MODELLING OF TERRESTRIAL EROSION AND CHANGE OF SOIL FEATURES UNDER SOIL EROSION ON THE HILLY RELIEF OF LITHUANIA

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ABSTRACT

Modelling of terrestrial erosion is important for better understanding of relief and soil formation as well as for better understanding of agro-physical soil degradation processes. Physical, chemical and biological weathering as a primary stage of geological (natural) erosion and accelerated soil erosion are mentioned in the model of presented terrestrial erosion. Wind (eolian) and water erosions are mentioned as the main parts of geological erosion. Mechanical, wind and water erosions are mentioned as the main parts of accelerated soil erosion. Designed model contains and deeper classification of all afore mentioned main parts of terrestrial erosion.

The Dystric Albeluvisols loamy sand and clay loam soils were investigated on the hilly-rolling relief of the Zemaiciai upland (Western Lithuania). Twenty-three longitudinal relief profiles, 87 soil profiles, and 69 boreholes were described and characterised by data of agro-physical and agro-chemical analysis. Losses of soil due to sheet erosion and rill (liner) erosion as stages of water erosion were estimated on the six long-term field experiments. There are monitoring plots with different land use/land cover on the slopes of different inclination and with different soil texture. Results of our investigations could be supplement the global databases supporting environmental monitoring and soil conservation. According to 12 years of field experiments' losses of soil due to water erosion on slopes of 2-5^0, 5-10^0 and 10-14^0 were as follows: 5.4-29.6 t ha^{-1} under winter ryes, 18.0-59.7 t ha^{-1} under spring barley and 44.4-196.2 t ha^{-1} under potatoes. Only perennial grasses completely stopped water erosion. Processes of soil erosion (tillage erosion, water erosion, wind erosion) led to deterioration of agro-physical soil features and to strong soil fertility decrease. The fertility of slightly, moderately and severely eroded soils has decreased 21.7-22.1%, 38.9-39.7% and 62.4%, respectively.

1 INTRODUCTION

The fragility of eco-systems, the permanently increasing earth population, the importance of agriculture and need for sustainable land use/land cover and the increased pollution require a comprehensive assessment and evaluation of the erosion phenomena. Measurement, classification and modelling of erosion in affected areas provides the basis for the design and implementation of erosion control and soil management programmes witch should be integrated within the International Geosphere-Biosphere programme (IGBP) and could be improve the global situation of terrestrial ecosystem.

Soil erosion is a hazard associated with ecology and especially with agriculture, and is important long-term effect on soil productivity and sustainable land use. The control of erosion processes and the design of control measures we now necessary in almost every country of the world, under every type of land use (Morgan, 1995). Due to the wide range of erosion models exist the intention to classify them in the following sequence: field-scale water erosion models, catchment or watershed-scale water erosion models, wind erosion models, models with a landscape-scale and larger focus (Boardman and Favis-Mortlock, 1998). One aim of the Soil Erosion Network launched by the Global Change and Terrestrial Ecosystem (GCTE) Core Research Project of the International Geosphere-Biosphere Programme (IGBP) is to refine and adapt current soil erosion models for use in global change studies from plot to regional scales (Valentin, 1998). There was endeavour (attempt) to extend the classification of erosion processes up to large scale (Zachar, 1982), however globalisation of erosion modelling is rare occurrence. Therefore one aim of our project was classification or modelling of terrestrial erosion.

Lithuania is a lowland country. The hilly-rolling relief, dissected by gullies and valleys of rivers, has been formed in early Holocene (Postglacial) period after melting of last glacier. The erodible glacial moraine, abundance and intensity of precipitation had created the favourable natural conditions for erosion of parent rock by water. There are two headwater regions on Lithuanian terrain. The islandlike Zemaiciai upland is in the Western part of the Republic, the edge of the Baltic upland is in the Eastern and Southern parts. Therefore 51.9% of terrain in Lithuania are on the hilly-rolling relief, where the soil is erodible (Kudaba, 1983). The erosivity of our soils depends on the erodible glacial parent rock, on the hilly-rolling relief, on abundance and intensity of precipitation, on the state of cover plants and on other circumstances. The natural vegetation (trees, shrubs and perennial grasses) is able to preserve our soils against erosion processes. However the farmers create the favourable conditions for soil erosion using the soil tillage equipment on the arable land areas, especially on the arable slopes. Therefore the mechanical tillage erosion is the primary course for water and wind erosion (Kiburys, 1989). We have investigated soil erosion processes on the Zemaiciai upland. Water pollution by products of water erosion is one of the ecological aspects of soil erosion. Another of these aspects is soil degradation, which directly depends on the extent of erosion. The after-effect of soil erosion is the deterioration of physical and chemical properties of soil, decreasing its biological activity and productivity (Lowery et. al., 1995).

