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A Management System for Soil Conservation on the Hilly-Rolling Relief of Lithuania

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ABSTRACT

A conservation management system was developed for the hilly-rolling relief using research data from experiments carried out in the Kaltinenai Research Station and Vezaiciai Branch of Lithuanian Institute of Agriculture. Most of the experimental results were obtained from experiments set up on the slopes, hilltops, and foot slopes. The prevailing soils were Dystric and Gleyic Podzoluvisols, which are loamy sands or clay loam with primary excess acidity (pH_{KCl} to 5.5), low amount of mobile P_2O_5 (50-100 mg kg^{-1}) and medium or higher amounts of mobile K_2O (100-200 mg kg^{-1}). The erosion prevention grouping of erodible hilly-rolling terrain contains 5 groups of relief in depending on slopes' gradient and texture of soil. The requirements for picking out of groups and recommended soil conservation measures were formed using research data of field experiments. The annual productivity of fertile hay meadow and pasture stands was 5666-7752 feed units (FU) ha^{-1} during the 6-year period. According to the average of 12 years of research data, the amount of metabolizable energy accumulated by soil conserving grass-grain crop rotations under optimum ground and fertilizer treatments was 14.1-32.7% higher than in the field crop rotation and 11.8-27.7% higher than in the grain-grass crop rotation. Only the soil conserving grass-grain crop rotations enabled land-managers to decrease losses of soil due to water erosion by 76.8-80.8% in comparison with field crop rotation. The minimizing of soil tillage system and anti-erosion liming-fertilizing enabled further decreasing of soil loss and increasing of plant productivity.

INTRODUCTION

Deforestation, overgrazing, and mismanagement of arable land are the major cause of soil degradation by water and wind erosion. About 1028 million ha are moderately to excessively affected by water and wind erosion (Griesbach, and Sanders, 1998). The annual rates of erosion on cultivated land vary from 0.1-20 t ha^{-1} in the United Kingdom to 150-200 t ha^{-1} in the China (Morgan, 1995).

Lithuania, as a lowland country, has two upland regions. The island-like Zemaiciai upland is in the western part of the Republic when the edge of the Baltic upland is in the eastern and southern parts. Some 51.9% of Lithuania's terrain is on hilly-rolling relief, where soil is erodible (Kudaba, 1983). Our investigation was carried out in the Zemaiciai upland, approximately 55º34' N and 22º29' E. The relief there is exposed to erosion processes, since it is either steeply dissected hills with gullies, rolling areas on the central watershed part of the upland, or rolling-hills and undulating plains on the outskirts of the upland. There are long, moderately to strongly sloping hills in the central part, or short, gently sloping, densely grouped hills on the outskirts of the upland (Kudaba, 1983). However, the natural vegetation (woods, shrubbery, or grasslands) is able to protect our soils against erosion processes. Therefore, hypothesis of this experiment contained involving more agricultural crops with high soil conserving capability and reducing of tillage operations for stabilization of soil erosion processes.

The intensity of soil erosion in Lithuania depends on the tillage intensity, which determines extent of tillage (mechanical) erosion. B. Kiburys (1989) comprehensively investigated this kind of soil erosion. Tillage erosion is the main cause of accelerated soil erosion by water or wind (Jankauskas, 1996). The annual rates of soil erosion by water on the Baltic uplands were: 56.6 t ha^{-1} under bare follow, 1.3 t ha^{-1} under grain crops and zero under waste and perennial grass stands (Bieliauskas, 1985, Svedas, 1974). The rates of soil erosion by water on the Zemaiciai upland were dependent on the crops cultivated, crop rotations, and the slope gradient. The results of our investigations have been presented at scientific conferences, and have been published (Jankauskas, 1998a, 1998b, Jankauskas & Jankauskiene, 1996). Our work showed that soil losses due to water erosion on the hilly-rolling relief of Western Lithuania were 28.8-82.4 m^3 ha^{-1} under potato, 11.7-26.4 m^3 ha^{-1} under spring barley and 3.5-8.3 m^3 ha^{-1} under winter rye (Fig. 1). Only the

