1.6

Lithuania

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1.6.1 PHYSICAL GEOGRAPHY AND SOILS

Lithuania has a temperate climate, transitional between maritime and continental. Weather conditions are variable, with frequent winter frosts and cool, humid summers. The mean annual temperature is 6 °C; the January mean is −4.8 °C and July 17.2 °C. The climate is humid, with a mean annual precipitation of 675 mm. However, this is spatially variable, being highest (920 mm) in the south-west Zemaiciai Uplands and lowest (520 mm) in the northern Central Lithuanian Lowland. The Lithuanian climate is conducive to water erosion and heavy showers are particularly erosive. Heavy showers with >30 mm of rain occur in the Central Lithuanian Lowland about once every 2 years, in the south-west Zemaiciai Uplands about three times every 2 years and elsewhere about once per year. The mean wind velocity on the Baltic coast is 5.5–6.0 $m\,s^{-1}$ and decreases to 2.9–3.5 $m\,s^{-1}$ inland. In winter, owing to active cyclonic activity, wind velocities are 1–2 $m\,s^{-1}$ greater than in summer (Arlauskiene *et al*., 2001).

Lithuania occupies the western fringe of the East European Plain and is predominantly a lowland country. These lowlands are separated by hilly uplands, forming two meridian-oriented stretches. The western edge of the Baltic Uplands is in the east and south of the Republic, where erosion processes affect large areas. The 'island-like' Zemaiciai Upland is in the west, where erosion processes affect 5.1–20 and 20–30% of the undulating terrain (Figure 1.6.1).

Moraines are the prevalent soil parent material, deposited in glacial margin and basal conditions. Ground moraine covers 30% of the national territory and glacial margin formations 27%. Glacio-lacustrine formations cover 23% and fluvioglacial formations 7%. Peaty, marine (littoral), aeolian and karst formations occupy only 0.2–1% (Arlauskiene *et al*., 2001).

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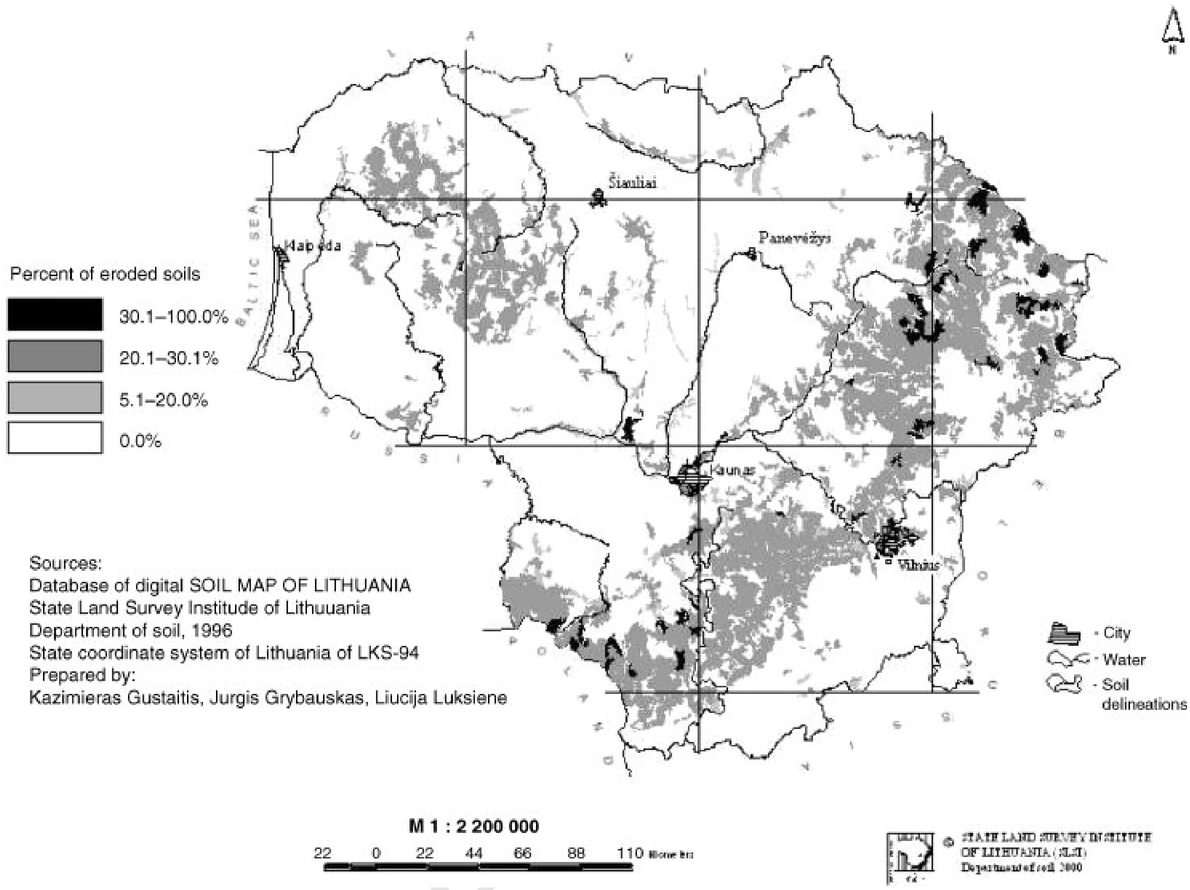