The research data showed, that the soil erosion extent can be rapidly decreased or overcome by means of minimisation of soil tillage operations (Arshad et al. 1997, Klima 1997, Kornmann et al. 1997, Morgan, 1996). The modern antierosion soil tillage equipment is require for such a tillage. We were short of such equipments'. Therefore our attention was concentrated on antierosion possibilities of different plants. The losses of clay loam soil due to water erosion on the slope of 5-7^0 (Eastern Lithuania) ranged from 1.3 t ha^{-1} under cereal grain crops to 56.6 t ha^{-1} under black follow. There were no losses of soil under the waste and under the perennial grass field. The adequate address of the soil erosion problems as well as the correct formulation of mitigation and prevention plans requires the understanding of the complexity of the soil erosion phenomenon and its implications.

2 MATERIALS AND METHODS

The research data presented in this paper were obtained from the hilly-rolling relief of the Zemaiciai upland. Comparison of erosion-preventive crop rotations on the slopes of various gradients has been investigated by field experiments since 1982. Four alternative agro-phytocenoses (six-course crop rotations) of the following structure were compared: I. The field crop rotation contained: 1. Winter rye *(Secale cereale* L.*)*, 2. Potato *(Solanum tuberosum* L.*),* 3-4. Spring barley, 5-6. Mixture of clover-timothy (CT) *(Trifolium pratense* L.*-Phelum pratense* L.*)*; II. The grain-grass crop rotation contained: 1. Winter rye, 2-4. Spring barley, 5-6. CT; III. The grass-grain I crop rotation contained: 1. Winter rye, 2. Spring barley, 3-6. CT; IV. The grass-grain II crop rotation contained: 1. Winter rye, 2. Spring barley, 3-6. Mixture of orchard grass-fescue red (OF) *(Dactylis glomerata* L.*-Fescue rubra* L.*).* Perennial grasses of multiple composition for long-term use were grown on the slope of 10-14^0 instead of the field crop rotation. This grass mixture included white clover (Trifolium repens L.), Kentucky bluegrass *(Poa pratensis* L.*),* birdsfoot trefoil *(Lotus corniculatus* L.*)* common timothy and red fescue (20% of each). The field experiments were carried out on the slopes of 2-5^0, 5-10^0 and 10-14^0. The width of all experimental plots was 3.6 m, the length was 100 m on the slopes of 2-5^0 and 10-14^0, or 50 m on the slope of 5-10^0. The soil was an eroded sandy loam with $pH_{(KCl)}$ of 5.3-5.8, hydrolytic acidity of 1.7-2.5 cmol (+) kg^{-1}, base saturation of 67.9-85.5%, available P_2O_5 of 42-114, available K_2O of 158-176 mg kg^{-1} of soil, and humus of 1.96-2.69%. The optimum soil management and fertiliser treatment were used according to the soil features. The soil losses due to water erosion were established using the method of rills' volume measurement. The soil textural classes (see Fig. 9) were established according to the classification of N. Kachinskij. The research data were calculated using the variance analysis at probability level of 95%. The annual precipitation amount during the period of study was from 635 to 1075 mm. The field experiments are part of the GCTE (Global Change and Terrestrial Ecosystem) Core Research Project, which belongs to the IGBP (International Geosphere-Biosphere Programme). Results of field experiments were as first stage for modelling of water as well as of mechanical tillage soil erosion. These results were widely published, therefore part of them in this presentation will be shortly presented from publications.

The expedition investigations were organised for better knowledge of properties of eroded soils on the hilly-rolling relief. Detailed description of 23 longitudinal relief profiles, 87 soil profiles, 69 boreholes and analysing of 647 soil samples from different horizons of soil profiles' permits us to prepare the database of properties of eroded soils. Loamy sand and clay loam soils prevailed on the research plots. Albeluvisols as the major soil group, and Dystric Albeluvisols as well as Gleyic Albeluvisols as soils individual units prevailed on the investigated slopes. The arable soil on the hilly or rolling relief is eroded by tillage implements, by water and by wind. The degree of soil erosion was determined by comparison of lost soil layer, slope gradient and different thickness of genetic soil horizons (Table 1). The standard (uneroded) soil profiles were found only in the forests or on theirs' borderline with fields. The natural soil fertility on the hilly relief of above mentioned longitudinal relief profiles were established by growing of spring barley. The gross yield of grain and straw at the growth stages of soft or hard dough development was harvested on the plain tops of hills (conditionally non-eroded soil), on the slopes of 2-5^0 (slightly eroded soil), 5-10^0 (moderately eroded soil), 10-14^0

(severely eroded soil) and on the deposit footslopes. The barley was grown on permanent plots during three successive years.

