International Conference on Land and Water Degradation
Processes and Management
COST Action 869 Mitigation options for nutrient reduction in
surface water and groundwaters
7-10 September 2009, Magdeburg, Germany

Predicting soil erodibility for a research model

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Background

Lake Balaton is still eutrophic in spite of the measures that eliminated point sources of phosphorus load

Water quality must be improved as required by the Water Framework Directive and River Basin Management Plans need ”roadmap” at operative level to mitigate diffuse P load

Soil test P levels cannot be reduced further (fertilizer use must increase instead)

Improvement in water quality can be achieved by reducing soil erosion and particulate phosphorus loads

Erosion rates are the highest where micro-rills abund on the shoulder of slopes

Rills represent an accelerated form of erosion, they can be easily recognized thus, their absence could be one of the indicators for Good Agricultural Practice

Objectives

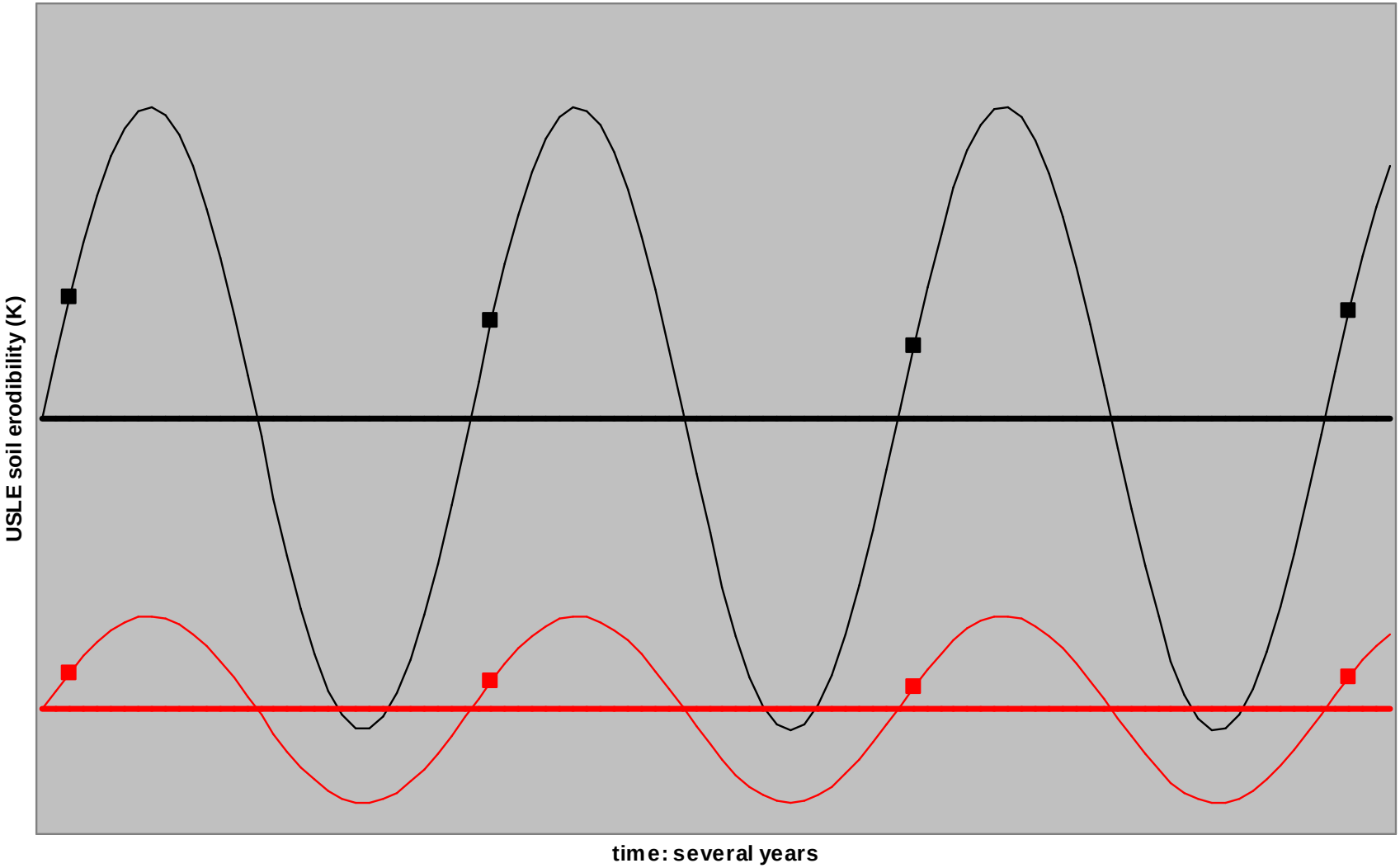
To predict soil properties that make rill formation probable in the watershed of Lake Balaton

To develop and test a physically based plot scale research model that represent random surface roughness in full detail thereby realistically describes rill initiation in a self-organizing way as Favis-Mortlock (1998) has used this term

A = R**K**LSCP

Hypothesis: yearly variation of USLE K value is due to the variability of infiltration, thus long term average of K should closely correlate with erodibility in a physically based model

Assumption: field experiments in a very well specified small time window give reliable comparisions between soils even if experiments are done in different years



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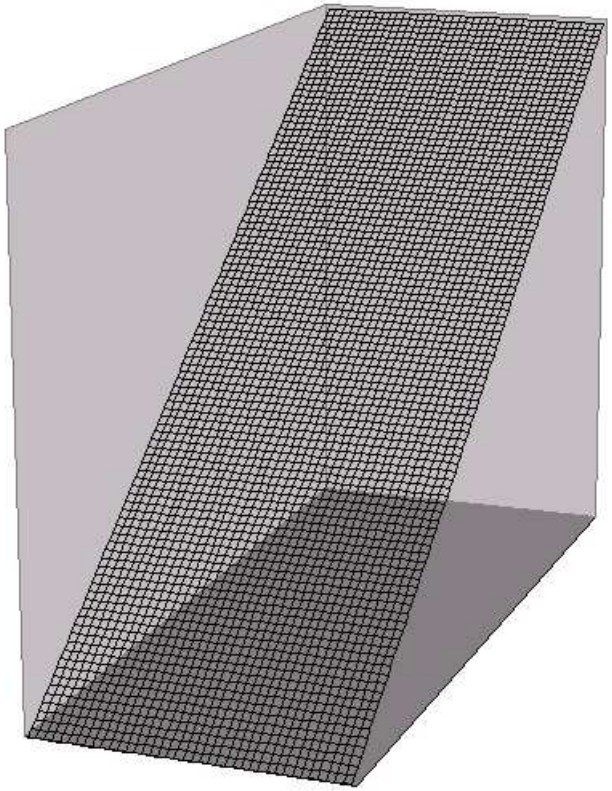
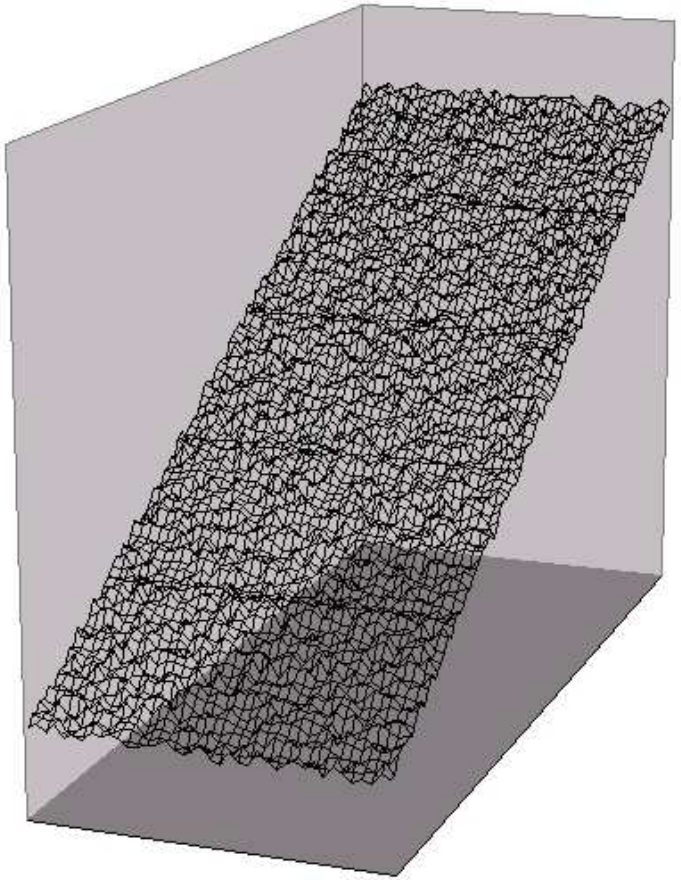
Plot size: 2 m x 5 m
Pixels size: 5 cm x 5 cm

