Which soil erosion processes should we model at continental scale in Europe?

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Erosion modelling workshop
JRC, Ispra, 20-22 March 2017
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Erosion modelling workshop
JRC, Ispra, 20-22 March 2017
• **Background** - problem statement

• **Objective**: to provide a perspective on continental-scale soil erosion modelling

• Which **soil erosion processes** do we need to scale up in Europe?

• **Scaling up** impacts of **SWC techniques** on soil loss rates

• **Conclusions**
Soil erosion

a geomorphic process that detaches and removes soil material from its primary location by

1) natural erosive agents: water (ice), wind, and gravity;

2) biological activities: tree fall, animal trampling, soil burrowing animals, …

3) human activities: soil tillage, land leveling, crop harvesting, road and building construction, quarrying,…
Soil erosion

a major soil degradation process worldwide having

on site effects: i.e. loss of ecosystem services of soils threatening long-term sustainability of agricultural production, environmental degradation, increasing poverty, …;

off site, sediment-related effects: muddy floods, surface water pollution, reservoir siltation, …
Given the importance of soil erosion, various maps have been produced over the last decades to better understand the **spatial patterns and intensity** of particular soil erosion processes in Europe.

Which erosion processes?
Water erosion

Interrill and rill erosion in almond groves inducing soil losses of ca. 50 – 100 ton/ha/year (Sierra de las Torrecillas, Almeria, Spain, JP).
Water erosion

De Ploey et al. (1989)
SEM (Cerdan et al. 2010)  

PESEERA (Kirkby et al. 2003)
Water erosion: soil loss by sheet and rill erosion

Panagos et al. 2015
Tillage erosion

Huldenberg, Belgium, JP
Tillage erosion

Van Oost et al. 2009
Wind erosion
(NE Germany)
Wind erosion

De Ploey (1989)
Figure 1. Index of Land Susceptibility to Wind Erosion (ILSWE) predicted for the agricultural land of 36 European countries.
Erosion by landslides

Tuscany (Borselli et al. 2006)
Landslide susceptibility

Van Den Eeckhaut et al. 2012
Sediment Yield (SY) at catchment scale

Walling & Webb, 1983
Sediment Yield (SY)

Vanmaercke et al. 2011

SY (t/km²/y)
- > 200 (n = 596)
- 40 - 200 (n = 591)
- < 40 (n = 607)

- Gauging Station (n = 1287)
- Reservoir (n = 507)
Conclusion:

The main focus of soil erosion prediction at European scale has been on the following processes:

- Sheet and rill erosion
- Tillage erosion
- Wind erosion
- Landsliding
- Sediment Yield
There are in Europe still other soil erosion processes that cause significant soil losses and that have received limited attention,

particularly when it comes to scaling up their occurrences and rates at (sub)continental scale

Which other erosion processes?
Which other soil erosion processes?

• Water erosion: **gully erosion** and **subsurface erosion by piping and tunneling erosion**

• **Erosion during crop harvesting**  
  (SLCH: Soil Loss by Crop Harvesting)

• **Land levelling**
Fig. 1 Sketch illustrating various gully types on agricultural lands (partly after Farres et al., 1993). 1 = pipe inlet; 2 = bank gully; 3 = ephemeral gully in valley-bottom; 4 = ephemeral gully in valley-side; 5 = ephemeral gully in linear landscape element; a = tillage direction; b = limit of headland; c = headland; d = bank (lynchet).
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Ephemeral gully (Cassel, France, June 5th, 2016, JP)
Falciu Hills, Moldavian Plateau, East Romania (May 2013, JP)
TABLE 2.5.1  Soil loss rates due to gully erosion (SLgully) and contribution of (ephemeral) gully erosion to overall soil loss rates and to sediment production rates by water erosion: SLgully (%) = 100 × (ratio between SLgully and total SL rates due to interrill, rill and gully erosion)