Table 1. Dependence of degree of erosion of Dystric Albeluvisols (ABd) on the level of their lessivation-podzolization and thickness of lost soil layer

Degree of erosion	Initials	Ploughed out horizon[a] on the soils: ABd$_3$	ABd$_2$	ABd$_1$	Thickness of lost soil layer cm[b]	Correspondence to slope gradient
Slight	N_1 (S)	Top E[c]	E	EB	5 - 20	2 - 3^0
Moderate	N_2 (M)	E	E, EB	Bt1	20 - 40	3 - 7^0
Severe	N_3 (V)	EB	Bt1	Bt2	40 - 60	7 - 10^0
Very severe	N_4 (E)	Bt1	Bt2	C(BC)	>60	>10^0

[a] *Soil horizons under arable layer. Their identities were established by colour of subsoil, which is ploughed out by ploughing to 25 cm depth: E - light grey, EB - light grey with brown patches, Bt1 - brown with light grey patches, Bt2 - brown, C(BC) - brown (calcareous).* [b] *It was established by difference in depths of a calcareous horizon between uneroded and eroded soils.* [c] *Top part of E horizon. AB d1-3 - degree of lessivation-podzoluvisation: AB d1 - slight, AB d2 - moderate, AB d3 - deep.*

Above mentioned database of research data served for modelling of erosion processes. Methods of image sequence and predictive modelling were used on the separate stages of terrestrial erosion modelling.

3 RESULTS AND DISCUSSION

We have investigated four changeable agrophytocenoses, which recur every 6 year as representative of different agricultural rotation systems on slopes of different gradient. The erosion-resisting capabilities of investigated agro-phytocenoses depend on the composition of crop rotations. Perennial grasses completely stopped water erosion, even on slopes of 10-14^0 gradient, while average annual rates of water erosion under winter rye, spring barley and potato were 5.4 - 29.6 t ha^{-1}, 18.0 - 59.7 t ha^{-1} and 44.4 - 196.2 t ha^{-1}, respectively. The role of different crops in composition of crop rotations determined the total erosion-resisting capability of investigated agro-phytocenoses, according to average annual results of twelve years (Fig. 1). The average annual rates of soil loss under erosion-preventive grass-grain crop rotations decreased 77.4-80.7% in comparison with the field crop rotation, while under grain-grass crop rotation it decreased 21.5-24.6%. However, even the grass-grain crop rotations could not completely stop soil erosion. The annual rates of soil losses by water erosion were 9.4-9.7 t ha^{-1} on the slope of 10-14^0 gradient.

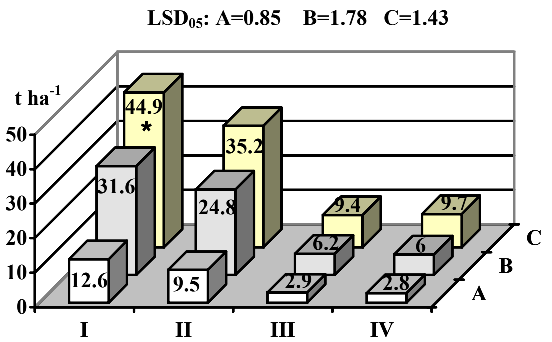

Fig. 1. Influence of crop rotations to the losses of soil on the slopes of different inclination

*Average annual data of twelve years. A-C - inclination of slopes: A - 2-5^0, B - 5-10^0, C - 10-14^0. I-IV - crop rotations (agro-phytocenoses): I- field, II- grain-grass, III- grass-grain I, IV- grass-grain II. *The perennial grasses of long-term use were grown instead of the field crop rotation on the slope of 10-14^0.*

The change of agrophysical properties of soil under agrarian measures is a long process. Therefore, significant differences were obtained only in a few cases of our 12 year field experiments. Changes in the dry bulk density and in the particle density of soil were insignificant. The total porosity and water field capacity of soil increased significantly under grass-grain crop rotations, but only on the test-slope of 2-5^0 gradient

The fertility of soil on different positions of hilly-rolling relief demonstrates the extent of soil degradation under the common influence of historic (natural) and present (accelerated) soil erosion. Such soil fertility on the Zemaiciai upland altered on a large scale. On the slopes of 2-5^0, 5-10^0 and 10-14^0 it decreased 21.7-22.1%, 38.9-39.7% and 62.4%, respectively. There was a close connection between the barley yield and the slopes' gradient or degree of soil erosion (Fig 2.). There is evident decrease in data dispersion with an increase in the degree of soil erosion. Presented research data demonstrate an unsatisfactory ecological situation in this region, as a result of unsuitable land use.