Random suface roughness: *[-2e, +2e]*
e: absolute value of the average deviation





Velocity and direction of flow

Δx: pixel size cm
$h_{x,y}$: altitude of the pixel with coordinates *(x, y)*
S: hydraulic friction
$(a_x)_{x,y}$, $(a_y)_{x,y}$: acceleration of water in cell with coordinates *(x, y)* in direction of *x* and *y*,
$(v_x)_{x,y}$, $(v_y)_{x,y}$ az *(x, y):* velocity of water in cell with coordinates *(x, y)* in direction of *x* and *y*
m_1, m_2 : masses of water before unification
v_1, v_2 : velocities of water before unification
$V_{új}$: velocity of water after unification (impulse preservation rule)
g: gravitational force

$$(a_x)_{x,y} = g\,sin\left(arctg\frac{h_{x+1,y} - h_{x-1,y}}{2\Delta x}\right) - S \cdot (v_x)_{x,y}$$

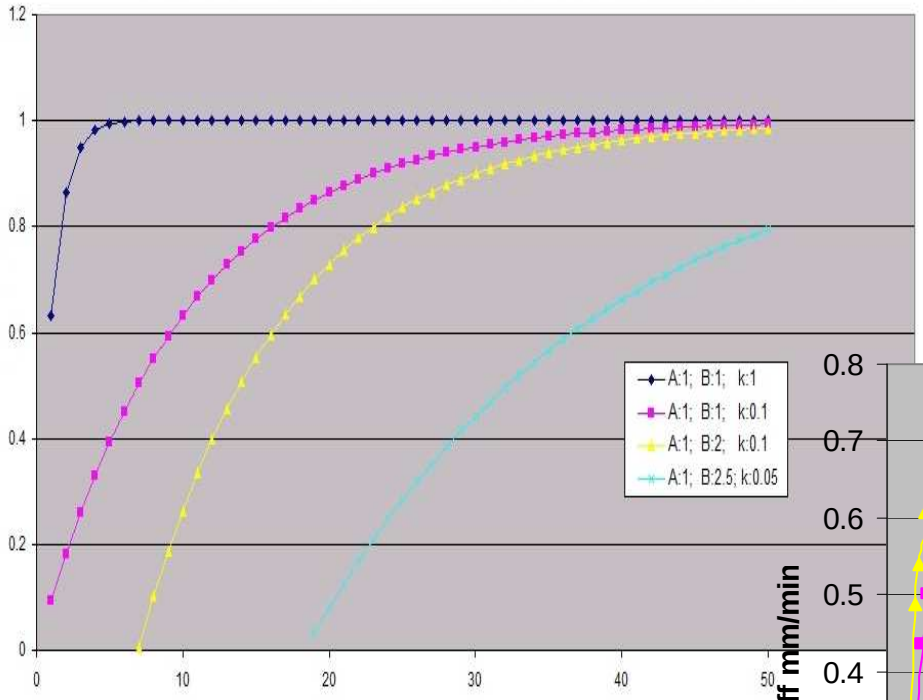
$$(a_y)_{x,y} = g\,sin\left(arctg\frac{h_{x,y+1} - h_{x,y-1}}{2\Delta x}\right) - S \cdot (v_y)_{x,y}$$

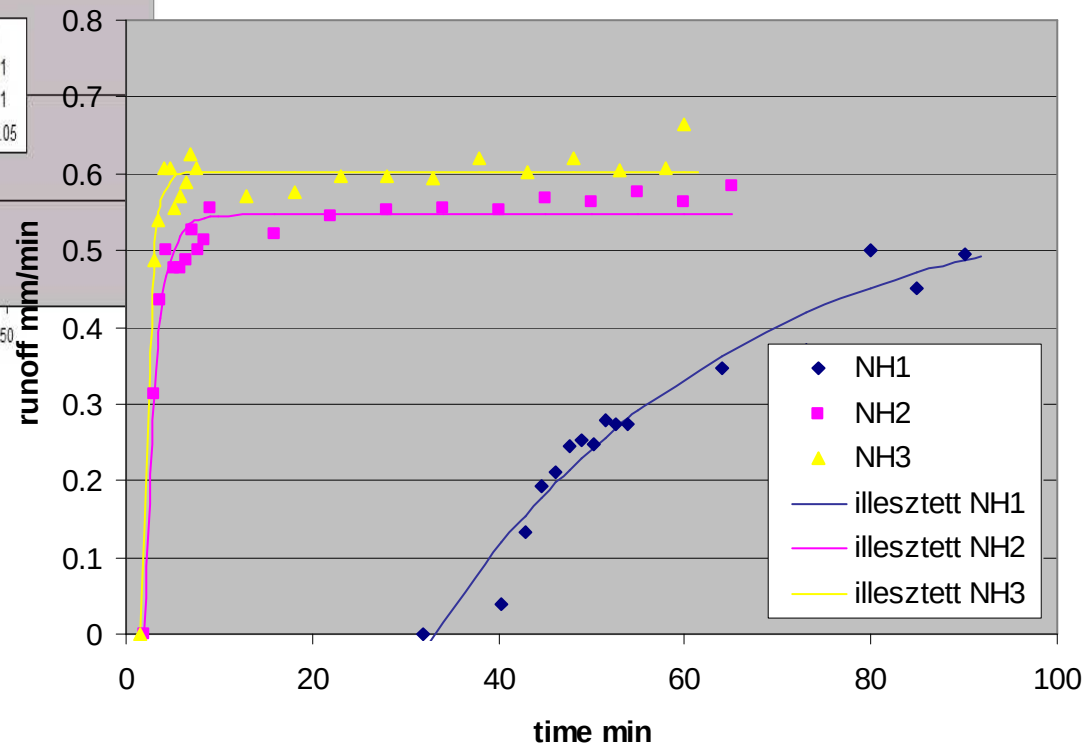
$$v_{új} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2},$$