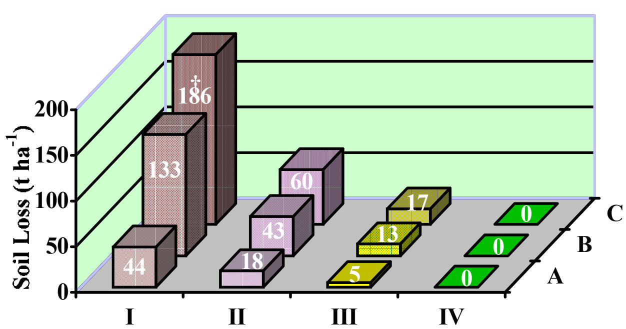

Figure 1. Influence of different crops to the losses of soil on the slopes of different gradient. Average annual data of 1983-1994. A-C - gradient of slopes: A - 2-5°, B - 5-10°, C - 10-14°. I-IV - losses of soil under: I - potato, II - spring barley, III - winter rye, IV - perennial grasses. †The perennial grasses for the long-term use.

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quick-growing grass stands completely stopped soil erosion. Mismanagement of land and water often leads to land degradation through erosion, waterlogging, and salinity as well as the depletion of groundwater resources. Moreover, soil and water degradation through contamination by agricultural, urban, and industrial effluents is of increasing importance in developed and developing countries (Eger et al., 1998). Therefore, we were seeking to develop a management system to achieve land conservation on the hilly-rolling relief of Lithuania. It was the main objective of our work.

MATERIALS AND METHODS

A large majority of the experimental results were from field experiments set up on the slopes, hilltops, and footslopes of hilly-rolling relief of Zemaiciai upland. Some research data were obtained by expedition investigations, when investigated plots (25 m^2) were located on the differently eroded slopes of Zemaiciai upland. The proposed management system combines the research data of several researchers of the Kaltinenai Research Station (Arlauskas and Feiza, 1996, Feiziene, 1996, Jankauskas, and Jankauskiene, 1998, Norgailiene, and Zableckiene, 1994).

The prevailing soils in the study area were Dystric and Gleyc Podzoluvisols (FAO-UNESCO, 1994) that are loamy sands or clay loam with primary excess acidity (pH_{KCl} up to 5.5), low amount of mobile P_2O_5 (50-100 mg kg^{-1}), and medium or higher amounts of mobile K_2O (100-200 mg kg^{-1}).

The long-term field experiments for comparing potential erosion controlling cropping systems on the slopes of varying gradients have been carried out since 1982. Four six-year crop rotations were compared:

A. The field crop rotation: year 1 - winter rye (*Secale cereale* L.), year 2 - potato (*Solanum tuberosum* L.), years 3+4 - spring barley (*Hordeum vulgare* L.), years 5+6 - mixture of clover-timothy (CT) (*Trifolium pratense* L. - *Phelum pratense* L.).
B. The grain-grass crop rotation: year 1 - winter rye, years 2+4 - spring barley, years 5+6 - CT.
C. The grass-grain I crop rotation: year 1 - winter rye, year 2 - spring barley, years 3+6 - CT.
D. D. The grass-grain II crop rotation: year 1 - winter rye, year 2 - spring barley, years 3+6 - mixture of orchard grass- red fescue (OF) (*Dactylis glomerata* L. - *Festuca rubra* L.).

The field experiments were carried out on the slopes of 2-5º, 5-10º and 10-14º. The perennial grasses of multiple composition for long-term use were grown on a slope of 10-14º instead of the field crop rotation. This grass mixture included 20% each of common timothy, red fescue, white clover (*Trifolium repens* L.), Kentucky bluegrass (*Poa pratensis* L.), and birdsfoot trefoil (*Lotus corniculatus* L.).