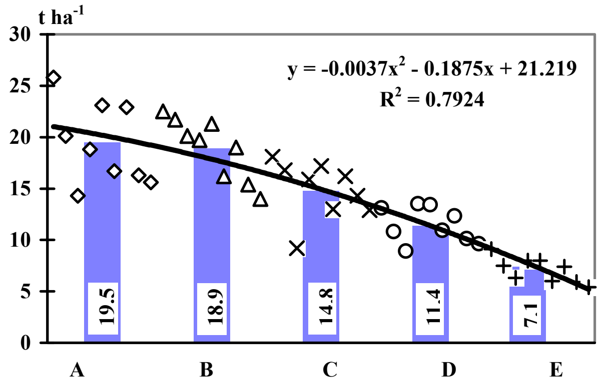

Fig. 2. Dependence of barley yield (y) on the slope gradient and degree of soil erosion

A. Deposition footslopes; B. Plains - conditionally uneroded soil; C. Slopes of 2-5⁰ - slightly eroded soil; D. Slopes of 5-10⁰ - moderately eroded soil; E. Slopes of 10-14⁰ - severely eroded soil. The average three year grass yield of grain and straw on the columns (y).

The fertility of differently eroded soils depended on physical soil properties (Fig. 3 and 4). The percentage of clay-silt (physical clay) and clay fractions increased in consecutive order with increasing of degree of soil erosion (Fig. 3). The bulk density of soil increased in order: 1.48, 1.5, 1.59 and 1.64 g cm^{-3} according to non-eroded, slightly, moderately and strongly eroded soils. Increasing of the particle density was hardly noticeable. It increased from 2.57 to 2.61 g cm^{-3}.

The percentage of soil porosity and water field capacity decreased significantly accordingly to increasing of degree of soil erosion (Fig. 4). Corelation of clay-silt and clay fractions of soil with other agro-physical attributes is evident from comparison results of particle-size analysis with that of soil bulk density, porosity and water field capacity. Clearly expressed increasing of clay and clay-silt fractions of eroded soils influenced consecutively to increasing of dry bulk density of soil and to decreasing of soil porosity and water field capacity.

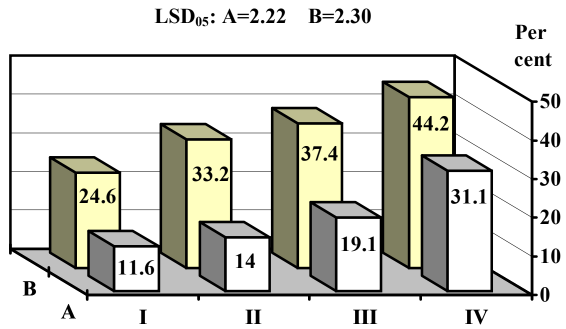

Fig. 3. Dependence of clay-silt and clay fractions upon the degree of soil erosion in the arable horizon of Dystric Albeluvisols

A- per cent of clay fraction (<0.001 mm); B- per cent of clay-silt (physical clay) fraction (<0.01 mm). I-IV degree of soil erosion: I-non-eroded, II-slightly eroded, III-moderately eroded, IV-strongly eroded

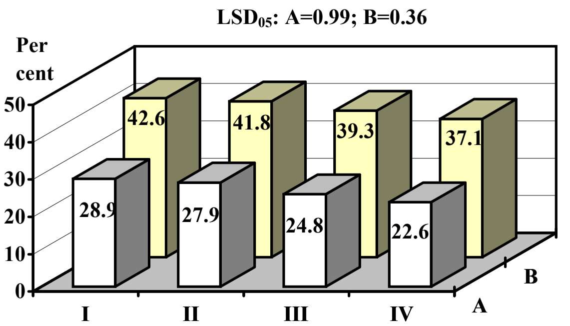

Fig. 4. Dependence of soil porosity and water field capacity upon the degree of soil erosion in the arable horizon of Dystric Albeluvisol

A- per cent of soil porosity; B- per cent of water field capacity. I-IV - same as in fig.3.

The extent of soil degradation due to combined action of tillage, water and wind erosion can be shown by comparison of soil profiles on different positions of arable hilly-rolling relief with the uneroded soil profile (Fig. 5). The thickness of lost soil layer ranged from 0.12 m (soil profile S2) to 0.94 m (soil profile S1), while the thickness of soil layers remaining above the calcareous horizon ranged from 1.85 m to 1.03 m, respectively. The thickness of soil layers deposited on the footslopes was 0.31-0.64 m in case of demonstrated longitudinal soil profiles S, and up to 1.62 m in the other soil profiles.