Runoff: negative exponential equation

$$y = A - B*e^{-k*x}$$

A: maximal runoff rate
B and k: parameters of the equation





Infiltration equations

C : water storage capacity of the active layer (WEPP analogue)
K : initial infiltration rate
V : equilibrium infiltration rate
$\Delta h^{(n)}$: infiltration in the nth step
$e^{(n)}$: change of water amount in the active layer
$t^{(n)}$ time to the nth step
Δt : elapsed time in one step

$$\frac{dh}{dt} = -K\left(\frac{C - e(t)}{C}\right)$$

$$\frac{de}{dt} = K\left(\frac{C - e(t)}{C}\right) - \left(\frac{e(t)}{C}\right)^5 V$$

$$\Delta h^{(n+1)} = K\left(\frac{C - h^{(n)}}{C}\right)\Delta t$$

$$e^{(n+1)} = e^{n} + \Delta h^{(n+1)} - \left(\frac{e^{(n)}}{C}\right)^5 V\Delta t$$

$$t^{(n+1)} = t^{(n)} + \Delta t$$

Erosion and deposition

Kinetic energy

m_{er}: eroded soil mass
E: erosion coefficient
v: velocity of water
m_{water}: mass of water

$$m_{er} = E v^2 m_{water}$$

Stokes-equation

v: settling velocity of a particle
$\Delta\rho$: difference of the density of the particle and the water
g : gravitational force
r : mean diameter particle
η: viscosity

Maximal sediment concentration

$$v = \frac{\Delta\rho \cdot g r^2}{9\eta}$$

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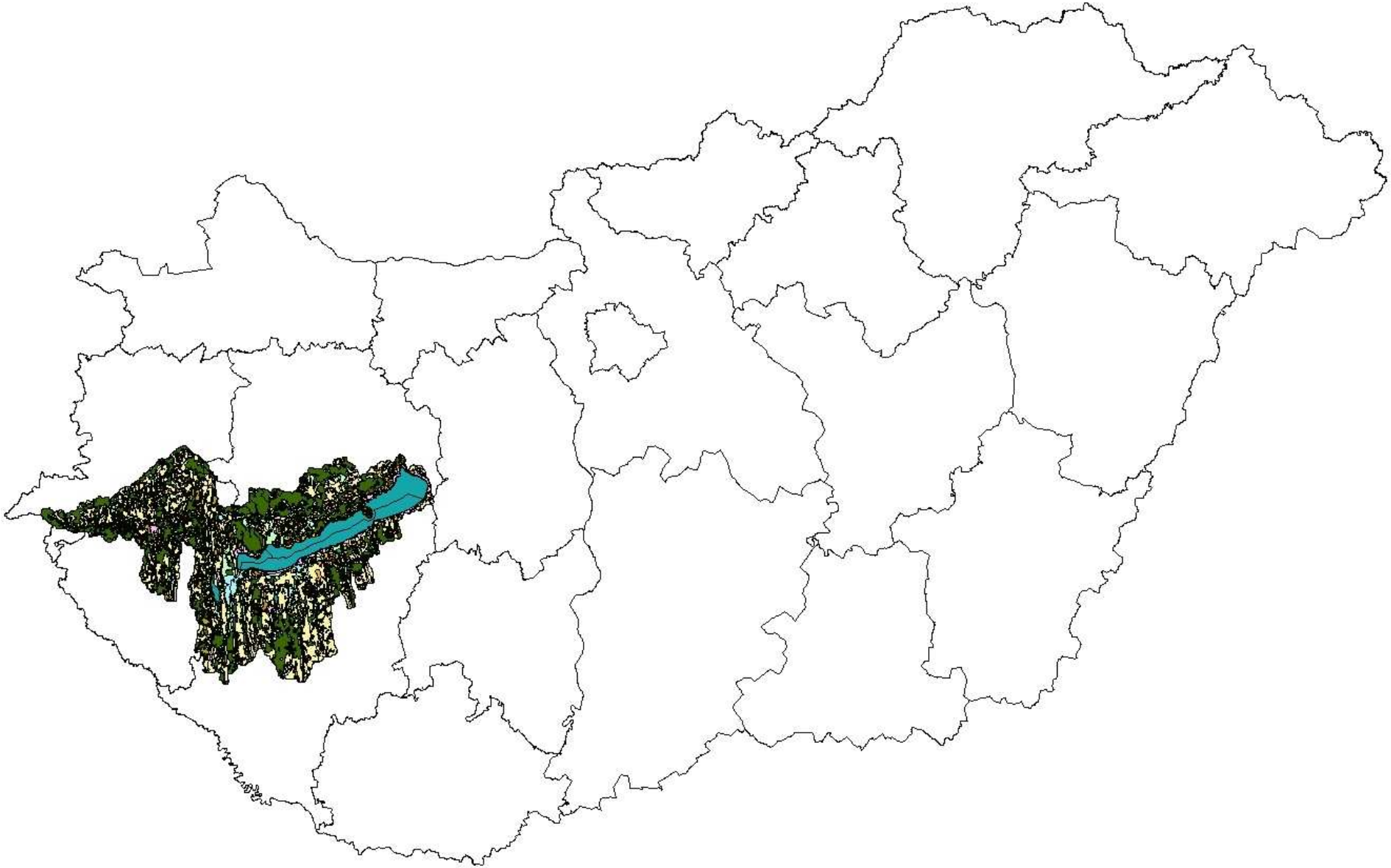
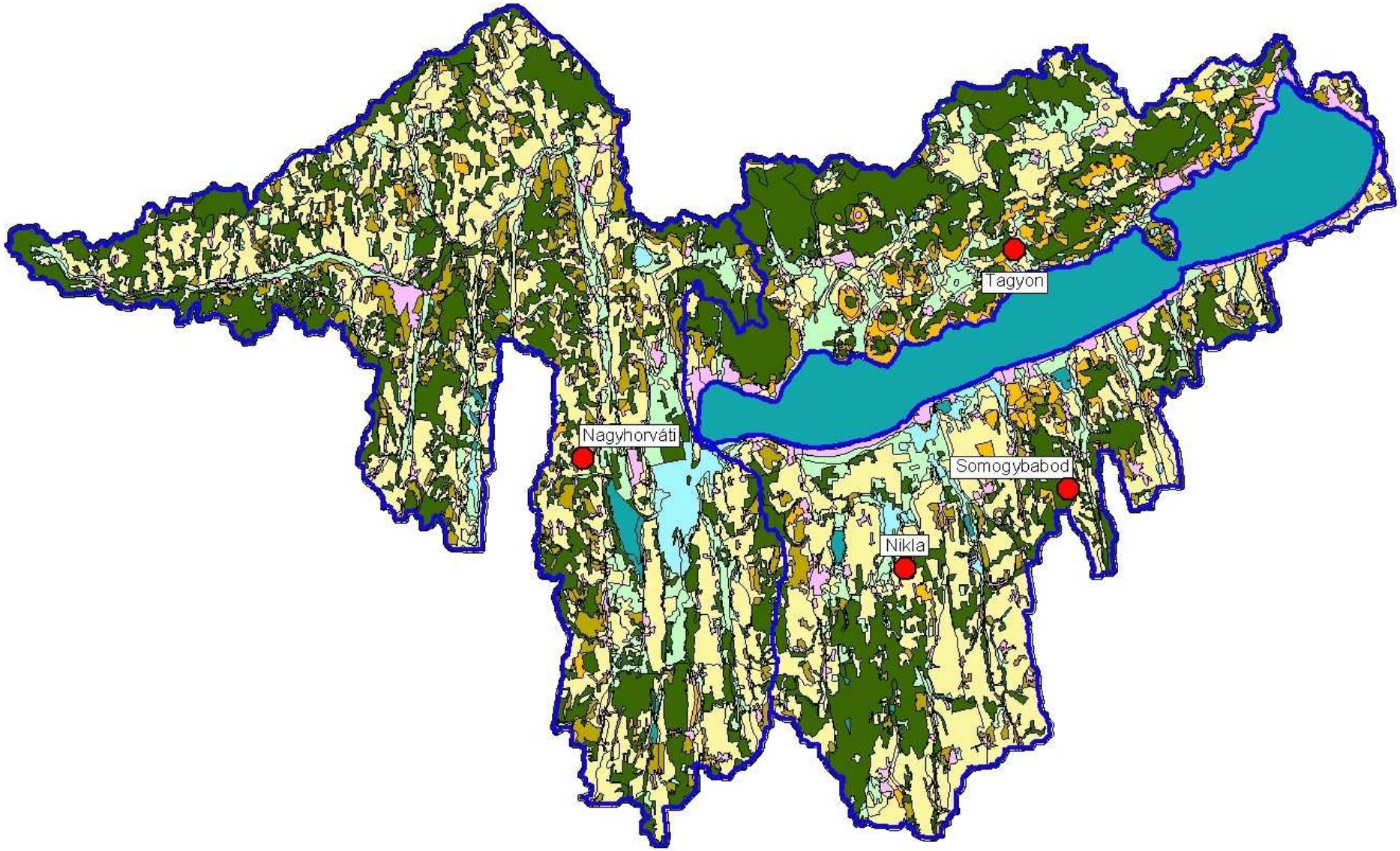
The watershed of Lake Balaton is the only one which is entirely within the borders



