ŽEMĖS ŪKIO MOKSLAI. 2004. Nr. 3. P. 1–7

Dirvotyra ir agrochemija
Soil Science and Agrochemistry
Почвоведение и агрохимия

Water erosion rates on slopes under different land use systems

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Research data were obtained on sandy loam *Eutric Albeluvisols* at the Kaltinėnai Research Station of the Lithuanian Institute of Agriculture on the undulating hilly topography of the Žemaičiai Upland of Western Lithuania. A combination of perennial grass species and selected crop rotations can help prevent soil erosion in upland regions and minimize the risk of soil erosion and associated water pollution. The aim was to identity crop and crop rotations as different land use systems that would minimize soil erosion during a long-term period. The measured water erosion rates according to 18 years of field experiments 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. Perennial grasses completely prevented water erosion. The erosion-preventive grass–grain crop rotations (66.7% of 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 (33.3% of grass) decreased the rates by 22.7–24.2% compared with the field crop rotation. The main attributes of the proposed land conservation and sustainable land-use system were careful selection of optimum erosion-preventive ecosystems (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. These results may have a wider applicability on the undulating landscapes of the temperate climate zone.

Key words: undulating hilly topography, water erosion rates, erosion-preventive crop rotations, temperate climate

INTRODUCTION

Water erosion is the main soil degradation factor in agricultural areas, which endangers 56% of the world's available arable land and has already eliminated an estimated 430 million ha from agricultural production, or 30% of the total available arable land [6]. The major causes of water and wind erosion include deforestation, overgrazing and mismanagement of arable land. About 1028 million ha of global soils are moderately to excessively affected by water and wind erosion [10]. Soil erosion is one of the world's most serious environmental problems, causing extensive losses of cultivated and potentially productive soil and an enormous annual loss of crop yields. Highly eroded soils tend to have a reduced productivity, degraded soil structure, lower organic matter and a poor environment for root growth [15]. Soil erosion is not always due to hostile climate, but it can result from land mismanagement and inappropriate policies. For example, erosion on agricultural land in Britain has increased over the last 20 years, with no evidence of significant climatic changes [2]. Soil erosion has considerably worsened in the Middleveld of Swaziland over the last 20 years [3]. During the last 50 years, erosion has increased about 30-fold in Russia and crop production on these soils has decreased by 50–60% [1]. Annual erosion rates on cultivated land vary from 0.1–20 Mg ha^{-1} in the U. K. to 150–200 Mg ha^{-1} in China [15]. The limited availability of soil resources for food production and renewable biotic resources, caused by steady population growth and accelerated soil degradation, may have greater negative impacts on global living conditions than the human-induced greenhouse effect [7]. Average values of soil erosion rates over large areas, for both practical and theoretical reasons, should be treated cautiously. The rate of erosion in Europe of 17 Mg ha^{-1} yr^{-1} or 10–25 Mg ha^{-1} yr^{-1}, referred to by several authors, was based on misinterpretation and uncritical use of original field data [2].

About 17% of Lithuania's agricultural land is eroded, this percentage increasing to 43–58% in the hilly regions. Water and wind erosion occurs mostly on arable soils and wind erosion occurs on the Baltic coast. Soil erosion severity on the uplands of western Lithuania was due to the combined action of natural (geological) and accelerated soil erosion. Soil erosion rates increased with slope steepness and changed soil physical and chemical properties. Therefore, natural soil fertility decreased by 22, 40 and 62% on slopes of 2–5°, 5–10° and 10–14°, respectively [11].

These results demonstrate the need for soil conservation measures on arable undulating land in Lithuania. Therefore, the main aims of the current investigation were: 1) to evaluate the degree of water erosion on undulating slopes under different crop rotations as land use systems, 2) to prepare suggestions for stabilization of soil erosion and for improving the ecological conditions in the vulnerable Baltic coastal zone; 3) to evaluate the potential for soil conservation on eroded undulating land and to advise policies for rural development in relation to environmental protection. The long-term goal of this research is to distribute results of investigations for possible implementation in other temperate climatic zones and to promote international co-operation in the development of erosion-resisting agro-environmental systems. Results from the first and second crop rotations (1983–1994) have been reported [12, 13]. This paper presents soil erosion data from three crop rotations (1983–2000).