<table>
<thead>
<tr>
<th>Location</th>
<th>SLgully (t ha(^{-1}) yr(^{-1}))</th>
<th>SLgully (%)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium, central</td>
<td>22.3</td>
<td>10</td>
<td>Govers and Poesen (1988)</td>
</tr>
<tr>
<td>Belgium</td>
<td>1.1–5.9</td>
<td>n.a.(^a)</td>
<td>Nachtergaele and Poesen (1999)</td>
</tr>
<tr>
<td>France, north</td>
<td>n.a.</td>
<td>10–45</td>
<td>Ludwig et al. (1992)</td>
</tr>
<tr>
<td>Germany, south</td>
<td>n.a.</td>
<td>12–29</td>
<td>Auerswald (1998)</td>
</tr>
<tr>
<td>France, Normandy</td>
<td>n.a.</td>
<td>21–56</td>
<td>Cerdan et al. (2002)</td>
</tr>
<tr>
<td>France, south-east</td>
<td>190</td>
<td>n.a.</td>
<td>Bufalo and Nahon (1992)</td>
</tr>
<tr>
<td>Spain, north-west</td>
<td>1.5</td>
<td>26</td>
<td>Valcarcel et al. (2003)</td>
</tr>
<tr>
<td>Germany, south-west</td>
<td>n.a.</td>
<td>36</td>
<td>Baade (1994)</td>
</tr>
<tr>
<td>Romania</td>
<td>n.a.</td>
<td>37</td>
<td>Nedelev (1999)</td>
</tr>
<tr>
<td>Belgium, central</td>
<td>3.6</td>
<td>44</td>
<td>Poesen et al. (1996)</td>
</tr>
<tr>
<td>France, north</td>
<td>n.a.</td>
<td>46–55</td>
<td>Auzet et al. (1995)</td>
</tr>
<tr>
<td>Italy, Sicily</td>
<td>5.0</td>
<td>n.a.</td>
<td>Capra and Scicolone (2002)</td>
</tr>
<tr>
<td>Portugal, Bragança</td>
<td>16.1</td>
<td>47</td>
<td>Vandekerckhove et al. (1998)</td>
</tr>
<tr>
<td>Spain, Guadalentin</td>
<td>37.6</td>
<td>51</td>
<td>Poesen et al. (2002)</td>
</tr>
<tr>
<td>Norway, Leira basin</td>
<td>12.7</td>
<td>55</td>
<td>Bogen et al. (1994)</td>
</tr>
<tr>
<td>Spain, Catalunia</td>
<td>n.a.</td>
<td>58</td>
<td>Martínez-Casasnovas et al. (2002)</td>
</tr>
<tr>
<td>Spain, Catalunia</td>
<td>123</td>
<td>n.a.</td>
<td>Martínez-Casasnovas et al. (2003)</td>
</tr>
<tr>
<td>Spain, south-east</td>
<td>1.2</td>
<td>59</td>
<td>Oostwoud Wijdenes et al. (2000)</td>
</tr>
<tr>
<td>Belgium, central</td>
<td>n.a.</td>
<td>60</td>
<td>Quine et al. (1994)</td>
</tr>
<tr>
<td>Spain, north</td>
<td>64.9</td>
<td>74</td>
<td>Casali et al. (2000)</td>
</tr>
<tr>
<td>Portugal, Alentejo</td>
<td>3.2</td>
<td>80</td>
<td>Poesen et al. (1996)</td>
</tr>
<tr>
<td>Spain, Almeria</td>
<td>9.7</td>
<td>83</td>
<td>Poesen et al. (1996)</td>
</tr>
</tbody>
</table>

\(^a\)Data not available.
Gully erosion contribution to sediment yield

SY for cropland in the loess belt of Belgium, Poesen et al. 2006
Conceptual model of sediment yield (SSY) at various scales (A) and contributing sediment sources and sinks for Mediterranean environments without badlands (de Vente et al. 2005)
Conceptual model of sediment yield (SSY) at various scales (A) for Mediterranean environments with and without badlands (Nadal-Romero et al. 2014)
Subsurface erosion

Piping and tunneling erosion are widespread in Europe and cause significant soil losses!