Figure 1.6.1 Map of eroded soils of Lithuania. (Reprinted from *NATO Science Series*, Vol. 44, Jankauskas B and Jankauskiene G, Ecological land use in the undulating landscape of Lithvania and Baltic sea environment, p. 206, copyright 2004, with permission of IOS Press)

About 52% of Lithuania's relief is undulating hills, where the soil is erodible (Kudaba, 1983) and ~17% of Lithuania's agricultural land is eroded, increasing to 43–58% in the hilly regions (Jankauskas, 1996; Jankauskas and Fullen, 2002). The hilly rolling relief of Lithuania, dissected by gullies and river valleys, was formed in the early Holocene, after glacial melting ~12 000 1 yerars BP (Baltrunas and Pukelyte, 1998).

1.6.2 HISTORICAL EROSION

The erodible glacial moraine, combined with the abundance and intensity of precipitation, created favourable conditions for water erosion in the early postglacial period. Agricultural activities commenced in Lithuania only at the end of the Neolithic, i.e. ~5000 (Dunduliene, 1963) or ~4000 (Gudelis, 1958) years BP. However, intensive husbandry and associated risks of soil erosion began in the 12th century, ~800 years BP.

One representative transect from the group of 18 investigated longitudinal transects on the Zemaiciai Uplands is shown in Figure 1.6.2. Soil profile S0 was an uneroded profile in a wood. The calcareous soil