MATERIALS AND METHODS

Study sites. Investigations were conducted on the Žemaičiai Upland. Data were obtained from the Kaltinėnai Research Station of the Lithuanian Institute of Agriculture during 1983–2000. The station is located on the southern-central Žemaičiai Upland (55°34'N, 22°29'E). Study sites A, B and C are on slopes of 2–5°, 5–10° and 10–14°, respectively. Field trial plot width was 3.6 m and length was 90 m on sites A and C (slopes 2–5° and 10–14°) and 40 m on site B (slope 5–10°). The field experiments 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).

Field experiments were performed on eroded Eutric Albeluvisol sandy loams [3]. 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 average agro-chemical properties of Ap horizons (0–20 cm) before field experiments show the topsoil to be slightly acid, P-deficient, medium rich in K and contained varying soil organic matter (SOM) contents (Table 1). The percentage of SOM was highest on the less eroded 2–5° slope and the lowest on the 10–14° slope.

In Lithuania, water erosion occurs mostly on arable slopes, as natural vegetation (woods, shrubs or grasslands) effectively protects soil from erosion [12]. Mean annual precipitation in Lithuania is 626 mm, with ~858 mm on the central Žemaičiai Upland and 750–800 mm on the Upland fringe. Annual precipitation during the study period was 635–1075 mm.

General methodological framework. Long-term field experiments were conducted on 2–5°, 5–10° and 10–14° slopes since 1982. Four six-course crop rotations were compared. These were:

I. The field crop rotation: 1: winter rye (*Secale cereale* L.), 2: potatoes (*Solanum tuberosum* L.), 3–4: spring barley, 5–6: clover–timothy mixture (CT) (*Trifolium pratense* L. – *Phelum pratense* L.);

Table 1. **Mean agrochemical soil properties of the arable layer (0–20 cm) before field experiments in 1981**

Steepness of slope	pH_{KCl}	Hydrolytic acidity	Exchangable bases	Available elements, mg kg^{-1}		Organic matter, %
		cmol(+)kg^{-1}		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

II. The grain–grass crop rotation: 1: winter rye, 2–4: spring barley, 5–6: CT;

III. The grass–grain I crop rotation: 1: winter rye, 2: spring barley, 3–6: CT;

IV. The grass–grain II crop rotation: 1 winter rye, 2: spring barley, 3–6: orchard grass–red fescue (OF) (*Dactylis glomerata* L. – *Festuca rubra* L.) mixture.

A multi-species mixture of perennial grasses for long-term use (sod-forming grasses: V) were grown on 10–14° slopes, instead of the field crop rotation, as tillage crops are not recommended in Lithuania on slopes >10°. 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 grain–grass crop rotation contained 33.3% of grass, when the grass–grain crop rotation contained 66.7% of grass.

Field experiments were not widely dispersed, due to the limited availability of homogenous soils. There were only two blocks of the above-mentioned crop rotations (Table 2) in four replications on study sites A and B or three comparable replications on study site C. Thus, over 6 years, data for one particular course in one particular rotation were obtained twice: once from Block 1 and once from Block 2. Locating the field experiments on two blocks of all investigated crop rotations enabled completion of six tests of every crop during 18 years. Only winter rye and spring barley were included in all crop rotations. A clover–timothy mixture was grown in three crop rotations (field, grain–grass and grass–grain I). Potatoes were grown only in the field crop rotation, while the orchard grass-red fescue mixture was grown only in the grass–grain II crop rotation.