Among 185 investigated soil profiles or borecholes, 116 shared sings of being eroded (74.8%). Very severely and severely eroded soils were found in 49 plots (31.6%). Twenty-nine profiles (18.7%) were moderately eroded, 18 profiles (11.6%) were slightly eroded and 20 profiles (12.9%) contained eroded-deposit soil.

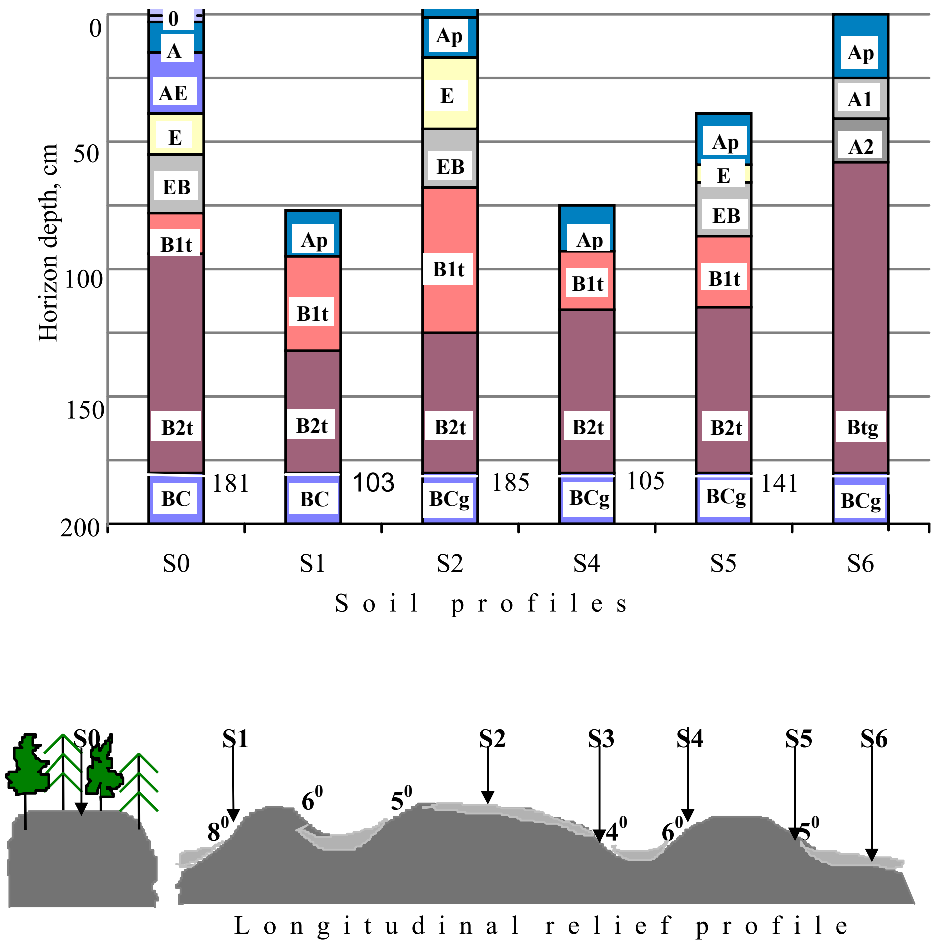

Fig. 5. The degree of soil erosion on the longitudinal relief profile S

S0-S6 - soil profiles: S0 - uneroded soil in woodland; S1 and S4 - very severely eroded soil (lost layer of soil 0.94 and 0.92 m, respectively); S2 - slightly eroded soil (lost layer 0.12 m) ; S5 - severely eroded soil (lost layer 0.53 m). The location of soil profiles is indicated by arrows. The white doted line indicates the depth of calcareous horizon, the numbers near dotted line indicates depth of this horizon in cm.

The main cause of accelerated soil erosion on the arable soils of Lithuania is mechanical tillage soil erosion. This kind of soil erosion was not valued and recognised properly during a long period. An international symposium "Tillage translocation and tillage erosion" (1997, Toronto, Canada) was first very important step for scientific developing of understanding of tillage translocation and tillage erosion. This kind of soil erosion was comprehensively examined in Lithuania since 1960 (Kiburys, 1989). The mechanical soil erosion is caused by the variation in soil translocation by tillage or land reclamation implements. This variation is responsible for redistribution of soil within a landscape that typically results in soil loss on convex upper slope positions and soil accumulation in concave lower slope positions. Mechanical soil erosion also operates synergistically with wind and water erosion by exposing erodible subsoil on slope convexities to wind and water erosion and by delivering unconsolidated soil material into areas of concentrated overland water flow where it is subject to rill and ephemeral gully erosion.