Optimum ground and fertilizer treatments were used based on soil properties. Soils were limed with one application of $CaCO_3$ (according to hydrolytic acidity) before field experiments commenced. A subsequent liming before each crop rotation enabled the standardization of soil reaction on all investigated slopes. Fertilization according to plant requirements and corrected according to soil properties contained the following rates of mineral nutrients:

– (N, P_2O_5, K_2O): $N_{60}P_{60}K_{60}$ under winter rye and spring barley,
– $N_{90}P_{90}K_{120}$ under potatoes,
– $P_{60}K_{90}$ under C-T of Year 1, $N_{120}P_{60}K_{90}$ under C-T of Year 2 and 3,
– $N_{180}P_{60}K_{90}$ under O-F of Year 1 to 3 and
– $N_{60}P_{60}K_{90}$ under C-T and O-F in the year of plowing, and
– 60 t ha^{-1} of farmyard manure under winter rye.

Therefore, the mean annual rates of fertilizers under different crop rotations were $N_{60}P_{65}K_{80}$ under the field crop rotation,

– $N_{50}P_{60}K_{70}$ under the grain-grass crop rotation,
– $N_{70}P_{60}K_{80}$ under the grass-grain I crop rotation and
– $N_{120}P_{60}K_{80}$ under the grass-grain II crop rotation.

The main tillage operations depended on the selected crop. The following tillage and crop operations were performed on the field of perennial grasses for the winter rye: stubble breaking after harvesting of grasses (last decade of June), disking (middle July), manure spreading and plowing (first decade of August), fertilizing by PK (last decade of August), cultivation-harrowing and sowing-rolling (first decade of September), fertilization with N (second half of April), spraying by herbicide (first half of May) and harvesting (first decade of August). The corresponding operations for spring barley were: stubble breaking (August), autumn plowing (September), cultivation, fertilization with NPK, cultivation-harrowing and sowing-rolling (last decade of April-first decade of May), spraying by herbicides (last decade of May-first decade of June) and harvesting (August). Autumn tillage operations for potato were the same as for spring barley, starting in spring with the following tillage and crop management: cultivation (second half of April), second cultivation (first days of May), fertilization with NPK and cultivation (end of first decade of May), planting (before 15th May), inter-row cultivation-harrowing twice before crop shoot development and inter-row cultivation twice after shoot emergence (every 3-5 days), spraying with herbicide (when potato shoots were 0.1-0.12 m), spraying with fungicides or insecticides (according to requirements), cutting of potato tops (first days of September) and potato digging (second decade of September). Fertilization of perennial grass with PK was performed in early spring, before vegetation started growing (first half of April) and with N on the early stage of vegetation, as well as after haymaking. The mixture of orchard grass-red fescue was harvested three times every year and other leys were harvested twice. Only one harvest was taken in the last year of perennial grass use before sowing of winter rye. The tillage, sowing-planting and harvesting directions were up-and-down slope. The seeding-machine 'Saxonia' with wedge coulters was used for sowing grain crops and perennial grasses, the four-row planting-machine 'SN-4B' was used for potato planting, the harvester 'SAMPO 500' was used for harvesting grain crops and the self-propelled hay mowing machine 'MF-70' was used for haymaking.

The yields of different crops were evaluated by the amount of metabolizable energy base on the chemical analysis of the harvestable portion of each crop. The losses of soil by water erosion were established by measuring the volume of the rills. The annual precipitation during the 12-yr. study was 635-1075 mm.

The spring barley grain and straw at the soft or hard dough development growth stage, was harvested from the plain hill tops (conditionally non-eroded soil), slopes of 2-5º (slightly eroded), 5-10º (moderately eroded), 10-14º (severely eroded), and on foot-slopes depositional (Fig. 2). The yield of different crops was evaluated by the amount of metabolizable energy accumulated, using the dry matter yield and chemical data. Calculation of metabolizable energy accumulated was based on the equation:

$$ME = 0.01746P+0.03123F+ 0.01365Fb+0.01478N,$$

where ME - metabolizable energy in MJ kg^{-1} DM (dry matter), P - digestible protein, F - digestible fat, Fb - digestible fibber, N - digestible nitrogen free extracted components in g kg^{-1} DM (Jankauskas et al. 2000).