Soil management. Optimum soil management and fertilizer treatments were applied in accordance with the measured soil properties and standard regional agricultural practice. Before field experiments, soils were limed with one $CaCO_3$ application (according to hydrolytic acidity). Subsequent liming before each crop rotation enabled pH standardisation on all study slopes. Chemical fertilizer doses (ammonium nitrate, granulated superphosphate and potassium chloride) varied according to plant requirements and soil properties. The following rates of mineral nutrients (N, P, K) were applied: $N_{60}P_{26}K_{50}$ under winter rye and spring barley; $N_{90}P_{39}K_{100}$ under potato; $P_{26}K_{90}$ under C–T of year 1; $N_{120}P_{26}K_{75}$ under C–T of year 2 and 3; $N_{180}P_{26}K_{75}$ under O–F of year 1 to 3, and $N_{60}P_{26}K_{75}$ under C–T and O–F in the year of ploughing; and 60 Mg ha^{-1} of farmyard manure under winter rye. Therefore, mean annual rates of applied fertilisers were: $N_{60}P_{28.4}K_{66}$ (field crops), $N_{50}P_{26.2}K_{58}$ (grain–grass crops), $N_{70}P_{26.2}K_{66}$ (grass–grain I crops) and $N_{120}P_{26.2}K_{66}$ (grass–grain II crops).

The main tillage, sowing–planting and harvesting directions were up-and-down slope to decrease soil losses during intense rainfalls, as recommended for the region. Contour cultivation on steep slopes can increase erosion rates during intense rainfalls, due to breaking of ridges by runoff and subsequent cascading [12].

Water erosion assessment. Water erosion rates were assessed by measuring the length and cross-sectional area of rills to calculate soil loss volume [6]. Lost soil volume was calculated using the formula:

$$x = [(\Sigma lp + \Sigma l_1 p_1 + \dots \Sigma l_n p_n) : n] : y, \qquad (1)$$

where x = volume of erosion rills (m^3 ha^{-1}); l, l_1, … l_n = rill depth (cm); p, p_1, … p_n: rill width (cm); n: number of rills on the measured plot width; y: measured plot width (m), and Σ: sum of 9 measurements from 1 m segments located at equal distances

Table 2. **Layout of crops in the field experiments (study sites A, B, C) during the third crop rotation***

Year of investigation	Block 1 of crop rotations:				Block 2 of crop rotations:			
	field	grain-grass	grass-grain I	grass-grain II	field	grain-grass	grass-grain I	grass-grain II
1995	1. R	1. R	1. R	1. R	4. B	4. B	4. C–T	4. O–F
1996	2. Pt	2. B	2. B	2. B	5. C–T	5. C–T	5. C–T	5. O–F
1997	3. B	3. B	3.C–T	3. O–F	6. C–T	6. C–T	6. C–T	6.O–F
1998	4. B	4. B	4.C–T	4. O–F	1. R	1. R	1. R	1. R
1999	5. C–T	5. C–T	5. C–T	5. O–F	2. P	2. B	2. B	2. B
2000	6. C–T	6. C–T	6. C–T	6. O–F	3. B	3. B	3. C–T	3. O–F

* The same crop layout was used during the first and second crop rotations.
1–6: numbers of crop rotation course. R: winter rye, Pt: potatoes, B: barley, C–T: clover-timothy mixture, O–F: orchard grass – red fescue mixture. The sod-forming perennial grass mixture was grown instead of field crop rotation on 10–14° slopes.

on the experimental plot. Data were transformed from $m^3\ ha^{-1}$ to $Mg\ ha^{-1}$ using soil bulk density data. The rill erosion rates form components of the total erosion rates and thus probably lead to underestimation of total erosion. The methodologies for evaluation of total soil erosion rates require separate discussion.

Equations relating soil loss to slope gradient were obtained from the mean annual data of 18 years using the Microsoft Graph 97 Chart, Trendline Polynomial. The significance of differences between treatment means was determined using Fisher's LSD_{05} [18]. Mean errors for investigations lasting over three years were calculated using the formula:

$$s_x = \pm \frac{\sqrt{s_{x_1}^2 + s_{x_2}^2 + \ldots + s_{x_n}^2}}{m}, \quad (2)$$

where s_{x_1}, s_{x_2}, s_{x_n} are individual errors of a single (one-year) investigation and m is the number of investigations.