Flemish Ardennes, Belgium (JP) Cieza, Spain (JP)
Faulkner (2006): ca. 260 000 km² is affected by soil piping in West Europe!
Soil loss rates (ton/ha/yr) due to piping in Europe (case-studies)

<table>
<thead>
<tr>
<th>Location</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium (Bertem)</td>
<td>1.5 – 3.0</td>
</tr>
<tr>
<td>Belgium (Flemish Ardennes)</td>
<td>2.3 – 4.6</td>
</tr>
<tr>
<td>Germany (Bonn area)</td>
<td>15.0</td>
</tr>
<tr>
<td>Hungary (Tokai)</td>
<td>14.3</td>
</tr>
<tr>
<td>Poland (Lublin upland)</td>
<td>0.96</td>
</tr>
<tr>
<td>Poland (East Carpathians)</td>
<td>1.3 – 13.1</td>
</tr>
<tr>
<td>Spain</td>
<td>287</td>
</tr>
</tbody>
</table>

Source: Verachtert et al 2011; Bernatek et al. 2017
Soil loss rates due to piping in Europe (case-studies; ton/ha/yr)

<table>
<thead>
<tr>
<th>Country</th>
<th>Rate</th>
<th>Land Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium (Bertem)</td>
<td>1.5 – 3.0</td>
<td></td>
</tr>
<tr>
<td>Belgium (Flemish Ardennes)</td>
<td>2.3 – 4.6</td>
<td>grassland</td>
</tr>
<tr>
<td>Germany (Bonn area)</td>
<td>15.0</td>
<td>grassland</td>
</tr>
<tr>
<td>Hungary (Tokai)</td>
<td>14.3</td>
<td></td>
</tr>
<tr>
<td>Poland (Lublin upland)</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>Poland (East Carpathians)</td>
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<td>grassland</td>
</tr>
<tr>
<td>Spain</td>
<td>287</td>
<td></td>
</tr>
</tbody>
</table>

Source: Verachtert et al 2011; Bernatek et al. 2017
Impact of land use on median annual runoff coefficients (RC) and median soil loss rates by sheet and rill erosion (SL) in Europe based on 1056 plots (PL) representing 7024 plot-years (PY) (Maetens et al. 2012)
Anthropogenic soil erosion processes

Soil Loss due to Crop Harvesting (SLCH; photos JP)
Root and tuber vegetables  (Knack 2 Jan 2012)
Figure 5  Relationship between gravimetric moisture content (GMC) of the top soil and soil loss per hectare of harvested sugar beet (SLCHcrop) in France. SLCHcrop was calculated using net soil tare data published by Duval (1988) and assuming a mean net sugar beet yield of 55 Mg ha$^{-1}$.

Source: Based on Poesen et al. (1999).
Figure 2.10.4  Time series of soil losses due to the harvest of sugar beet (SLCHcrop) for different European countries. Data are derived from soil tare measurements at beet-processing factories and from beet yield statistics and corrected for an assumed soil moisture content of 15%. (After Ruysschaert et al., 2005, with permission from Elsevier)
Soil loss rates due to Crop Harvest LCH in Europe (ton/ha/harvest)

• Potato: 2 – 3 (up to 45!)
• Sugar beet: 9 (up to 100!)
• Chicory root (inuline): 8
• Chicory root (witloof): 12 (up to 71);
• Carrot: 16 (up to 66!);
• Black salsify: 7 – 11 (up to 28!)