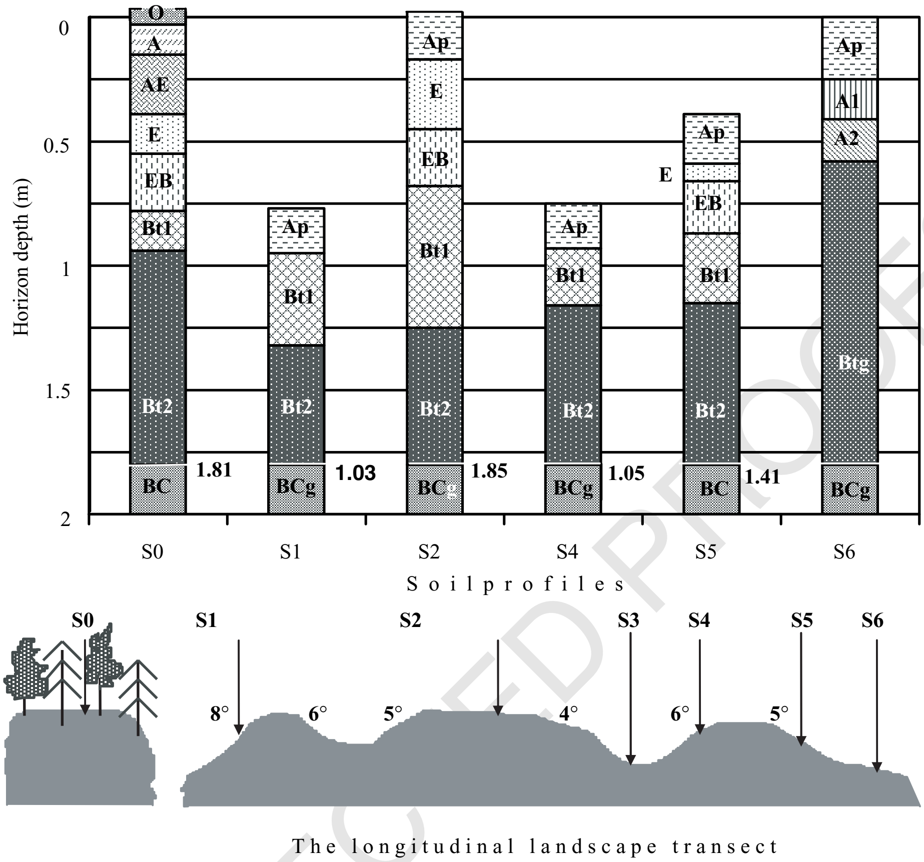

Figure 1.6.2 Severity of soil erosion on transect S. S0–S6, soil profiles: S0, noneroded soil in a woodland; S1 and S4, very severely eroded soil; S2, slightly eroded soil; S5, severely eroded soil; S6, colluvial soil on a foot-slope. Arrows indicate the locations of soil profiles. The white line indicates the depth of calcareous horizon and the adjacent numbers indicate depth (m)

horizon there was at 1.81 m depth and 1.85 m on soil profile S2 on the sloping plateau (Figure 1.6.2). This depth to the calcareous soil horizon was used as the basis for the calculation of eroded soil on the transect. The thickness of soil above the calcareous horizon was 1.03 m (soil profile S1), 1.05 m (soil profile S4) and 1.41 m (soil profile S5). Therefore, the estimated approximate thickness of lost (truncated) soil was 0.8 m on the 8° (13.9%) slope (soil profile S1), 0.8 m on the 6° (10%) slope (soil profile S4) and 0.4 m on the 5° (8.3%) slope (soil profile S5).

1.6.3 CURRENT EROSION

Soil erosion intensity in Lithuania depends mainly on tillage (mechanical) erosion, which has been identified as the main cause of accelerated soil erosion on arable slopes (Kiburys, 1989; Jankauskas, 1996). Agricultural implements (such as ploughs, cultivators and harrows) were used for tillage, which encouraged soil

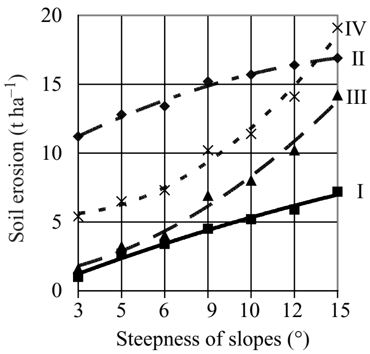

Figure 1.6.3 Dependence of tillage soil erosion on slope steepness after single mouldboard ploughing in different directions (Jankauskas and Kiburys, 2000). I, up and down slope; II, along the contour; III, slantwise across the slope in the right direction; IV, slantwise across the slope in the left direction