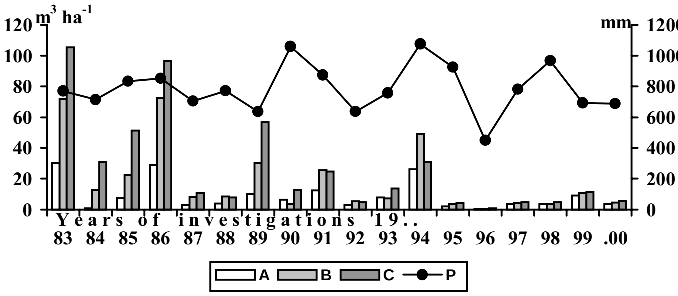

Fig. 1. Soil losses ($m^3\ ha^{-1}$) from slopes of different gradient (columns) under spring barley and total precipitation (line) Columns: slopes of A: 2–5°, B: 5–10° and C: 10–14°. P: total precipitation (mm)

RESULTS AND DISCUSSION

Only spring barley and perennial grasses were grown every year. There was a considerable annual soil loss variability under spring barley on the 5–10° slope (Fig. 1). This included low values of 0.5–5.2 $m^3\ ha^{-1}$ in 1992, 1995, 1996, 1997, 1998 and 2000, moderate values of 7.2–12.6 $m^3\ ha^{-1}$ in 1984, 1987, 1988, 1990, 1993 and 1999 and high rates of 22.4–72.6 $m^3\ ha^{-1}$ in 1983, 1985, 1986, 1989, 1991 and 1994.

Water erosion rates under different crops during the second crop rotation are presented in Table 3. These crops were grown twice during six courses of crop rotation: the first indicated year corresponds to Block 1 and the second to Block 2. The high LSD_{05} values indicate a considerable soil loss variability, which is characteristic of soil erosion data. Perennial grass cover was the most effective soil conservation measure, with only one notable erosion episode under perennial grass (clover–timothy) in 1992 when 0.7 $m^3\ ha^{-1}$ of soil was lost. The largest soil losses were from the field crop rotation and the least under grass–grain crop rotations; soil losses increased with increasing slope steepness.

The erosion-protection capability of different crops varied. Mean soil losses (1983–2000) under winter rye were 3.17, 6.70 and 8.60 $m^3\ ha^{-1}\ yr^{-1}$ and under spring barley 9.01, 19.11 and 27.09 $m^3\ ha^{-1}\ yr^{-1}$ from slopes of 2–5°, 5–10° and 10–14°, respectively. Perennial grasses prevented erosion almost completely. There was only a small soil loss from the fields of grass–grain I crop rotation due to a poor red clover cover in 1992. Potatoes showed the least erosion-protective 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

Table 3. **Influence of plant cover and slope steepness on water erosion rates**

Slope steepness	Soil loss ($m^3\ ha^{-1}$) when growing:			
	perennial grasses	winter rye	spring barley	potato
		1st crop rotation, 1983–1988		
2–5°	0	2.50 ± 0.400	12.40 ± 1.770	38.80 ± 9.610
5–10°	0	10.60 ± 1.390	32.70 ± 2.840	99.0 ± 17.520
10–14°	0	14.20 ± 2.620	52.10 ± 7.050	*157.73 ± 21.360
		2nd crop rotation, 1989–1994		
2–5°	0	4.39 ± 0.175	10.98 ± 0.286	18.67 ± 1.172
5–10°	0	6.00 ± 0.173	20.14 ± 0.516	65.67 ± 3.385
10–14°	0,11	7.37 ± 0.237	23.95 ± 0.984	*78.09 ± 3.208
		3rd crop rotation, 1995–2000		
2–5°	0	2.61 ± 0.104	3.65 ± 0.084	15.13 ± 0.950
5–10°	0	3.50 ± 0.101	4.49 ± 0.115	22.00 ± 1.134
10–14°	0	4.27 ± 0.137	5.21 ± 0.214	*25.53 ± 1.049
		Mean, 1983–2000		
2–5°	0	3.17 ± 0.259	9.01 ± 1.036	24.20 ± 5.590
5–10°	0	6.70 ± 0.853	19.11 ± 1.668	62.22 ± 10.323
10–14°	0.04±0.001	8.60 ± 1.521	27.09 ± 4.112	*87.12 ± 12.485

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

higher than under spring barley (Table 3). The highest soil losses were during the first crop rotation (1983–1988) and the least during the third crop rotation (1995–2000). Erosion largely depended on rainfall intensity when cultivated soil was not covered with plants.