Ruysschaert et al. (2006)
**Need for integrated assessments of soil erosion rates!**

Central Belgium (Poesen et al. 2001)

<table>
<thead>
<tr>
<th>Process</th>
<th>Soil losses (ton ha(^{-1}) year(^{-1}))</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water erosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interrill and rill erosion</td>
<td>6.9 (26.5%)</td>
<td>Poesen et al. (1996b)</td>
</tr>
<tr>
<td>Ephemeral gully erosion</td>
<td>5.4 (20.8%)</td>
<td></td>
</tr>
<tr>
<td>Tillage erosion</td>
<td>8.7 (33.5%)</td>
<td>Van Oost et al. (2000)</td>
</tr>
<tr>
<td>SLRH</td>
<td>5.0 (19.2%)</td>
<td>This study</td>
</tr>
<tr>
<td>Total</td>
<td>26.0 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

The production of 1 kg of wheat causes 2.6 kg of soil loss!
Anthropogenic soil erosion processes

Soil erosion due to land levelling

Central Spain April 2012 (JP)
Soil erosion due to land levelling

Antas, Spain, 2010 (JP)
Soil loss rates by land levelling ranks among the most intense erosion processes. 1 m of soil surface lowering represents 15 000 ton/ha in < 1 year! SE Spain (JP)
Land levelling, South Norway (JP)
Major research gaps for scaling up soil erosion rates to the continental scale!

1. Need for better understanding of particular soil erosion processes, their factors and their interactions

2. Scaling up soil erosion rates in space and time: need for improved models.
Fig. 5. Comparison of semi-quantitative models with other model types with respect to scale, input requirements and kind of output.
De Vente et al. 2014

Changing process domination and process complexity occurring with **increasing spatial unit** is not represented in most erosion and SY models which are typically formulated on empirical observations made on smaller spatial units, despite the recognition of the role of scale in controlling dominant erosion processes, de Vente et al. 2013.
Conceptual model of sediment yield (SSY) at various scales (A) and contributing sediment sources and sinks for Mediterranean environments without badlands. de Vente et al. 2005.
Need for improved models and data mining

Need to further integrate

1) field observations on various erosion processes and their interactions at different spatial and temporal scales and

2) different model concepts to predict sediment sources, sinks, connectivity and yield,

so as to better predict current and future soil loss and sediment yield under scenarios of environmental change.
Scaling up impacts of SWC techniques on soil loss rates

Need to better understand process interactions when upscaling!
How effective are soil conservation techniques in reducing plot runoff and soil loss in Europe and the Mediterranean?

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ABSTRACT

The effects of soil and water conservation techniques (SWCTs) on annual runoff (Rao), runoff coefficients (RCao) and annual soil loss (SLao) at the plot scale have been extensively tested on field runoff plots in Europe and the Mediterranean. Nevertheless, a comprehensive overview of these effects and the factors controlling the effectiveness of SWCTs is lacking. Especially the effectiveness of SWCT in reducing Rao is poorly understood. Therefore, an extensive literature review is presented that compiles the results of 101 earlier studies. In each of these studies, Rao and SLao was measured on field runoff plots where various SWCTs were tested. In total, 353 runoff plots (corresponding to 2093 plot-years of data) for 103 plot-measuring stations throughout Europe and the Mediterranean were considered. SWCTs include (1) crop and vegetation management (i.e. cover crops, mulching, grass buffer strips, strip cropping and exclusion), (2) soil management (i.e. no-tillage, reduced tillage, contour tillage, deep tillage, drainage and soil amendment) and (3) mechanical methods (i.e. terraces, contour bunds and geotextiles). Comparison of the frequency distributions of SLao rates on cropland without and with the application of SWCTs shows that the exceedance probability of tolerable SLao rates is ca. 20% lower when SWCT are applied. However, no notable effect of SWCTs on the frequency distribution of RCao is observed. For 224 runoff plots (corresponding to 1567 plot-year data), SWCT effectiveness in reducing Rao and/or SLao could be directly calculated by comparing measured Rao and/or SLao with values measured on a reference plot with conventional management. Crop and vegetation management techniques (i.e. buffer strips, mulching and cover crops) and mechanical techniques (i.e. geotextiles, contour bunds and terraces) are generally more effective than soil management techniques (i.e. no-tillage, reduced tillage and contour tillage). Despite being generally less effective, no-tillage, reduced tillage and contour tillage have received substantially more attention in the literature than the other SWCTs. Soil and water conservation techniques are generally less effective in reducing Rao than in reducing SLao, which is an important consideration in areas where water is a key resource and in regions susceptible to flooding. Furthermore, all SWCTs show a more consistent and effective reduction of both Rao and SLao with increasing Rao and SLao magnitude, which is attributed to the reduced influence of measurement uncertainties. Although some significantly negative correlations between SWCT effectiveness and plot slope length, slope gradient or annual precipitation were found, the importance of these factors in explaining the observed variability in effectiveness seems limited. Time-series analyses of Rao during multiple years of SWCT application strongly indicate that no-tillage and conservation tillage become less effective in reducing Rao over time. Such an effect is not observed for SLao.
Soil and Water Conservation Techniques (SWCT) for cropland
plot measuring stations
- SWCT, individual plots (n=22)
- SWCT, pairwise plots (n=81)