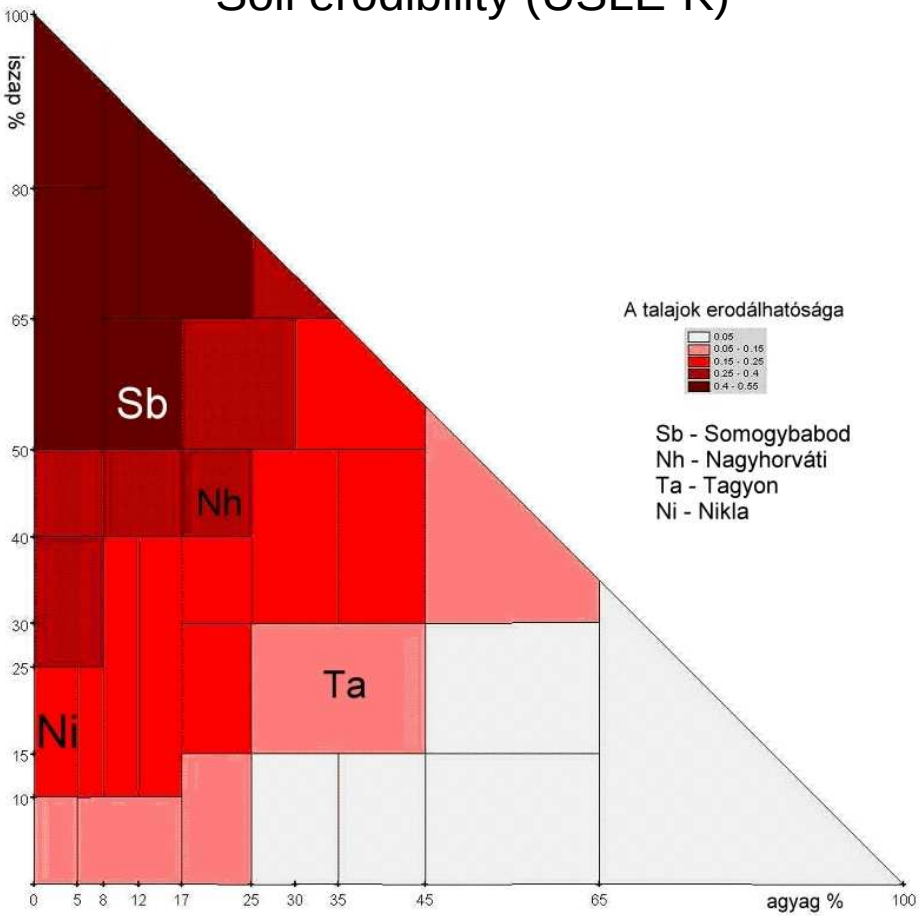
Four experimental sites (representative for the watershed)



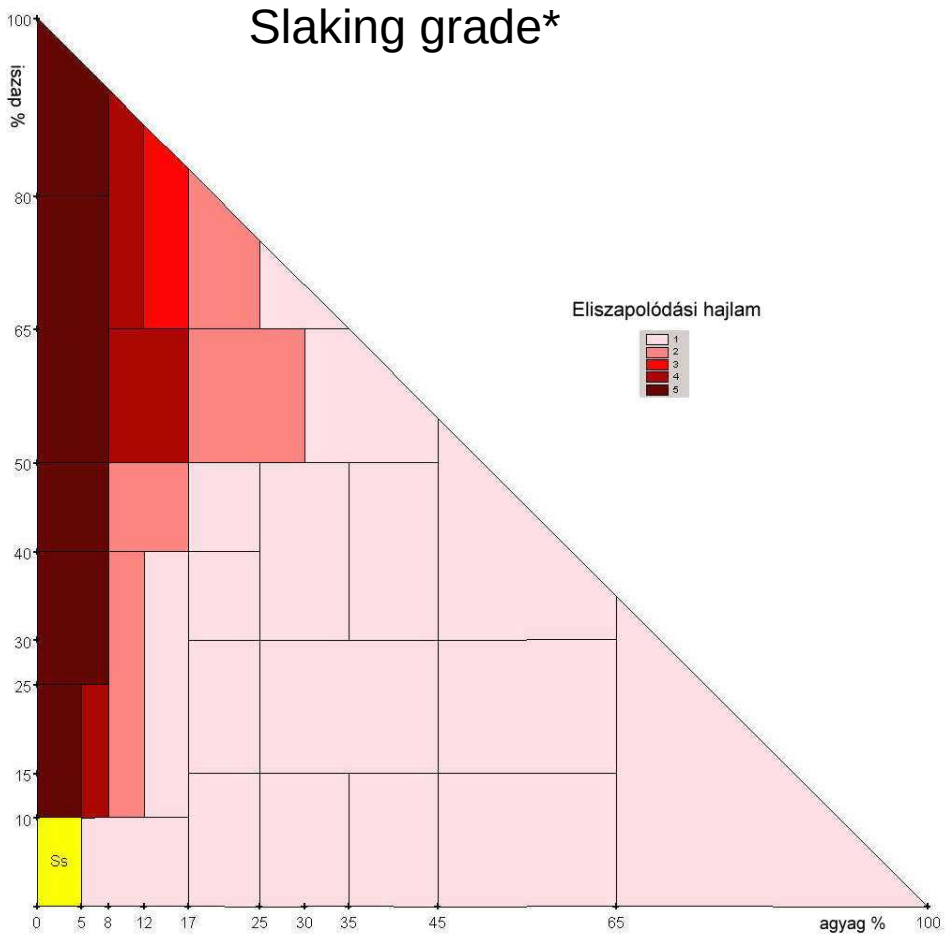
Sites	Soil texture classes	Designation in the German system*
Nikla (19 %)	slightly silty sand	Su2
Somogybabod (13 %)	sandy loamy silt	Uls
Nagyhorváti (7 %)	slightly sandy loam	Ls2
Tagyon (6 %)	sandy clay loam	Lts