The soil losses (6.43–20.5 m^3 ha^{-1} yr^{-1}) were largest under the field crop rotation (Table 4). Lesser losses (4.88–15.88 m^3 ha^{-1} yr^{-1}) were under the grain–grass crop rotation and least (1.62–4.65 m^3 ha^{-1} yr^{-1}) under the grass–grain crop rotations that contained four fields of perennial grasses. There was no significant differences in soil losses between the grass–grain I and II crop rotations.

The mean soil losses (11.42 m^3 ha^{-1} yr^{-1}) were largest from the 10–14° slopes, and they decreased with decreasing slope steepness, losing a mean of 7.91 m^3 ha^{-1} yr^{-1} from the 5–10° slope and 3.64 m^3 ha^{-1} yr^{-1} from the 2–5° slope.

Agroecosystems play a key role in promoting biodiversity [19], therefore, the multi-species agroecosystems (sod-forming perennial grasses and grass–grain crop rotations) are potential components for both soil conservation and biodiversity strategies. Therefore, the long-term information from this study well assists the design of conservation cropping systems for the hilly undulating topography of Lithuania [12]. Annual soil losses were extremely variable during the 18-year investigation period (see Fig. 1). It terms of causality, the correlation between total precipitation and soil loss was insignificant (r^2 = 0.21–0.40, n = 12, P > 0.05). Soil erosion rates depended mostly on rainfall amount and intensity during the periods when soil was unprotected by a plant cover, or during snowmelt from non-frozen slopes [14]. This accords with results from plot studies in the U. K., where prolonged, low intensity rainfall events caused a relatively little erosion and most was accomplished by short, intense (>10 mm h^{-1}) convective rainstorms [9].

Different plant covers afford different degrees of protection so that the human impact, by determining land use, can exert much influence on erosion rates [15]. Field experiments at the Kaltinėnai Research Station showed that perennial grasses completely prevented water erosion, even on slopes of 10–14° [13], which agrees with the results from plot studies in the U. K. [8]. Other recommendations include establishing stiff grass hedges as an alternative technique to prevent ephemeral gully development [17]. Mean annual rates of water erosion under winter rye, spring barley and potatoes were 5.4–29.6, 18.0–59.7 and 44.4–196.2 Mg ha^{-1}, on 2–5°, 5–10° and 10–14° slopes, respectively [13]. These results agree with the notion that erosion rates increase with both slope steepness and length, due to an increase in runoff velocity and volume [15]. Erosion of clay loams in the Baltic Uplands of Eastern Lithuania varied from 4.5 Mg ha^{-1} yr^{-1} under annual crops to 46.6 Mg ha^{-1} yr^{-1} under bare fallow [4].

The erosion-protective capabilities of different crop rotations and land use systems varied widely (Fig. 2). According to the mean data of 36 experiments (18 years of investigation on two blocks), the mean annual erosion rates under erosion-preventive grass–grain rotations decreased by 74.7–79.5% compared with the field crop rotation, while under the grain–grass crop rotation it decreased by 22.7–24.2%. However, even grass–grain crop rotations could not completely prevent water erosion, with mean annual rates of 7.2–7.4 Mg ha^{-1} on the 10–14° slopes, which are not tolerable [9]. Therefore, it was recommended that slopes >10° be grassed and erosion-protective crop rota-

Table 4. **Influence of different crop rotations on water erosion rates**

Crop rotations (treatments)	Soil losses, m^3 ha^{-1}			
	I crop rotation, 1983–1988	II crop rotation, 1988–1994	III crop rotation, 1994–2000	Mean, 1983–2000
	2–5° slope			
Field	7.99	8.45	2.73	6.43
Grain–grass	6.81	5.62	2.16	4.88
Grass–grain I	1.39	2.36	1.08	1.61
Grass–grain II	1.35	2.32	1.20	1.63
LSD_{05}	1.34	1.03	0.19	0.57
	5–10° slope			
Field	24.13	14.91	4.16	14.53
Grain–grass	19.84	10.8	2.57	11.16
Grass–grain I	5.82	1.8	1.17	3.03
Grass–grain II	5.49	1.86	1.15	2.93
LSD_{05}	2.84	2.13	0.35	1.18
	10–14° slope			
Sod-forming grasses	0	0	0	0
Grain–grass	29.56	14.78	3.07	15.88
Grass–grain I	8.08	3.98	1.52	4.61
Grass–grain II	8.71	3.62	1.49	4.69
LSD_{05}	2.50	1.37	0.41	0.92