translocation on the hilly relief in the mid-20th century. Soil management systems became particularly intensive during the Soviet period. Therefore, investigations of tillage erosion processes were initiated at the Department of Agriculture of Vilnius Pedagogical University in 1960 (Kiburys, 1989). The rate of soil translocation under tillage erosion depends on slope steepness, tillage equipment and the direction of tillage operations. Farmers often create favourable conditions for water and wind erosion using tillage equipment on hilly relief. For example, the mass of soil moved downslope was 17.6 t ha^{-1} after a single mouldboard ploughing along the contour on a 100 m length and 10° (17.7%) slope and the mass of soil moved upslope was 1.9 t ha^{-1}. Therefore, the net rate of tillage erosion (difference between downslope and upslope movement, 17.6−1.9) was 15.7 t ha^{-1}. Tillage erosion was 11.4 t ha^{-1} when ploughing slantwise across the slope in the left direction and 8.0 t ha^{-1} when ploughing slantwise in the right direction. Tillage erosion was only 5.2 t ha^{-1} when ploughing up and down slope (Kiburys, 1989). Tillage erosion rates due to a single sequence of mouldboard ploughing on slopes from 3 to 15° (5 to 26.3%) were 1.0–7.2 t ha^{-1} when ploughing up and down slope, and 11.2–16.8 t ha^{-1} when ploughing across the slope (Figure 1.6.3).

According to the data presented in Figure 1.6.3, the relationship between slope steepness and tillage erosion can be expressed by the following equations:

$$y_{\mathrm{I}} = -0.09x^2 + 1.67x + 9.63, r^2 = 0.987,\ p < 0.05$$

$$y_{\mathrm{II}} = -0.03x^2 + 1.22x + 0.04, r^2 = 0.987,\ p < 0.05$$

$$y_{\mathrm{III}} = 0.18x^2 + 0.53x + 1.1, r^2 = 0.987,\ p < 0.01$$

$$y_{\mathrm{IV}} = 0.3x^2 - 0.28x + 5.6, r^2 = 0.986,\ p < 0.01$$

where y is soil losses (t ha^{-1}), x is slope inclination (°), $n = 10$.

Tillage erosion only moved soil over a short distance (75–85 cm), whereas water and wind erosion transported soil much further (Kiburys and Jankauskas, 1997). Therefore, formation of natural agro-terraces near natural or artificial boundaries is characteristic of arable hillslopes as a result of tillage erosion (Jankauskas and Kiburys, 2000).

Investigations of water erosion have been concentrated at the Kaltinenai and Dukstas Research Stations of the Lithuanian Institute of Agriculture. Both Stations were established in 1960. The oldest operational soil erosion monitoring sites have been operated by the efforts of Dr A. Pajarskaite in 1960 at the Dukstas Research Station (Pajarskaite, 1965). There were monitoring sites with bare fallow, grain crops, grasses and wasteland (untilled/uncultivated land) from 1961 to 2002. The research data of the Dukstas Research Station represent soil and meteorological conditions in the Baltic Uplands. Runoff and losses of clay loam soil due to water erosion on the hillslopes of Eastern Lithuania ranged markedly, from 6.6 mm yr^{-1} of runoff water from wasteland to 151 mm yr^{-1} under bare fallow, or from 1.3 t ha^{-1} yr^{-1} of soil under cereal grain crops to 56.6 t ha^{-1} yr^{-1} under bare fallow on 5–7° (8.3–11.9%) slopes (Svedas, 1974; Bieliauskas, 1985).

Investigations of soil erosion on the Zemaiciai Uplands of western Lithuania at the Kaltinenai Research Station were initiated by Dr E. Cicelyte, and had been developed and comprehensively described by Dr O. Visockis. The physical and chemical properties of eroded soil were investigated and initial recommendations were made for soil conservation on arable slopes (Visockis, 1971). Evidence was presented that perennial grasses provided excellent protection against soil erosion, even on 10–15° (17.7–26.3%) slopes. Permanent legume–grass mixtures with a high percentage (90%) of common alfalfa (*Medicago sativa* L.) were more suitable for pastures on eroded slopes, if soils were suitable for growing alfalfa.