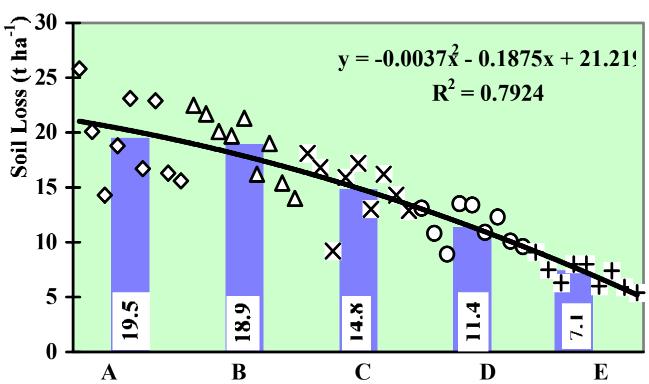

Figure 2. Dependence of barley yield (y) on degree of soil erosion and on the slope gradient (in degree - x) A. Footslopes depositional; B. Plains: conditionally non-eroded soil; C. Slopes of 2-5º: slightly eroded soil; D. Slopes of 5-10º: moderately eroded soil; E. Slopes of 10-14º: severely eroded soil. y - the three-year average grass yield of grain and straw. On the columns - the average yield.

RESULTS AND DISCUSSION

Arable soils are eroded by tillage operations, water, and wind on the hilly-rolling relief. The natural fertility of the soil on the slightly, moderately, and severely eroded slopes of Zemaiciai upland has decreased by 21.7, 39.7 and 62.4% (Fig. 2). This was due to deterioration of physical and chemical properties of soil. The bulk density and the percentage of clay-silt and clay fractions increased, while the total porosity and water field capacity decreased (Table 1). The strong acidity of the E, EB and B1t horizons, and the increased acidity throughout the soil profile are characteristic features of Dystric Podzoluvisols (Jankauskas, 1996).

Our suggested soil+crop management program for land conservation is presented in the Table 2. The farmland on the hilly-rolling relief should be divided into 5 groups. Group I includes the highly erodible soils that are on slopes <10º, and have sandy, loamy sand or gravel textures (light soils) or on slopes <15º with loamy or clay textures (heavy soils). We suggest planting trees on such slopes. Growing long-term perennial grasses was recommended on the light soils with 7-10º slopes and heavy soils with 10-15º slopes, and on surrounding soil that is unsuitable for any other exploitation (Group II). We suggested soil conserving grass-grain crop rotations, including 50-80% of perennial grasses, for soils in Group III that are on 5-7º slopes with light soils and on 7-10º slopes with heavy soils. These slopes should be arranged into fields suitable for tillage. Group IV includes 2-5º slopes with light soils and 3-7º slopes with heavy soils, and utilizes soil conserving grain-grass crop rotation, including 33-50% perennial grasses. When growing grain crops, it is important to use soil conservation tillage and fertilizers on the undulating and rolling relief. Group V includes the remaining fields with flat to gently undulating relief. Common field crop rotations can be used on these soils, however we suggest using conservation tillage on 2-3^0 slopes.

Perennial grasses provide full protection from soil erosion, even on the 10-15^0 slopes. Permanent legume-grass mixtures were studied on the Kaltinenai Research Station. Grass mixtures with a high percentage (90%) of common alfalfa *(Medicago sativa* L.) were more suitable for hilly pastures if soils were suitable for growing alfalfa. The annual average yield was 6.12 t ha^{-1} dry matter or 0.92 t ha^{-1} digestible protein. Later investigations showed that majority soils' of the Zemaiciai upland are not suitable for growing

Table 1. Dependence of clay-silt and clay fractions as well as soil porosity and water field capacity upon the degree of soil erosion in the arable horizon of Dystric Podzoluvisols.