According to our investigations soil translocation by tillage erosion is large even over a short distance, whereas water and wind erosion only operate over much longer in distance (Kiburys and Jankauskas, 1997). Our model of mechanical soil erosion contains erosion of slopes (agricultural and forestry activities), of plains (land reclamation) and of quarries (Fig. 6).

The wind erosion in Lithuania is clearly expressed only on the narrow belt of the Baltic see coast. The forest there was cut dawn at the end of 18th century. Therefore drift of sand started and 14 villages were buried under the dunes during 1786 - 1854.

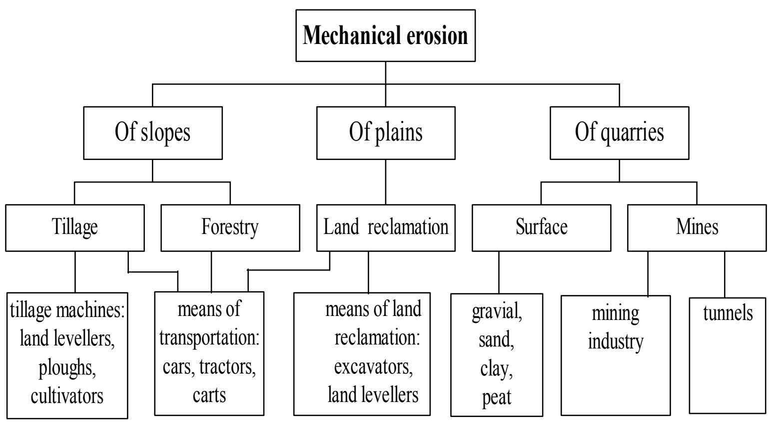

Fig. 6. Model of mechanical soil erosion

The speed of dunes moving there was 4 - 7,5 m yr^{-1}. On the continental part of Lithuania occur of wind erosion depended mostly on agricultural activity: the exposed large area of sandy or peaty soils. Therefore model of wind erosion has better developed only agrarian wind erosion position (Fig. 7). Desert and mountain positions are not developed.

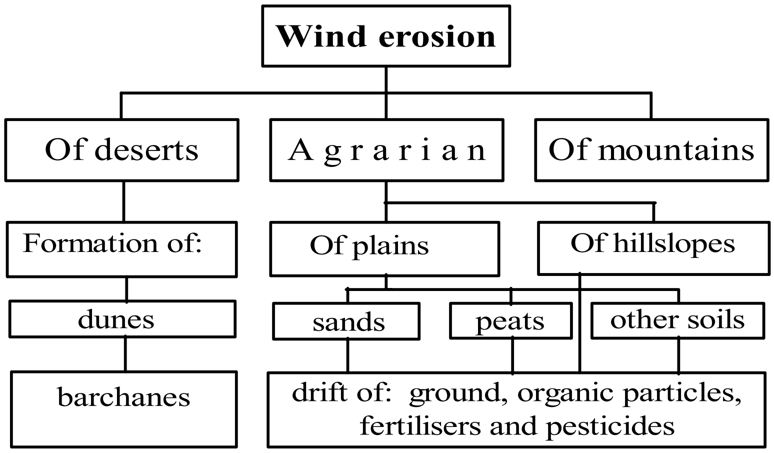

Fig. 7. Model of wind (eolian) erosion

Under the prevailing conditions of the temperate zone water erosion is more important than wind erosion therefore more attention is devoted for this type of soil erosion. The water erosion is divided into two main groups: subsurface erosion of parent rock and surface soil erosion (Fig. 8). Subsurface erosion rise part of precipitation, which percolate through the arable soil horizon. Subsurface erosion is divided into four groups. The percolated water raises the lessivation process at first. The smallest soil particles are washed from the arable and alluvial (E) soil horizons to illuvial (B) horizon without chemical changes of mentioned particles. Accumulation of clay fraction in the Bt horizons of Dystric Albeluvisols is evident from presented our investigations (Fig. 9). We named lessivation as a phenomenon of subsurface soil erosion, because it's correspond main requirements of water erosion. The mentioned phenomena exist in the deeper horizons of soil as well as in the underground caves.