Requirements for other kinds of products (such as grain, tuber crops and root vegetables) encouraged investigations of crop rotations suitable for undulating hilly relief. Erosion-preventive 6-year crop rotations have been investigated on experimental plots at the Kaltinenai Research Station since 1983. Heavy losses of Eutric Albeluvisols (Aquic Glossoboralfs) occur owing to water erosion on the Zemaiciai Uplands under the field crop rotation (Jankauskas, 1996; Jankauskas and Jankauskiene, 2000). Study sites A, B and C were on slopes of 2–5, 5–10 and 10–14°, respectively (Figure 1.6.4). Field trial plot size was 338.4 m^2 (3.6 × 90 m) on sites A and C (slopes 2–5 and 10–14°) and 158.4 m^2 (3.6 × 40 m) on site B (slope 5–10°). On the long-term monitoring sites, the mean water erosion rate under the field crop rotation, containing 1 year of potatoes, 3 years of cereal grains and only two fields of grasses, was 23.4 t ha^{-1} yr^{-1} on the 5–10° (8.3–17.7%) slope. The rates increased with increasing slope inclination and were lower on the 2–5° (3.5–8.3%) slope. The erosion-protection capabilities of different crop rotations and land use systems varied widely. 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 crop rotations decreased by 74.7–79.5% compared with the field crop rotation, containing 4 years of perennial grasses and 2 years of cereal grain crops. Under the grain–grass crop rotation, containing 4 years of cereal grains and 2 years of grasses, the rate decreased by 22.7–24.2% (Figure 1.6.4). However, even grass–grain crop rotations could not completely prevent water erosion, with mean rates of

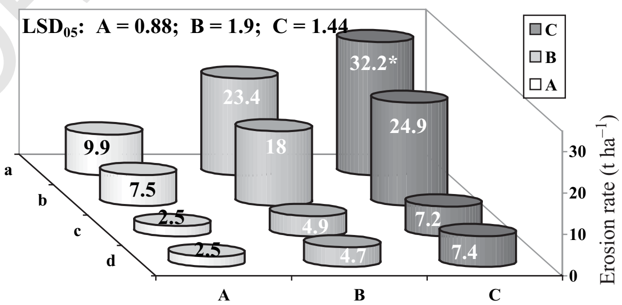

Figure 1.6.4 Annual water erosion rates under different crop rotations. The heights of columns represent the mean data for 1983–2000 on slopes: A, 2–5° (3.5–8.3%); B, 5–10° (8.3–17.7%); C, 10–14° (17.7–24.5%). (a) Field crop rotation; (b) grain–grass crop rotation; (c) grass–grain I crop rotation; (d) grass–grain II crop rotation. *The sod-forming perennial grasses were grown instead of the field crop rotation on the slope of 10–14°. Therefore, the water erosion rate for field crop rotation on the slope of 10–14° was calculated by the method of data group comparison

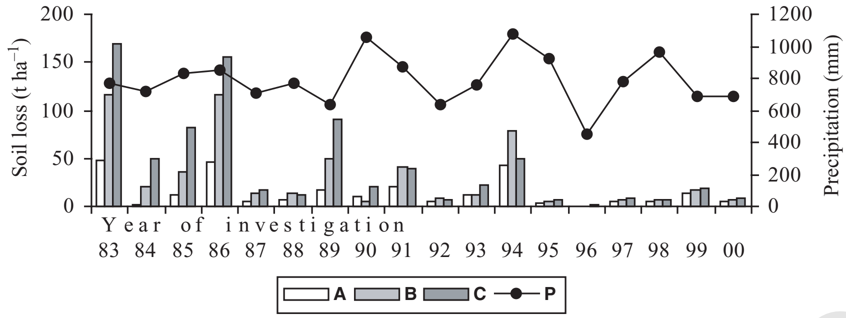

Figure 1.6.5 Soil losses from slopes of different gradient (columns) under spring barley; annual precipitation (line). Columns: slopes of A, 2–5° (3.5–8.3%); B, 5–10° (8.3–17.7%); and C, 10–14° (17.7–24.5%). P: total precipitation (mm)

7.2–7.4 t ha^{-1} yr^{-1} on the 10–14° (17.7–24.5%) slopes, which exceed tolerable levels (Fullen and Reed 1986; Richter 1997). Therefore, it was recommended that slopes >10° (17.7%) be grassed and erosion-protective crop rotations, erosion-protective tillage and fertilizer-liming treatments be used on 2–10° (3.5–17.7%) slopes (Jankauskas and Jankauskiene, 2003).