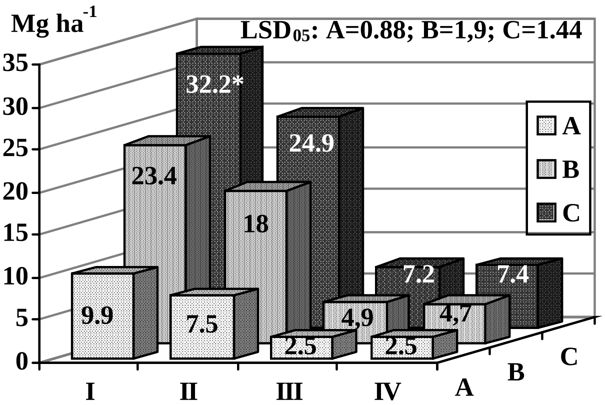

Fig. 2. Annual water erosion rates under different crop rotations
The heights of columns represent the mean data of 1983–2000 on slopes: A. 2–5°, B. 5–10°, C. 10–14°. Crop rotations: I. Field. II. Grain–grass. III. Grass-grain I. IV. Grass-grain II. *On the 10–14° slope potatoes were not grown. The data were calculated by the method of group comparison

tions, erosion-protective tillage and fertiliser-liming treatments be used on 2–10° slopes [12].

The erosion-preventive capability of crop rotations depended on the erosion-protective properties of constituent crops, and the need for these measures increases with the slope gradient. The research data enabled to design appropriate erosion-resisting crop rotations [13]. There was no background for changing these crop rotations after the 3rd crop rotation, and these rotations are recommended for erodible soils on 2–10° slopes. Long-term perennial grasses should be grown on slopes over 10°. Thus, sod-forming perennial grasses and erosion-protective crop rotations could assist both erosion control and the ecological stability of the vulnerable Baltic coastal zone.

CONCLUSIONS

Investigations of water erosion on sandy loam *Eutric Albeluvisols* on the hilly undulating topography of Western Lithuania showed that:

1. Water erosion rates were highest under potatoes less under spring barley and winter rye and zero under perennial grasses.

2. The erosion-protective grass–grain crop rotation and sod-forming perennial grasses significantly decreased water erosion rates compared to the other rotations on each slope position. The mean annual erosion rates under erosion-preventive grass–grain crop rotations decreased by 74.7–79.5% compared with the field crop rotation, while sod-forming perennial grasses completely ststabilised soil erosion.

3. The erosion-preventive capability of rotations depended on the erosion-resisting properties of constituent crops and the need for these measures increases with the slope gradient. Sod-forming perennial grasses and erosion-preventive crop rotations assist both erosion control and the ecological stability of the landscape.

4. In the immediate future, Lithuania could export food at economically competitive rates, and this production should be provided in an environmentally friendly and sustainable way. Therefore, research data and experience in soil conservation practices on the undulating relief of the Republic is very important for sustainable agricultural development. The multi-species agroecosystems (sod-forming perennial grasses and grass–grain crop rotations) are potential components of a soil conservation strategy. It is imperative that the soil resource base is conserved for future generations.

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ŠLAITŲ DIRVOŽEMIO VANDENINĖS EROZIJOS PRIKLAUSOMYBĖ NUO ŽEMDIRBYSTĖS SISTEMŲ