*(Bodenkundliche Kartieranleitung)

Soil erodibility (USLE-K)*



Slaking grade*



Methodology developed in the DESPRAL project
2x5 m plot size, 3-4 replicates
Seedbed condition in July-August (2000-2005)
Gentle pre-wetting to field capacity
60 mm/h simulated rainfall until equilibrium runoff rate reached
3-4 consecutive simulations on the same plot with 2-3 day return time

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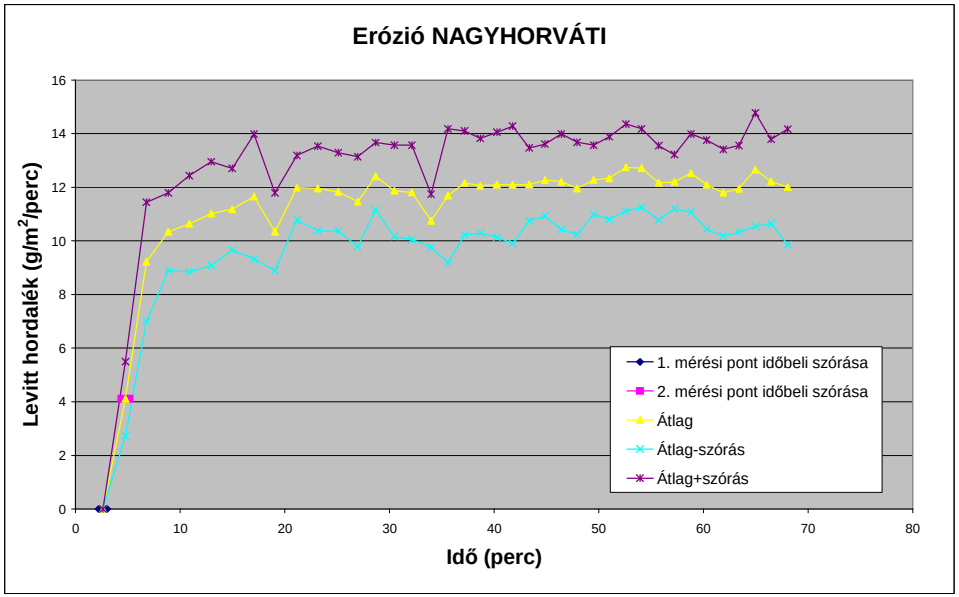
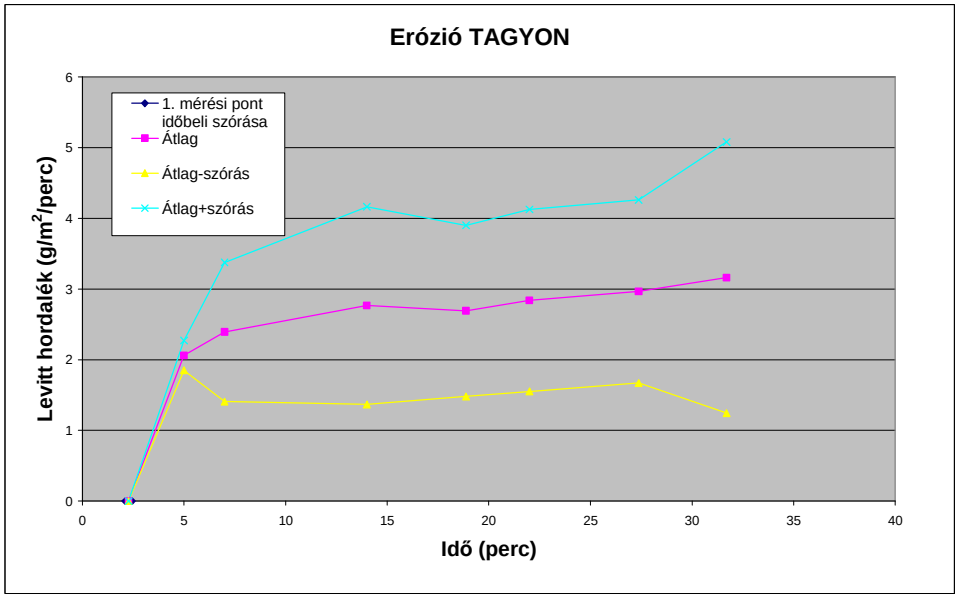
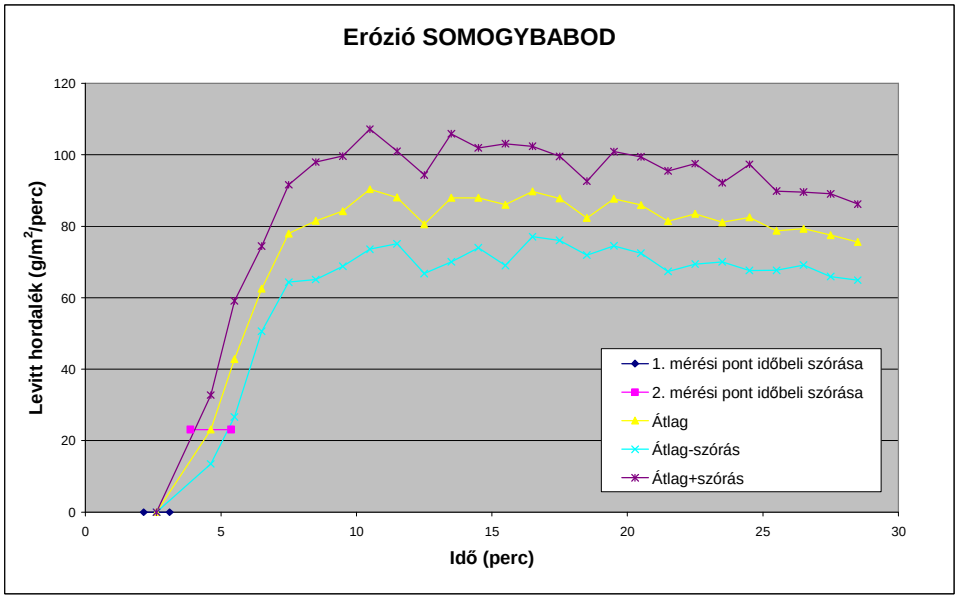
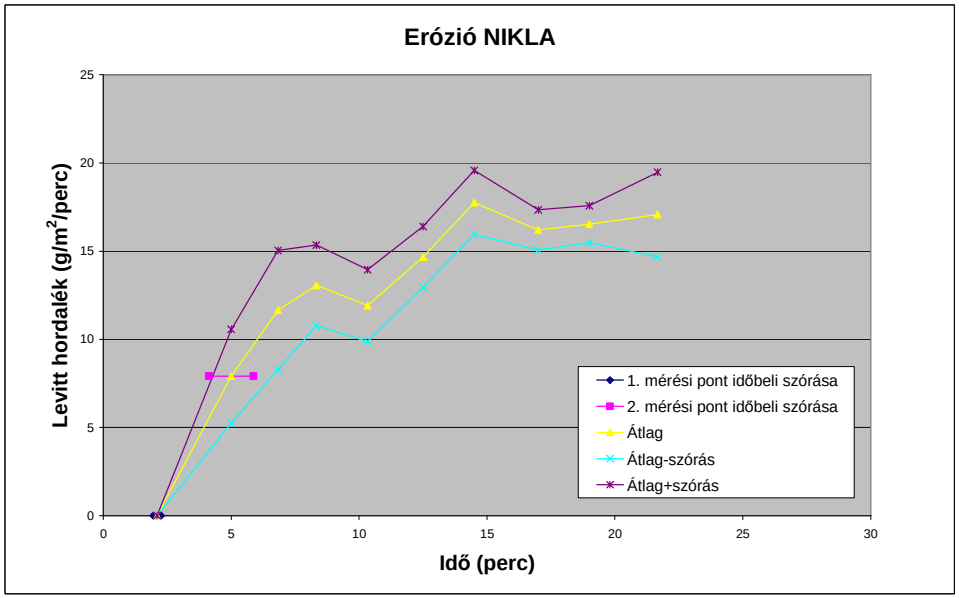
Erosion rates with the variability at the four sites interpolated to round minutes