There was considerable annual soil loss variability under spring barley on the 5–10° (8.3–17.7%) slope (Figure 1.6.5). This included low values of 0.8–8.4 t ha^{-1} (1992, 1995, 1996, 1997, 1998 and 2000), moderate values of 11.6–20.6 t ha^{-1} (1984, 1987, 1988, 1990, 1993 and 1999) and high rates of 36.1–116.9 t ha^{-1} (1983, 1985, 1986, 1989, 1991 and 1994).

Annual soil losses were extremely variable during the 18-year investigation period (Figure 1.6.5). However, the correlation between total precipitation and soil loss was not significant ($r^2 = 0.21 - 0.40, p > 0.05, n = 12$). Soil erosion rates depended mostly on rainfall amount and intensity during periods when soil was unprotected by plant cover, or during snowmelt from nonfrozen slopes (Jankauskas, 1996; Jankauskas and Svedas, 2001). This accords with results from plot studies in the UK, where prolonged, low-intensity rainfall events caused relatively little erosion on bare soils and most was accomplished by short, intense (>10 mm h^{-1}) convective rainstorms (Fullen and Reed, 1986). Studies at several locations have shown that most soil erosion over an extended period occurs during a few large storms (Larson *et al.*, 1997).

Soil erosion has led to significant deterioration in the physico-chemical properties of loamy sand and clay loam Albeluvisols. Dry bulk density and percentage of clay–silt and clay fractions have increased and total porosity and water field capacity decreased. Strong acidity of E, EB and B1 soil horizons, exhumed owing to soil erosion, is a characteristic feature of eroded Albeluvisols (Jankauskas, 2000; Jankauskas and Fullen, 2002). Deterioration of soil attributes leads to decreased soil fertility (Jankauskas, 2001). The natural fertility (using barley yield as a surrogate measure) was less on eroded soils. On slopes of 2–5° (3.5–8.3%), 5–10° (8.3–17.7%) and 10–14° (17.7–24.5%) barley yield decreased by 21.7–22.1, 38.9–39.7 and 62.4%, respectively (Table 1.6.1).

1.6.4 SOIL CONSERVATION

The erosion-preventive capability of crop rotations depended on the erosion-protective properties of constituent crops and the need for these measures increases with slope gradient. The research data allowed modelling of appropriate erosion-resisting crop rotations (Table 1.6.2) and these rotations are recommended for erodible soils on 2–10° (3.5–17.7%) slopes. Long-term perennial grasses should be grown on slopes >10°

TABLE 1.6.1 Dependence of barley yield on slope steepness and soil erosion severity

Landscape segment	Severity of soil erosion	Yield[a] from 48 investigated plots		
		$t\ ha^{-1}$	Relative numbers	Decrease ($t\ ha^{-1}$)
Flat land	Noneroded	18.9	100	—
Slopes of 2–5° (3.5–8.3%)	Slightly eroded	14.8	78.3	4.1
Slopes of 5–10° (8.3–17.7%)	Moderately eroded	11.4	60.3	7.5
Slopes of 10–14° (17.7–26.3%)	Severely eroded	7.1	37.6	11.8
Foot slopes	Deposited soil	19.5	103.2	—
LSD_{05}[b]		1.1		

[a]The mean of 3 years grain and straw gross yield.
[b]Least significant difference at the 95% probability level.