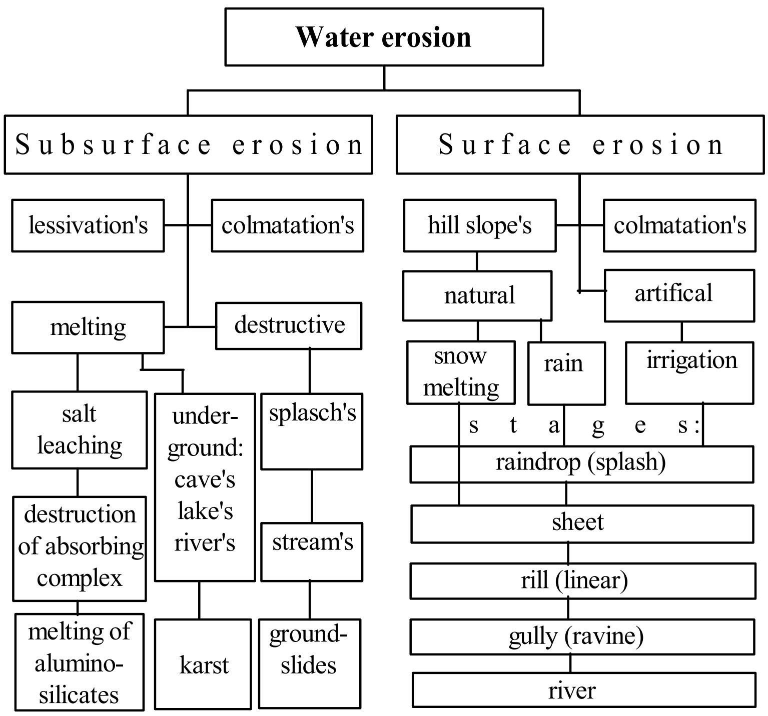

Fig. 9. Model of water erosion

The percolated water, enriched by carbon acid, melt and leach of soil salts, destroys of absorbing soil complex and aluminosilicates and is able to form the underground caves, “laces” and “rivers”. The melting subsurface erosion contains all or part of mentioned phenomena. The process of filling up the underground spaces by sediments from upper parts of underground cave or by parent rock slumped from the “ceiling” of cave we named as a colmatation subsurface erosion. The phenomena, when slumping of ground comes from the soil surface have name of karst erosion. Such a phenomenon is common on the northern part of Lithuania.

The surface water erosion has developing on the hillslopes. The hillslope water erosion can be rise by natural (rain of snow melting) and artificial (irrigation) sources of water. It contains raindrop (splash), sheet, rill or linear, gully and river stages of water erosion.

Further developing of water erosion is shown on the full model of terrestrial erosion (Fig. 10), where lateral, riverbed, waterfall and landslide stages of water erosion have developing as a geological (natural) erosion. The full model of terrestrial erosion contains weathering as an initial stage of geological (natural) and accelerated soil erosions and geological as well as accelerated soil erosions as separate parts of terrestrial erosion. The accelerated soil erosion contains three main parts of soil erosion: mechanical, water and wind erosions and three mixed forms: mechanical - water, mechanical - wind and water - wind erosions.

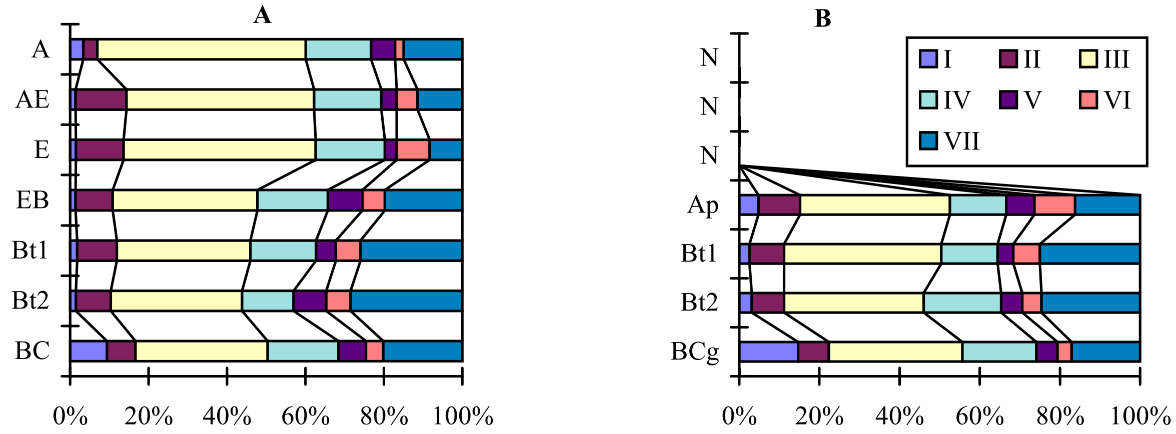

Fig. 9. Concentration of clay fraction in a Bt soil horizons as phenomena of lessivation soil erosion
A - Uneroded soil profile on the forest; B - Severely eroded soil profile on the arable slope of 6 degree; N - Loss layer of soil. I-VII - Structural parts of soil texture: I - washing HCl losses, II - 1-0.25 mm, III - 0.25-0.05 mm, IV - 0.05-0.01 mm, V - 0.01-0.005 mm, VI - 0.005-0.001 mm, VII - < 0.001 mm.