Cumulative soil loss-time functions for 25 minutes were used for calibration

Site	Slope (%)	Total soil loss in 25 minutes from the whole plot kg
Nagyhorváti	7	2.10
Somogybabod	13	16.73
Tagyon	6	0.52
Nikla	19	3.06

Parameters which did not change during parameterization
precipitation
slope
size of the plot
pixel size

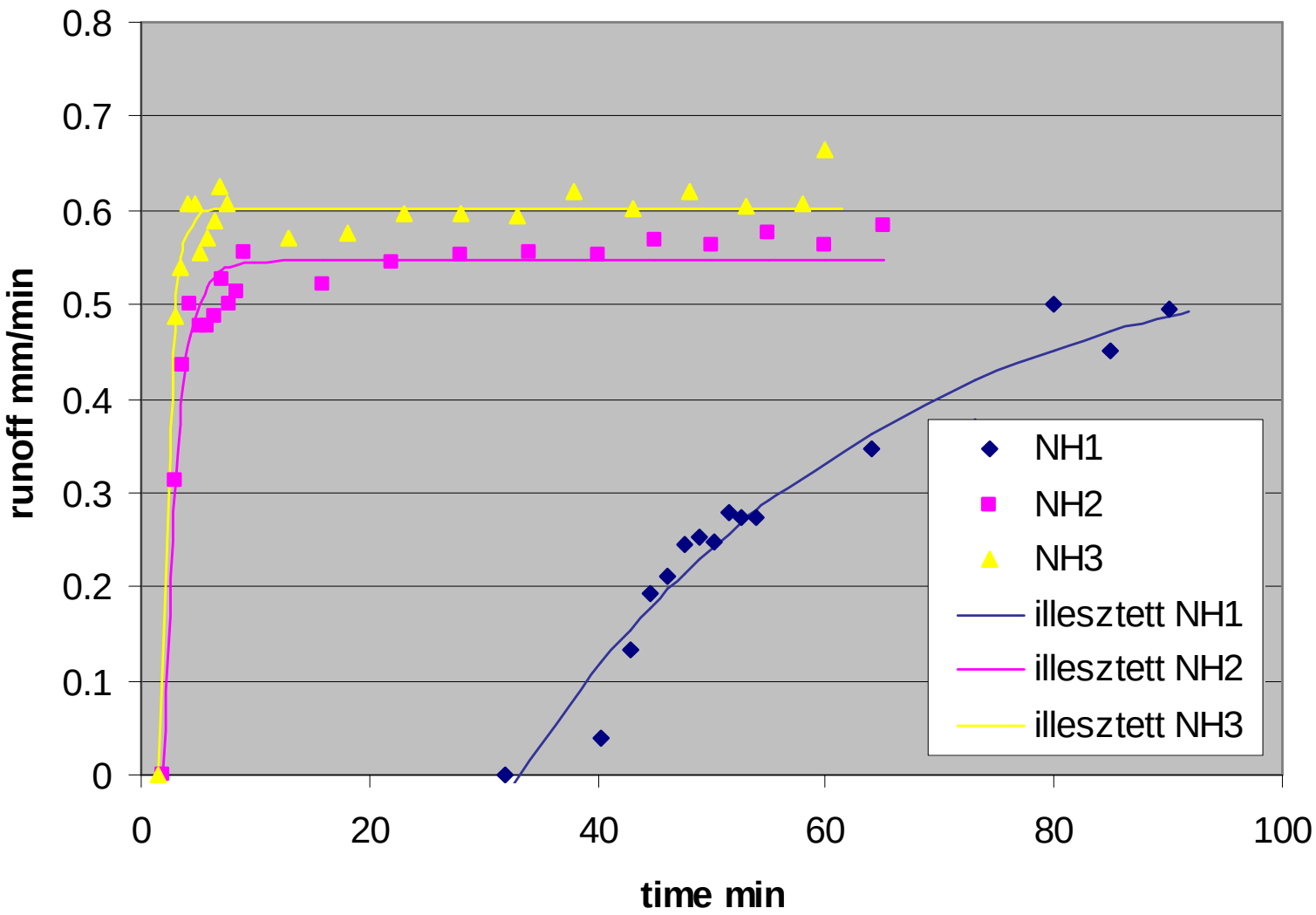
Parameters for which initial values were derived from the field experiment
water storage capacity of the active layer
initial infiltration rate
equilibrium infiltration rate

Parameters for which initial values were taken from literature
density and diameter of the settling particles