Degree of soil erosion	Clay fraction (<0.001 mm)	Clay-silt fraction (<0.01 mm)	Soil porosity	Water field capacity
	(%)			
Non-eroded	11.6	24.6	28.9	42.6
Slightly eroded	14.0	33.2	27.9	41.8
Moderately eroded	19.1	37.4	24.8	39.3
Strongly eroded	31.1	44.2	22.6	37.1
LSD_{05}	2.22	2.30	0.99	0.04

Table 2. The erosion control groupings of erodible terrain and management practices

Groups	Texture of soil† and gradients of slopes		Type of land use	Requirements	Recommended erosion-resisting measures
	S, LS, G	L, C			
I	< 10º	< 15º	Woods	Slopes <10^0 and 15^0 unsuitable for land reclamation.	Plant trees or shrubs, and carefully tended perennial grasses.
II	7-10º	10-15º	Grass-land	Slopes that are inconvenient for tillage. Establish the pasture or grassland.	Plant perennial grasses for long-term use. To renovate it by mixture of another composition. Cover crop must be annual grasses such as mixture of spring barley and field pea (*Pisum sativum L.*) for green forage.
III	5-7º	7-10º	Arable land or grass-land	Similar to Group II, but must be suitable for tillage.	Use the recommended erosion controlling grass-grain crop rotation. Apply soil conserving tillage practices.
IV	2-5º	3-7º	Arable land	Similar to Group III, may include up to 10% of the light textured soils on <7^0 gradient slopes.	Practice the erosion controlling grain-grass crop rotation. Apply soil conserving tillage practices. Avoid growing tilled crops and flax.
V	Up to 2º	Up to 3º	Arable land	Plain, suitable for tillage plots, these remained after forming Groups I-IV.	Use intensive field crop rotations. On the slopes of 2-3º, apply soil conserving tillage practices.

†S - sand, LS - loamy sand, G - gravel, L - loam, C - clay.

Table 3. Influence of management systems to the losses of soil on the slopes of different gradient

Crop rotations as management system	Average annual data of 1983-1994					
	Losses of soil t ha^{-1} on the slopes of:			Amount of metabolizable energy in GJ ha^{-1} on the slopes of:		
	2-5º	5-10º	10-14º	2-5º	5-10º	10-14º
Field	12.6	31.6	44.9†	82.9	77.9	71.6†
Grain-grass	9.5	24.8	35.2	84.6	81.0	75.8
Grass-grain I	2.9	6.2	9.4	94.6	95.1	88.9
Grass-grain II	2.8	6.0	9.7	102.5	103.4	95.8
LSD_{05}	0.85	1.78	1.43	1.80	1.80	1.90

† The perennial grasses of long-term use were grown instead of the field crop rotation on the slope of 10-14^0.

alfalfa due to excess soil acidity and a high percentage of waterlogged subsoil. It was therefore necessary to establish that long-term perennial grasses were more suitably for such soils. The grass mixtures of high fertility for early, medium and late hay making or grazing were established. The annual average productivity of the most fertile hay meadow mixture during a 6-year period was 7.9-9.2 t ha^{-1} dry mater. The productivity of the pastureland was 5.6-7.1 t ha^{-1}. The productivity of these grass mixtures did not decrease during a 6-year period, indicating that the duration of these grass mixtures might be longer (Norgailiene and Zableckiene, 1994). These long-term perennial grass mixtures can be used for grasslands on the areas in Group II with erodible terrain.

Soil conserving six-year crop rotations has been investigated at the Kaltinenai Research Station since 1983. The grain-grass crop rotations contained 67% grains and 33% perennial grasses. The grass-grain crop rotation contained 33% grain crops and 67% perennial grasses. Tillage crops and flax are not grown in these crop rotations.