S a n t r a u k a

Analizuojami Žemaičių aukštumos kalvoto reljefo lengvo priemolio pasotintame balkšvažemyje (*Eutric Albeluvisol*) Lietuvos žemdirbystės instituto Kaltinėnų bandymų stotyje gauti duomenys. Žinota, kad suderinus daugiamečių žolių mišinius su sumaniai parinktomis sėjomainomis gali sumažėti kalvoto reljefo dirvožemių ardymas ir su tuo susijęs paviršinių vandenų teršimas. Tyrimų tikslas buvo surasti geriausiai dirvožemio ardymą mažinančius augalus ir jų derinius sėjomainose, įgalinančius ilgą laiką minimalizuoti dirvožemio ardymą. Lauko bandymais per 18 metų nustatytas toks dirvožemio vandeninės erozijos intensyvumas: 3,17–8,6 m^3 ha^{-1} m.$^{-1}$ auginant žieminius rugius, 9,01–27,09 m^3 ha^{-1} m.$^{-1}$ auginant vasarinius miežius, 24,2–87,12 m^3 ha^{-1} m.$^{-1}$ auginant bulves. Daugiametės žolės visiškai sulaikė dirvožemio ardymą vandeniu. Antierozinės žolių ir javų sėjomainos (su 66,7% žolių) sumažino dirvožemio nuostolius nuo periodiškai dirbamų 2–5°, 5–10° ir 10–14° statumo šlaitų 74,7–79,5%, o javų ir žolių sėjomainos (su 33,3% žolių) 22,7–24,2%, palyginti su dirvožemio nuostoliais nuo lauko sėjomainos augalais užimtų šlaitų. Pagrindinė pasiūlytos stabilios dirvosauginės žemdirbystės sistemos kalvose priemonė liko didelės antierozinės galios ekosistemos (velėną formuojančios daugiametės žolės ar antierozinės sėjomainos), kruopščiai parinktos atsižvelgiant į šlaito ir dirvožemio savybes. Tokios ekosistemos įgalina stabilizuoti dirvožemio ardymą ir užtikrinti kalvoto reljefo ekologinį stabilumą. Tyrimų rezultatai gali būti taikomi plačios vidutinės klimato zonos kalvotam kraštovaizdžiui.

Raktažodžiai: banguotas-kalvotas reljefas, vandeninės erozijos intensyvumas, antierozinės sėjomainos, vidutinis klimatas

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ИНТЕНСИВНОСТЬ ВОДНОЙ ЭРОЗИИ НА СКЛОНАХ ПОД ВЛИЯНИЕМ РАЗНЫХ СИСТЕМ ЗЕМЛЕДЕЛИЯ

Р е з ю м е

Исследования проводились на дерново-подзолистой (*Eutric Albeluvisol*) легкосуглинистой почве Кальтиненской опытной станции Литовского института земледелия на склонах холмисто-волнистого рельефа Жямайтской возвышенности Западной Литвы. Было известно, что умелое сочетание многолетних трав и противоэрозионных севооборотов может стабилизировать эрозию почв холмистых регионов и минимизировать риск соответствующего загрязнения поверхностных вод. Поэтому целью исследований явилось определение наилучших культур и севооборотов, способствующих минимизации почвенной эрозии на долгосрочный период. Полевыми исследованиями 18-и лет установлены следующие потери почвы от водной эрозии: 3,17–8,6 м^3 га$^{-1}$ г.$^{-1}$ под озимую рожь, 9,01–27,09 м^3 га$^{-1}$ г.$^{-1}$ под яровую пшеницу и 24,2–87,12 м^3 га$^{-1}$ г.$^{-1}$ под картофель. Многолетние травы способствовали полной стабилизации водной эрозии. Противоэрозионные травяно-зерновые севообороты (66,7% трав) снизили потери почв на пахотных склонах крутизной 2–5°, 5–10° и 10–14° на 74,7–79,5%, а зерново-травяные севообороты (33% трав) – на 22,7–24,2% по сравнению с потерями почвы полевого севооборота. Основным требованием стабильной почвозащитной системы земледелия холмистого рельефа стал умелый подбор оптимальной экосистемы (дернину формирующие многолетние травы или противоэрозионные севообороты), обладающей высокой противоэрозионной способностью. Состав такой экосистемы должен меняться в зависимости от свойств склона и почвы. Подобные экосистемы способствуют уменьшению почвенной эрозии и придают экологическую стабильность холмистому рельефу в целом. Результаты исследований применимы на обширных территориях холмистого рельефа умеренной климатической зоны.

Ключевые слова: холмисто-волнистый рельеф, интенсивность водной эрозии, противоэрозионные севообороты, умеренный климат