study areas
- non-Mediterranean
- Mediterranean

Fig. 1. Geographical distribution of runoff and soil loss plot measuring stations included in the individual and paired plot SWCT databases for Europe and the Mediterranean. Black circles represent stations included in the paired plot database, while open circles represent stations which are only included in the individual plot database. The division between Mediterranean and Non-Mediterranean was derived from the LANMAP2 database (Mücher et al., 2010; Metzger et al., 2005). n = number of plot measuring stations.
How effective are SWC techniques in reducing plot runoff and soil loss in Europe and the Mediterranean?

RR = runoff ratio
SLR = soil loss ratio
n = 224 paired plots; 1567 plot-year data, Maetens et al. 2012
Frequency distribution of the number of plots (PL) in the plot database for Europe and the Mediterranean as a function of plot length, Maetens et al. 2012.
Impact of plot length on the effectiveness of different soil-surface covers in reducing runoff and soil loss by water

T. Smets, J. Poesen and E. Bochet
Impact of soil surface cover on runoff (RR) and soil loss (SLR)

Runoff ratio ($RR$)

Soil loss ratio ($SLR$)

$$RR = 1 - a.C$$

$$SLR = e^{-b.C}$$

“$a$” and “$b$” reflect the effectiveness of a cover (mulch or vegetation) in reducing RR and SLR respectively.
Figure 2  Calculated $a$-values in the equation $RR = 1 - a \cdot C$ (with $RR =$ runoff ratio and $C =$ cover (%)) as a function of plot length ($L$, m) for studies investigating the effects of rock fragments, organic mulch and vegetation on runoff rate (for studies, see Tables 2, 3 and 4)
Figure 4  Calculated $b$-value in the equation $SLR = e^{-b \cdot C}$ (with $SLR =$ soil loss ratio and $C =$ cover (%)) as a function of plot length ($L$, m) for studies investigating the effects of rock fragments, organic mulch and vegetation on soil loss by water erosion (for studies, see Tables 6, 7 and 8)
Figure 5  Expected runoff ratio ($RR$) as a function of cover ($C$, %) for different plot lengths ($L$, m), based on equation 5
Figure 6  Expected soil loss ratio (SLR) as a function of cover (C, %) for different plot lengths (L, m), based on equation 6.
Conclusion 1

The main focus of soil erosion prediction at the European scale has been on:

- Sheet and rill erosion
- Tillage erosion
- Wind erosion
- Landsliding
- Sediment Yield
Conclusion 2

Given their importance at European scale, there is an urgent need to also consider other soil erosion processes: i.e.

• Water erosion: gully erosion and subsurface erosion by piping and tunnelling erosion

• Erosion during crop harvesting
  (SLCH: Soil Loss by Crop Harvesting)

• Erosion by land levelling
Conclusion 3

Assessments of the effectiveness of SWC measures in reducing rates of soil erosion by water based on runoff plot studies are most likely underestimating their true effectiveness at landscape scale!

This needs to be taken into account when scaling up the effects of SWC measures on soil erosion rates at European scale!
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