The research data of 12 years of the field experiments (1983-1994) showed that the average annual loss of soil under the soil conserving grass-grain crop rotations decreased 77-81% in comparison with the field crop rotation, while losses from the grain-grass crop rotation decreased 22-24% (Table 3). The amounts of metabolizable energy accumulated in these grass-grain crop rotations were 88.9-103.4 GJ ha^{-1} or 14-33% higher than in the field crop rotation, and 12-28% higher than in the grain-grass crop rotation (Table 3). This research data enabled us to design and recommend the soil conserving crop rotations (Table 4). These crop rotations can be used on soils in Groups III and IV of erodible terrain (Table 1).

Even grass-grain crop rotations could not completely stop soil erosion. The annual rates of soil loss from water erosion were 9.4-9.7 t ha^{-1} on the 10-14º slope, 6.0-6.2 t ha^{-1} on the 5-10º slope, and 2.8-2.9 t ha^{-1} on the 2-5º slope. Soil losses on the >10º slopes are greater than soil formation rates according to our soil profile depth (Richter, 1997). Therefore

Table 4. The crop rotations promoting soil conservation for fields with differing gradients.

Biggest slope Gradient	Per cent of grasses in a crop rotation	Composition of crop rotation
7-10º	80.0	A. 1 - winter grains or barley, 2-5 - perennial grasses.
	71.5	B. 1 - winter grains, 2 - barley, 3-7 - perennial grasses.
	67.0	C. 1 - winter grains, 2 - barley, 3-6 perennial grasses.
	62.5	D. 1-2 winter grains, 3 - barley, 4-8 - perennial grasses.
	62.5	E. 1 - winter grains, 2 - spring grains, 3 - barley, 4-8 - perennial grasses.
	60.0	F. 1 - winter grains, 2 - barley, 3-5 - perennial grasses.
5-7º	57.0	G. 1-2 - winter grains, 3 - barley, 4-7 - perennial grasses.
	57.0	H. 1 - winter grains, 2 - spring grains, 3 - barley, 4-7 - perennial grasses.
	50.0	I. 1-2 - winter grains, 3 - barley, 4-6 - perennial grasses.
	50.0	J. 1 - winter grains, 2 - cereal grains with leguminous, 3 - barley, 4-6 - perennial grasses.
	43.0	K. 1 - winter grains, 2 - cereal grains with leguminous, 3 - winter grains, 4 - barley, 5-7 - perennial grasses.
	43.0	L. 1 - winter grains, 2 - cereal grains with leguminous, 3 - spring grains, 4 - barley, 5-7 - perennial grasses.
	40.0	M. 1 - winter grains, 2 - barley or their mixture with leguminous, 3 - barley, 4-5 - perennial grasses.
2-5º	37.5	N. 1 - winter grains, 2 - spring grains, 3 - cereal grains with leguminous, 4 - winter grains, 5 - barley, 6-8 -perennial grasses.
	37.5	O. 1 - winter grains, 2 - spring grains, 3 - cereal grains with leguminous, 4 - spring grains, 5 - barley, 6-8 -perennial grasses.
	33.3	P. 1 - winter grains, 2 - spring grains, 3 - cereal grains with leguminous, 4 - barley, 5-6 -perennial grasses.
	33.3	R. 1-2 - winter grains, 3 - cereal grains with leguminous, 4 - barley, 5-6 -perennial grasses.

we recommended grassing the >10º slopes, and using of conservation tillage and fertilizing-liming the 2-10º slopes as well as the soil conserving crop rotations.

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

CONCLUSION

The need for soil conserving management system on the hilly-rolling relief increases with increase of slope gradient and length as well as with increase of human activities. The soil conserving capability of investigated crop rotations depended on the erosion-resisting capability of constituent crops. The erosion-resisting tillage and fertilizing-liming intensify an erosion-preventive capability of crops. Therefore, introduction of optimum management system for soil conservation (sod-forming perennial grasses, soil conserving crop rotations, erosion-resisting soil tillage and fertilizing-liming) assists both soil erosion control and stability of crop production on the hilly-rolling relief.

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