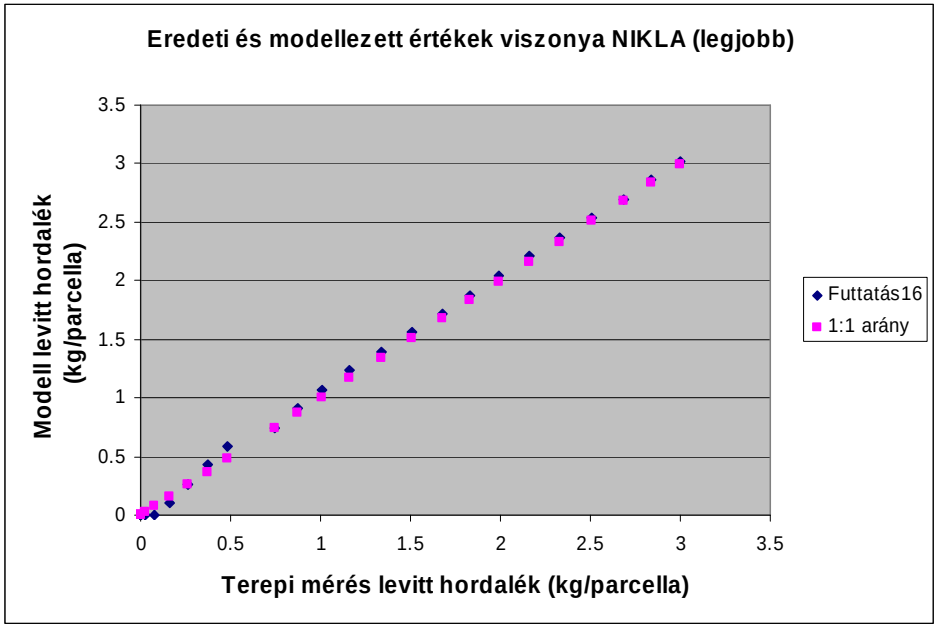
All other parameters were calibrated by several iterations (10 runs for each set of parameters) and mean, median, and variance were calculated

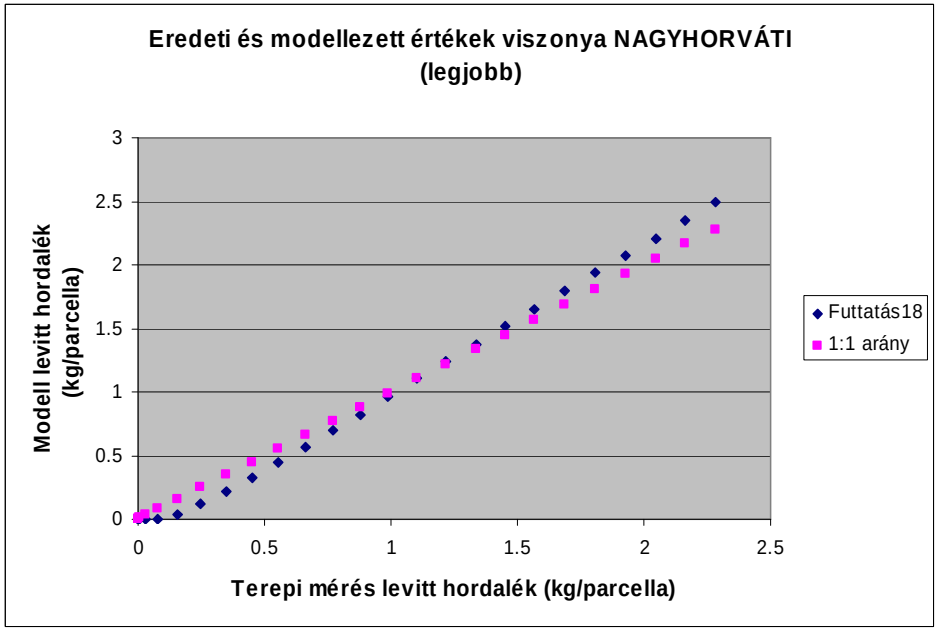
Runoff and infiltration

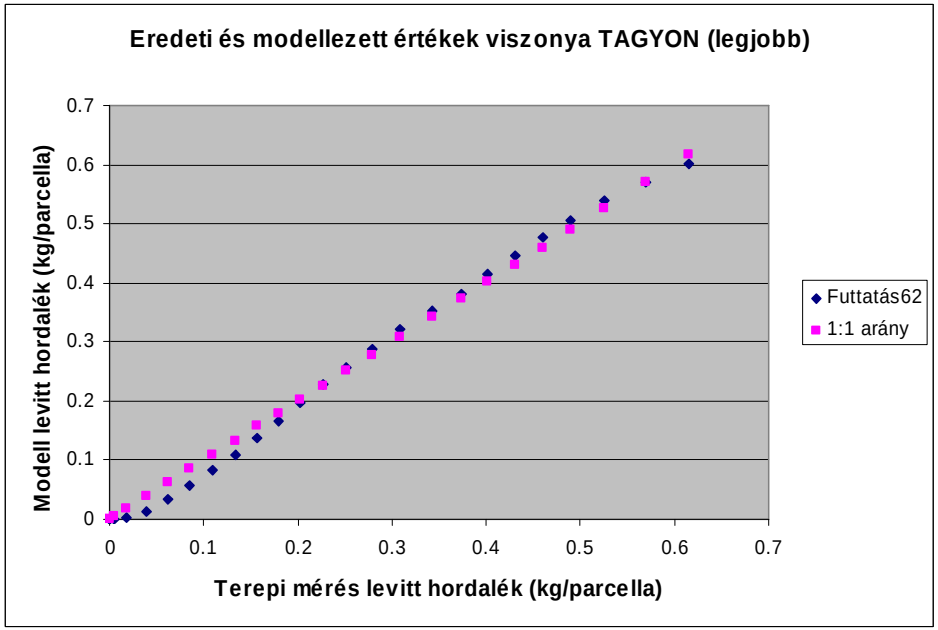
Significant differences has been tested with F-test (replicates, consecutive irrigations)
Results of the last simulation were used for parameterization

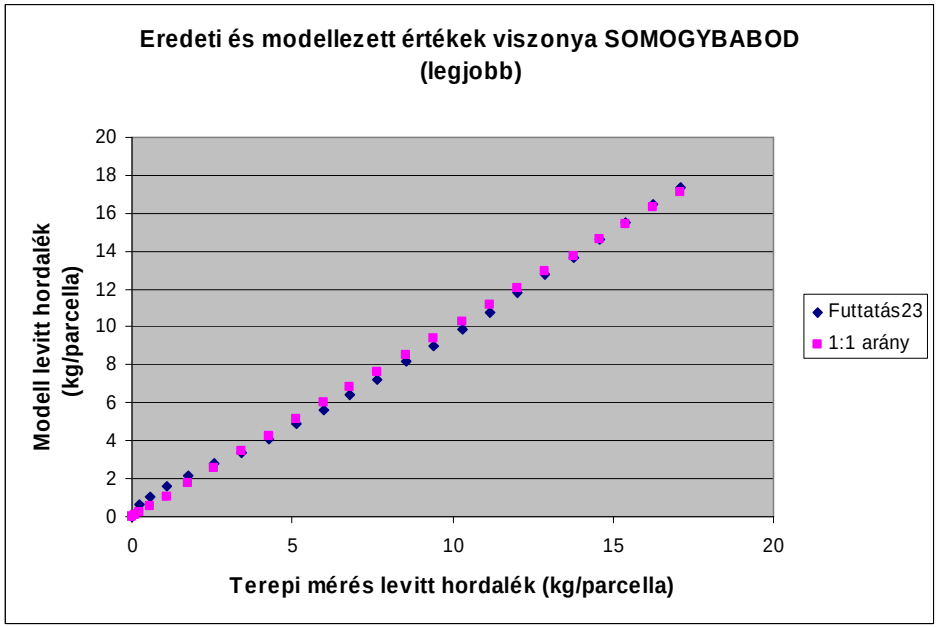


Calibrated cumulative soil losses (measured vs. modelled values) R^2=0.9807-0.9981



