.7926 | 6.20 | 3.08 | 0.4271 | 2.64 |
| Foot of the slope (high SOM content) / *Pašlaitė (didelis organinės medžiagos kiekis)* | | | | | | | |
| Shallow ploughing | 5–10 | 9.50 | 0.9545 | 9.00 | 3.81 | 0.5798 | 3.80 |
| *Seklus arimas* | 15–20 | 42.67 | 1.2692 | 18.59 | 18.64 | 0.9506 | 8.93 |
| Deep ploughing | 5–10 | 3.70 | -0.2652 | 0.54 | 0.80 | -0.4167 | 0.38 |
| *Gilus arimas* | 15–20 | 22.61 | 1.2519 | 17.86 | 5.43 | 0.6949 | 4.95 |

We noticed that on the slope in the 5–10 cm layer after 1 h of measurement *Ks* was 1.70 L h$^{-1}$ under shallow ploughing and approximately 2.9 times higher than under deep ploughing (Table 9). In the 15–20 cm layer *Ks* was 9.84 L h$^{-1}$ under shallow ploughing whereas under deep ploughing it tended to decrease. On the foot of the slope in the 5–10 cm layer after 1 h of measurement *Ks* was 9.00 L h$^{-1}$ under shallow ploughing and approximately 16.7 fold lower than under deep ploughing, while in the 5–20 cm layer *Ks* was very similar in both tillage treatments. We propose that tillage can influence soil stratification according to hydraulic properties, but the character of this stratification depends on relief position and SOM content.

After 24 h of measurement, the hydraulic conductivity reduced concerning both tillage treatments and landscape positions. On the slope, the value of this index in the 5–10 and 15–20 cm layers reduced by 31 and 71 % respectively under shallow ploughing and by 56 and 57 % respectively under deep ploughing. On foot of the slope, the hydraulic conductivity also reduced significantly. After 24 h of measurement *Ks* in the 5–10 and 15–20 cm layers was lower by 58 and 52 %, respectively, under shallow ploughing and by 30 and 72 %, respectively, under deep ploughing.

It is important to notice that soil at the foot of the slope was able to transmit more water than soil at the slope position at both measurement intervals.

The regression equation to express the relationship between soil macro-porosity and saturated hydraulic conductivity was fitted and presented in Fig. 6.

According to the Guideline for Soil Description (1990), the hydraulic conductivity of the arable layer on the foot of slope position after 1 h of measurement is considered as rapid, and on the slope as moderately rapid. Moreover, the data after 24 h of measurement can be used as an index of the soil's ability to withstand extremely difficult conditions for water transmission. These data revealed that the reduction in hydraulic conductivity (*Ks*) on the slope reached, on average, 3.44 L $h^{-1}$, while on the foot of slope the reduction was greater: 6.98 L $h^{-1}$. This means that the plough layer of the foot of slope position was less prone to conduct water after being flooded for 24 h. The explanation of this might be that the pores in the soil were clogged by slaked soil particles and water flow was hindered.

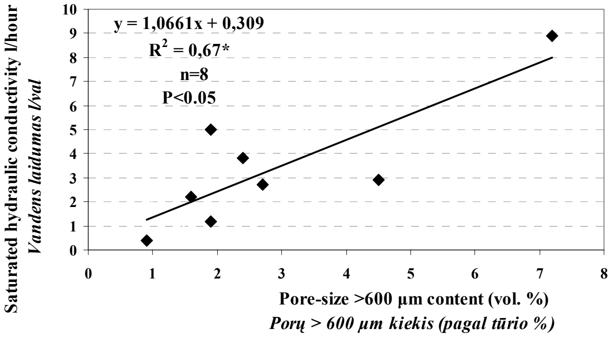

***Figure 6.*** Relationship between macro-porosity and saturated hydraulic conductivity in the 5–20 cm soil layer at both landscape positions after 24 h of flooding
***6 paveikslas.*** *Tarpusavio priklausomumas tarp dirvožemio makroporingumo ir dirvožemio (po 24 h po jo prisotinimo vandeniu) laidumo dviejuose reljefo elementuose 5–20 cm dirvožemio sluoksnyje*

Although of the hydraulic conductivity of the soil reduced markedly after being saturated for 24 h, it was still rapid in most specimens. The exception was the shallow ploughing treatment on the foot of slope position, where it still remained moderately rapid.

On the whole, the feature of the soil to rapidly transport downward an excess of water is very important on the hill slope, since water run-off and, finally, water erosion extension can be diminished. On the other hand, this feature of our soils should be taken into consideration when solving problems of environmental pollution due to risks of leaching plant nutrients from the soil.

## Conclusions

1. 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.

2. Erosion-preventive cropping systems (grass-grain crop rotations and long-term perennial grasses) significantly increased SOM/SOC when maintained for ≥12 years.

3. The greatest erosion damage occurred in the ploughed treatments (7.25 t $ha^{-1}$ $yr^{-1}$). When deep autumn ploughing (CT) was replaced by deep cultivation with a heavy cultivator ($RT_{chisel}$), soil losses through erosion declined 3.1 fold. Soil losses under $RT_{autumn}$ and $RT_{spring}$ were 8.9 fold lower compared to CT and 2.9 fold lower compared to $RT_{chisel}$.