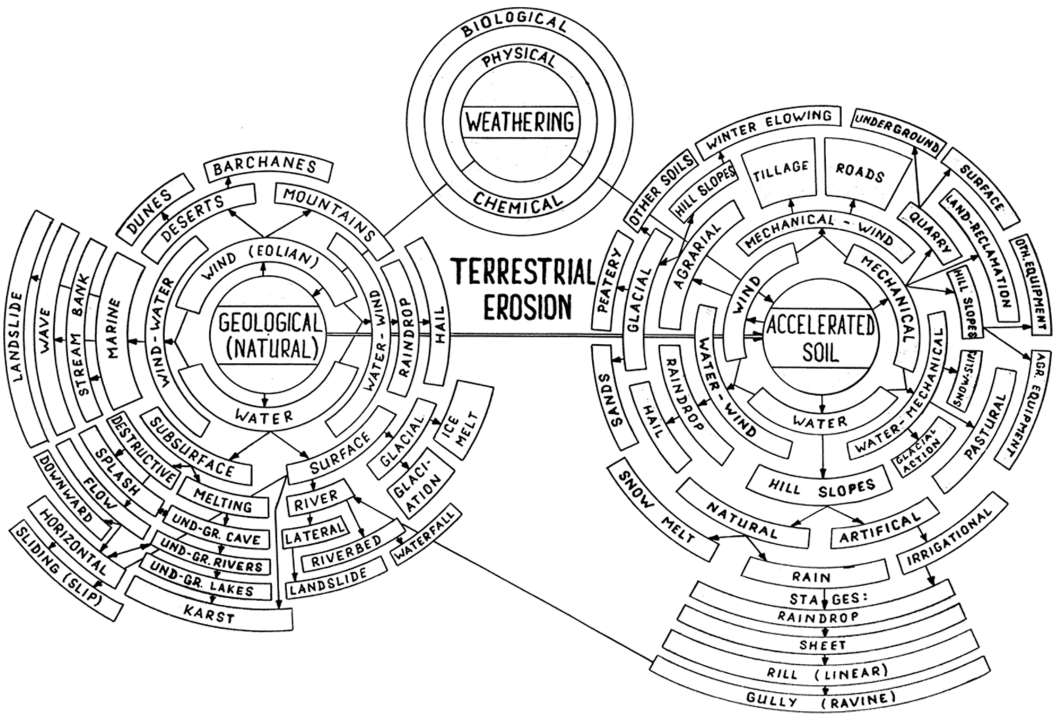

Fig. 10. The full model of terrestrial ground/soil erosion

4 CONCLUSIONS

The complex nature of the erosion phenomena with multiple physical factors implied calls for a sound scientific basis, with an experimental programme. The adequate address of the soil erosion problems and prevention plans requires the clear understanding of the complexity of the phenomena and their implications. It is important to join the mechanical soil erosion into model of accelerated soil erosion. The mechanical tillage erosion is main primary stage of accelerated soil erosion on the hilly rolling relief of temperate climate. Water or wind erosions are as a consequence of tillage erosion.

Losses of soil due to water erosion have changed from 5.4 t ha^{-1} under winter rye on a slope of 2-5^0 to 133 t ha^{-1} under potato on a slope of 5-10^0. Only perennial grasses completely stopped water erosion. The average annual losses of soil have decreased 77-81 per cent under erosion-preventive grass-grain agro-phytocenose in comparison with the field crop rotation. Processes of soil erosion (tillage erosion, water erosion, wind erosion) led to deterioration of agro-physical soil features and to strong soil fertility decrease. The fertility of slightly, moderately and severely eroded soils has decreased 22, 39 and 62 per cent, respectively.

Terrestrial landcape is the result of long and intense interactions between natural environment and human activities. The soil is the essential component interfacing these relationships, and consequently has been deeply affected. The dry bulk density and percentage of clay-silt and clay fractions has increased, the percentage of total porosity and water field capacity has decreased with increasing of degree of soil erosion on the arable soil layer. Agro-phytocenoses with long-term use of perennial grasses and grass-grain crop rotations lead to improving of agro-physical features of eroded soils.

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