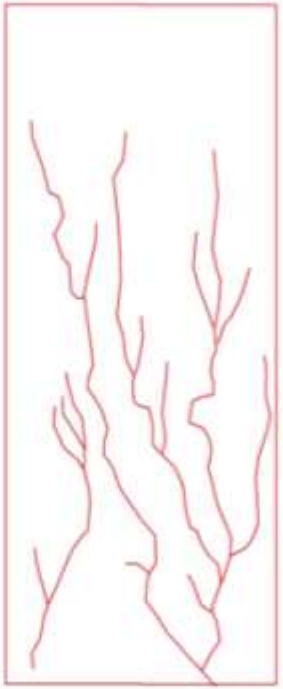


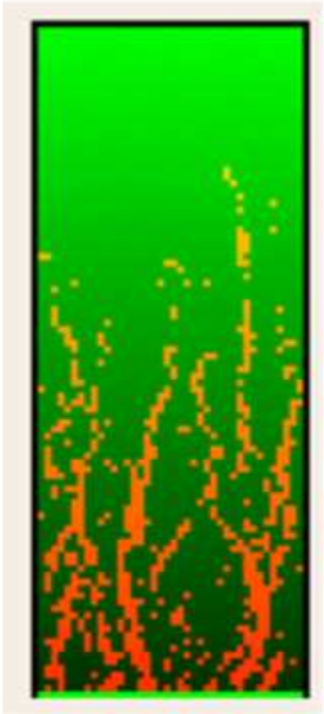




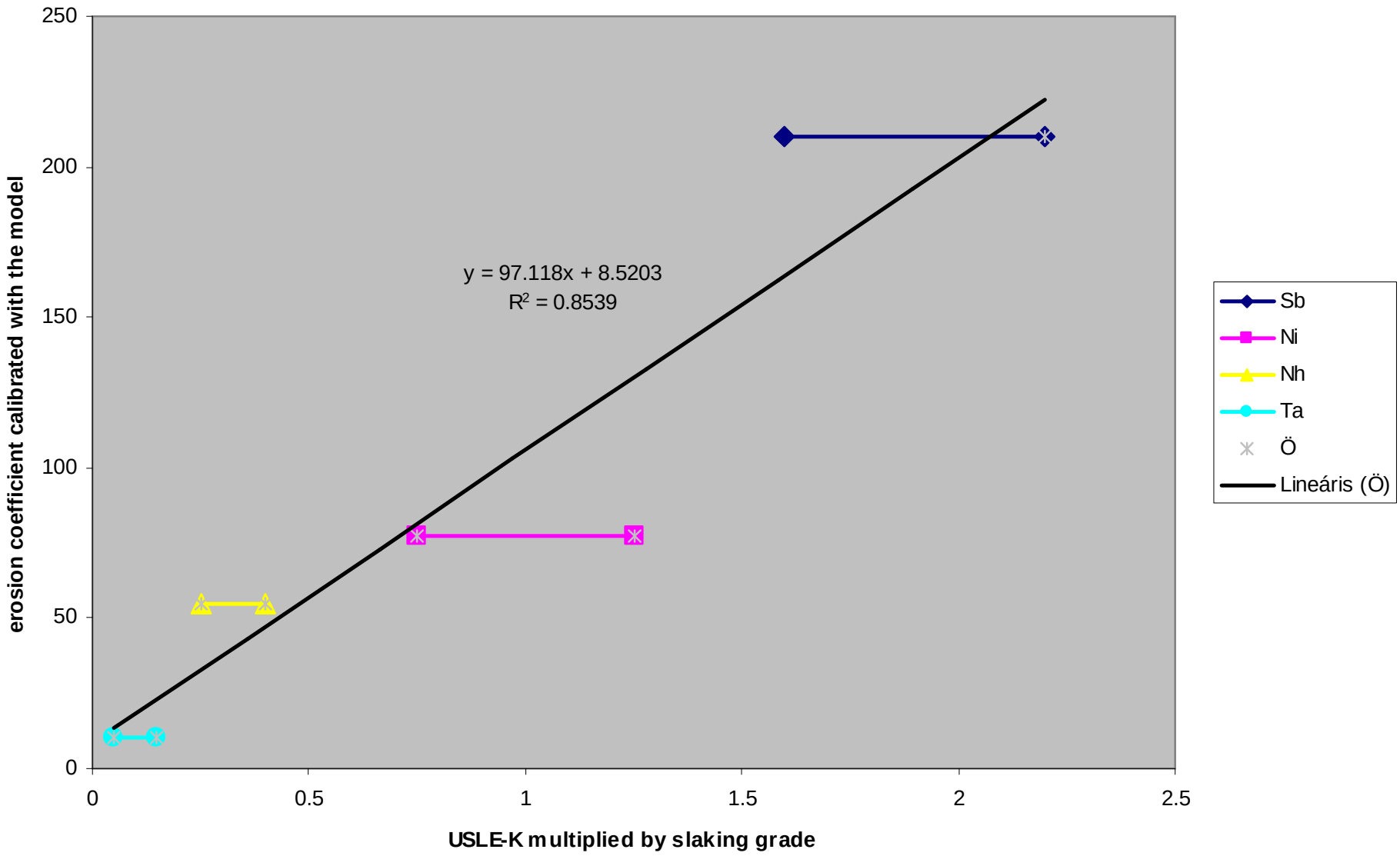
Parameter	Nikla	Tagyon	Nagyhorváti	Somogybabod
Initial infiltration rate (mm/h)	136	43	50	41
water storage capacity of the active layer (mm)	3	3.5	6	6
equilibrium infiltration rate (mm/h))	36	7	18	3
Erosion coefficient (s^2/m^2)	**77**	**10**	**55**	**210**
Maximal sediment concentration (g/l)	150	150	75	150
Hydraulic friction (1/s)	19	19	19	19
Particle size of detached soil (mm)	0.05	0.05	0.05	0.05
Density of detached particles (g/cm^3)	2.6	0.65	2.6	2.6
Absolute value of the average roughness (mm)	6	2	3	5.4


Nagyhorváti
Somogybabod
Tagyon





Relationship between a calculated value from German Soil Mapping Guide (Bodenkundliche Kartieranleitung) and the calibrated erosion coefficient



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Relative difference of the total soil loss in 25 minutes
due to the 20 % change of the parameters
(plus and minus 10 % compared to the calibrated value)
Somogybabod

Particle size	0.71%
Roughness	1.82%
Max.sediment conc.	2.73%
Init. infiltr. rate	4.09%
Slope	4.58%
Equil. infiltr. rate	5.29%
Particle density	5.54%
Wat. stor. cap. active layer	6.11%
Hydr. friction	16.15%
Pixel size	19.98%
Erosion coefficient	24.36%
Rainfall intensity	38.25%

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Conclusions

Further refinement of calibration is needed

Validation with another set of measured data is necessary

Soils of the watershed must be evaluated based on real conditions
(1:10,000 soil map and DEM)

Rill formation risk is successfully predicted

It seems to be possible to use USLE soil erodibility and slaking grade to predict erosion coefficient of physically based models

Thank you for your attention