Predicting soil erodibility for a research model

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Background and objectives
Model structure
Experimental
Parameterization
Sensitivity analysis
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**Background and objectives**
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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 abound 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 comparisons 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 surface roughness: [-2e, +2e]
e: absolute value of the average deviation
Velocity and direction of flow

$\Delta x$: 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 $y$,
$(v_x)_{x,y}, (v_y)_{x,y}$ at $(x, y)$: 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
$V_{uij}$: velocity of water after unification (impulse preservation rule)
$g$: gravitational force

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

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

\[
v_{uij} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2},
\]
Runoff: negative exponential equation

\[ y = A - B e^{-k \cdot x} \]

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

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

\[
\frac{dh}{dt} = -K \left( \frac{C - e(t)}{C} \right)
\]
\[
\frac{de}{dt} = K \left( \frac{C - e(t)}{C} \right) - \left( \frac{e(t)}{C} \right)^s V
\]

\[
\Delta h^{(n+1)} = K \left( \frac{C - h^{(n)}}{C} \right) \Delta t
\]
\[
e^{(n+1)} = e^n + \Delta h^{(n+1)} - \left( \frac{e^{(n)}}{C} \right)^s V \Delta t
\]
\[
t^{(n+1)} = t^{(n)} + \Delta t
\]
Erosion and deposition

Kinetic energy

\[ m_{er} = E v^2 m_{water} \]

Stokes-equation

\[ v = \frac{\Delta \rho \cdot gr^2}{g \eta} \]

- \( m_{er} \): eroded soil mass
- \( E \): erosion coefficient
- \( v \): velocity of water
- \( m_{water} \): mass of water
- \( \Delta \rho \): difference of the density of the particle and the water
- \( g \): gravitational force
- \( r \): mean diameter particle
- \( \eta \): viscosity

Maximal sediment concentration
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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)
<table>
<thead>
<tr>
<th>Sites</th>
<th>Soil texture classes</th>
<th>Designation in the German system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikla (19 %)</td>
<td>slightly silty sand</td>
<td>Su2</td>
</tr>
<tr>
<td>Somogybabod (13 %)</td>
<td>sandy loamy silt</td>
<td>Uls</td>
</tr>
<tr>
<td>Nagyhórváti (7 %)</td>
<td>slightly sandy loam</td>
<td>Ls2</td>
</tr>
<tr>
<td>Tagyon (6 %)</td>
<td>sandy clay loam</td>
<td>Lts</td>
</tr>
</tbody>
</table>

*(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

<table>
<thead>
<tr>
<th>Site</th>
<th>Slope (%)</th>
<th>Total soil loss in 25 minutes from the whole plot kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nagyhorváti</td>
<td>7</td>
<td>2.10</td>
</tr>
<tr>
<td>Somogybabod</td>
<td>13</td>
<td>16.73</td>
</tr>
<tr>
<td>Tagyon</td>
<td>6</td>
<td>0.52</td>
</tr>
<tr>
<td>Nikla</td>
<td>19</td>
<td>3.06</td>
</tr>
</tbody>
</table>
Parameters which did not change during parameterization
precipitation
slope
class 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) $R^2=0.9807-0.9981$
<table>
<thead>
<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>Initial infiltration rate (mm/h)</td>
<td>136</td>
<td>43</td>
<td>50</td>
<td>41</td>
</tr>
<tr>
<td>Water storage capacity of the active layer (mm)</td>
<td>3</td>
<td>3.5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Equilibrium infiltration rate (mm/h)</td>
<td>36</td>
<td>7</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Erosion coefficient (s²/m²)</td>
<td>77</td>
<td>10</td>
<td>55</td>
<td>210</td>
</tr>
<tr>
<td>Maximal sediment concentration (g/l)</td>
<td>150</td>
<td>150</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Hydraulic friction (1/s)</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Particle size of detached soil (mm)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Density of detached particles (g/cm³)</td>
<td>2.6</td>
<td>0.65</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Absolute value of the average roughness (mm)</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>5.4</td>
</tr>
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</table>
Relationship between a calculated value from German Soil Mapping Guide (Bodenkundliche Kartieranleitung) and the calibrated erosion coefficient

\[ y = 97.118x + 8.5203 \]

\[ R^2 = 0.8539 \]
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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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td>0.71%</td>
</tr>
<tr>
<td>Roughness</td>
<td>1.82%</td>
</tr>
<tr>
<td>Max. sediment conc.</td>
<td>2.73%</td>
</tr>
<tr>
<td>Init. infiltr. rate</td>
<td>4.09%</td>
</tr>
<tr>
<td>Slope</td>
<td>4.58%</td>
</tr>
<tr>
<td>Equil. infiltr. rate</td>
<td>5.29%</td>
</tr>
<tr>
<td>Particle density</td>
<td>5.54%</td>
</tr>
<tr>
<td>Wat. stor. cap. active layer</td>
<td>6.11%</td>
</tr>
<tr>
<td>Hydr. friction</td>
<td>16.15%</td>
</tr>
<tr>
<td>Pixel size</td>
<td>19.98%</td>
</tr>
<tr>
<td>Erosion coefficient</td>
<td>24.36%</td>
</tr>
<tr>
<td>Rainfall intensity</td>
<td>38.25%</td>
</tr>
</tbody>
</table>

Somogybabod
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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