(17.7%). Hence sod-forming perennial grasses and erosion-protective crop rotations could assist both soil conservation and the ecological stability of the vulnerable Baltic coastal zone.

Deep soil chisel tillage can be used instead of deep mouldboard ploughing. Spraying stubble with Glifosat ($C_3H_8O_5NP$) herbicide can be used instead of the usual deep ploughing used in autumn soil tillage systems.

TABLE 1.6.2 Erosion-preventive crop rotations as soil conserving measures for fields of varying gradient

M.a.s.g.[a]	M.r.p.g.[b]	Composition of crop rotations
7–10° (11.9–17.7%)	80	I. 1, winter grains or spring barley; 2–5[c], perennial grasses
	72	II. 1, winter grains; 2, spring barley; 3–7, perennial grasses
	67	III. 1: winter grains, 2: spring barley, 3–6: perennial grasses
	63	IV. 1–2 winter grains, 3: spring barley, 4–8: perennial grasses
	63	V. 1: winter grains, 2: spring grains, 3: spring barley, 4–8: perennial grasses
	60	VI. 1: winter grains, 2: spring barley, 3–5: perennial grasses
5–7° (8.3–11.9%)	57	VII. 1–2: winter grains, 3: spring barley, 4–7: perennial grasses
	57	VIII. 1: winter grains, 2: spring grains, 3: spring barley, 4–7: perennial grasses
	50	IX. 1–2: winter grains, 3: spring barley, 4–6: perennial grasses
	50	X. 1: winter grains, 2: cereal grains with legumes, 3: spring barley, 4–6: perennial grasses
	43	XI. 1: winter grains, 2: cereal grains with legumes, 3: winter grains,4: spring barley, 5–7: perennial grasses
	43	XII. 1: winter grains, 2: cereal grains with legumes, 3: spring grains,4: spring barley, 5–7: perennial grasses
	40	XIII. 1: winter grains, 2: spring barley or their mixture with legumes,3: spring barley, 4–5: perennial grasses
2–5° (3.5–8.3%)	38	XIV. 1: winter grains, 2: spring grains, 3: cereal grains with legumes, 4: winter grains, 5: spring barley, 6–8: perennial grasses
	38	XV. 1: winter grains, 2: spring grains, 3: cereal grains with legumes,4: spring grains, 5: spring barley, 6–8: perennial grasses
	33	XVI. 1: winter grains, 2: spring grains, 3: cereal grains with legumes, 4: spring barley, 5–6: perennial grasses
	33	XVII. 1-2: winter grains, 3: cereal grains with legumes, 4: spring barley, 5–6: perennial grasses

[a]M.a.s.g., maximum available slope gradient.
[b]M.r.p.g., minimum requirement of grasses in a crop rotation (%).
[c]Years of crop rotations.

Soil erosion rates were reduced 2–9-fold by using these measures, while productivity remained fairly constant (Arlauskas and Feiza, 1996).

These results demonstrate the need for soil conservation measures on arable undulating environments in Lithuania. The aim of current soil erosion research is to evaluate the potential for soil conservation on eroded undulating land and to advise on policies for rural development in transitional EU Accession State economies in relation to environmental protection. Promoting soil conservation in transitional economies is crucial for effective agricultural management. In the immediate future, Lithuania could export food produce at economically competitive rates. Any such production should be provided in an environmentally friendly and sustainable way. Therefore, research data and experience of soil conservation practices on the undulating relief of the Republic are very important for sustainable agricultural development. The multi-species agro-ecosystems (sod-forming perennial grasses and grass–grain crop rotations) are potential components for both soil conservation and biodiversity strategies. It is imperative that the soil resource base is conserved for future generations. Therefore, current investigations of carbon sequestration in Lithuanian soils, funded by the Leverhulme Trust (UK), may have important benefits for environmental protection. These benefits are both national (increasing soil organic carbon and thus decreasing soil erodibility) and international (by helping to ameliorate global warming).

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