4. Soil moisture retention characteristics (free water content and field moisture capacity) were higher in the soil with a higher SOM content (i.e. on the foot of the slope).

5. On the *slope,* the amounts of fissures, transmission pores and residual pores were similar, while the amount of storage pores was higher under shallow ploughing than under deep ploughing. On the *foot* of the slope, the amount of fissures, transmission pores and storage pores were higher compared to deep ploughing, while the content of residual pores was higher under deep ploughing than under shallow ploughing.

6. Soil at the foot of the slope was able to transmit more water than soil at the slope position at 1 h and 24 h measurement intervals. The hydraulic conductivity of the arable layer on the foot of slope position after 1 h of measurement was rapid, and on the slope it was moderately rapid.

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# DIRVOŽEMIO NAUDOJIMO ĮTAKA PAVIRŠINIAM VANDENS NUOTĖKIUI, ORGANINĖS MEDŽIAGOS KIEKIUI IR HIDROLOGINĖMS DIRVOŽEMIO SAVYBĖMS VAKARŲ LIETUVOS BANGUOTO RELJEFO DIRVOSE

V. Feiza, D. Feizienė, B. Jankauskas, G. Jankauskienė

## Santrauka

Šio straipsnio tikslas – apibendrinti ilgamečių tyrimų rezultatus apie vandeninės erozijos įtaką nešmenų mastui, organinės medžiagos nuostoliams bei dirvožemio drėgmės potencialui.

Tyrimų rezultatai parodė, kad didėjant dirvožemio nešmenų kiekiui, esant vandeninei erozijai didėja ir dirvožemio organinės medžiagos (OM) nuostoliai. Be to, skirtingi žemės naudojimo būdai skirtingai lėmė erozijos mastą bei dirvožemio hidrologinių savybių pokyčius. Priešerozinė žolių ir javų sėjomaina su ilgo naudojimo daugiametėmis žolėmis patikimai padidino OM kiekį 2–5$^{o}$ ir 5–10$^{o}$ statumo šlaituose, palyginti su lauko sėjomaina. Velėną formuojančios daugiametės žolės padidino OM kiekį 10–14$^{o}$ statumo šlaite, palyginti su javų ir žolių sėjomaina. Priešerozinė žemės naudojimo sistema (žolių ir javų sėjomaina ir daugiametės žolės) iš esmės padidino dirvožemio organinės medžiagos ir organinės anglies kiekį, kai ji buvo taikoma ≥12 metų. Didžiausi vandeninės erozijos nuostoliai nustatyti dirvas giliai ariant rudenį (7,25 t ha$^{-1}$ absoliučiai sauso dirvožemio per metus). Gilų rudeninį arimą pakeitus neverstuviniu giliu rudeniniu purenimu sunkiuoju kultivatoriumi, dirvožemio nuostoliai dėl vandeninės erozijos sumažėjo 3,1 karto. Seklus neariminis rudeninis ir seklus neariminis pavasarinis žemės dirbimas sumažino vandeninės erozijos daromą žalą 8,9 karto, palyginti su giliu rudeniniu arimu, bei 2,9 karto, palyginti su neverstuviniu giliu rudeniniu purenimu sunkiuoju kultivatoriumi.

Dirvožemio drėgmės potencialas buvo didesnis dirvožemyje, kuris pasižymėjo didesniu OM kiekiu, t. y. pašlaitėje (5–10 cm sluoksnyje $R^2 = 0,77^*$ ir 15–20 cm sluoksnyje $R^2 = 0,74^*$). Sekliai ariant dirvą, *šlaite* didžiųjų tranzitinių bei pačių mažiausių dirvožemio porų tūris buvo panašus kaip ir giliai ją suarus, tačiau vandenį dirvožemyje talpinančių ir kaupiančių porų tūris, sekliai dirvą suarus, buvo didesnis nei dirvą giliai ariant. Sekliai ariant dirvą, *pašlaitėje* didžiųjų tranzitinių bei vandenį dirvožemyje talpinančių ir kaupiančių porų tūris buvo didesnis nei giliai ją suarus, tačiau pačių mažiausių dirvožemio porų tūris, giliai suarus dirvą, buvo didesnis nei ją suarus sekliai. Dirvožemio, prisotinto vandeniu, laidumas pašlaitėje buvo didesnis nei šlaite, atliekant matavimus po 1 h ir po 24 h. Buvo nustatytas tarpusavio priklausomumas tarp dirvožemio makroporingumo ir dirvožemio laidumo (po jo prisotinimo vandeniu po 24 h). Dirvožemio laidumas vandeniui ariamajame dirvos sluoksnyje po 1 h matavimo įvertintas kaip greitas, o šlaite – vidutiniškai greitas.

Reikšminiai žodžiai: priešerozinės sėjomainos, vandeninė erozija, žemės dirbimas, organinė medžiaga, dirvožemio drėgmės potencialas.