Crop residue management to save organic carbon in European agricultural soils

Juraj Balkovič & Marijn van der Velde

Ecosystems Services and Management Program (ESM), International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

E-mail: balkovic@iiasa.ac.at, velde@iiasa.ac.at

Introduction

Agricultural land has a high potential for carbon sequestration and quantification of emissions versus burial of C is a high priority (Lal, 2004). Shifting from conventional to carbon-friendly land cultivation preferring reduced or minimum tillage systems was suggested as a measure to decrease GHG emissions and promote SOC sequestration. Large-scale implementations of biophysical models are increasingly used to quantify impacts of crop management strategies in agricultural sector (e.g., van der Velde et al. 2009).

In this study we use an European implementation of the **Environmental Policy Integrated Climate model** (EPIC, Williams 1995) with the use of coarse resolution data that are available at European scale to evaluate impacts of reduced opposed to conventional tillage on the SOC stocks under a winter wheat production system. The two tillage systems imply different crop residue management (CRM) as they differ in their effectiveness in mixing crop residues into soil. We focus on changes in topsoil SOC stocks and soil erosion.

European EPIC implementation

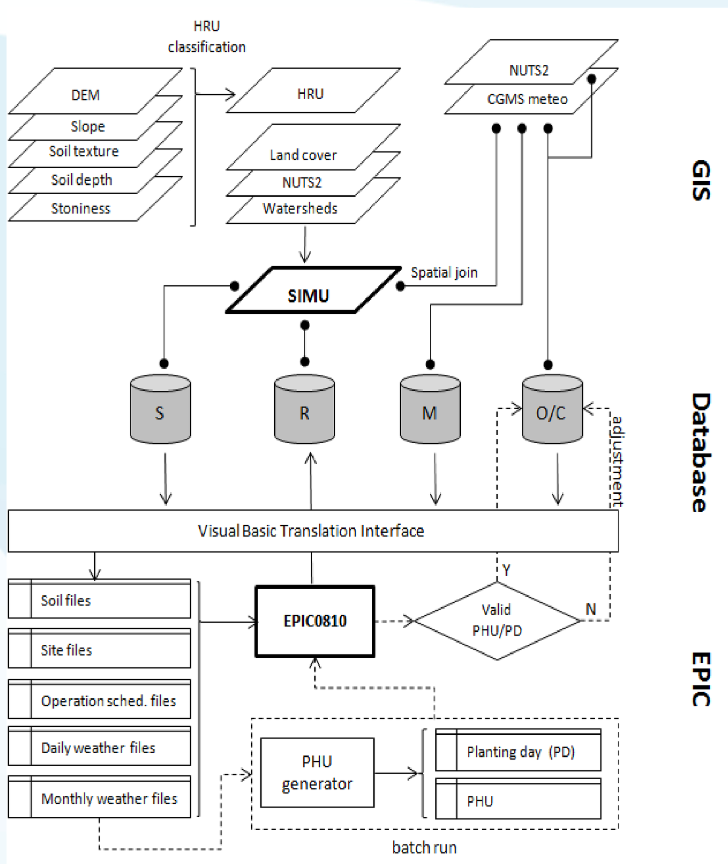

Fig. 1. Schematic diagram of the European EPIC implementation. S – soil and topographical database, M – meteorological database, O/C – field operation schedule and EPIC control database, R – results database

Data sources:
- JRC's MARS meteorological data 1995-2007
- CORINE 2000 and PELCOM
- SRTM and GTOPO
- European Soil Bureau Database, v.2
- Geographic Information System of the EC
- European River Catchment Database, v. 2
- Statistical Office of the European Communities

Integration with GIS and Up-Scaling:
- Loose coupling of EPIC v. 0810 with ArcGIS
- Constructed over the INSPIRE-compliant 1km grid
- 1st-level integration through Homogeneous Response Units (HRU): a unique combination of elevation, slope, soil texture, soil depth and stoniness classes
- 2nd-level Integration through Simulation Units (SimU): a unique combination of HRU, NUTS2, land cover, and watershed; 38 738 SimUs for arable land

Winter wheat production system setup comprises spatially explicit a) ***sowing densities***, b) ***Potential Heat Units*** (PHU), c) ***sowing and harvesting dates***, and d) ***maximum annual application of N,P,K fertilizers***. Wheat was simulated in 1-year mono-crop rotation on all cropland.

Conventional versus reduced tillage

We evaluate a shifting from **conventional** to **reduced tillage** systems. The two tillage systems differ in their effectiveness in mixing crop residues into soil. The other crop management options (e.g. fertilization) remained constant.

Conventional tillage
- Mouldboard plough
- Tillage depth: 150mm
- Mixing efficiency: 99%
- Crop residue left on soil: 1%

Reduced tillage
- Disk and chisel plough
- Tillage depth: 150mm
- Mixing efficiency: 85%
- Crop residue left on soil: 15%

Validation against EUROSTAT yields

Since crop growth determines the accumulation of biomass, it represents a precondition for SOC sequestration. The EPIC model was therefore validated for the simulated yields to match the observed yields reported by EUROSTAT. A comparison between simulated and observed annual yields aggregated at NUTS2 level is presented in Fig. 2a. EPIC slightly under-predicted yields in highly productive regions of Western Europe. The systematic error in the EPIC simulations is presented through relative errors in Fig. 2c.

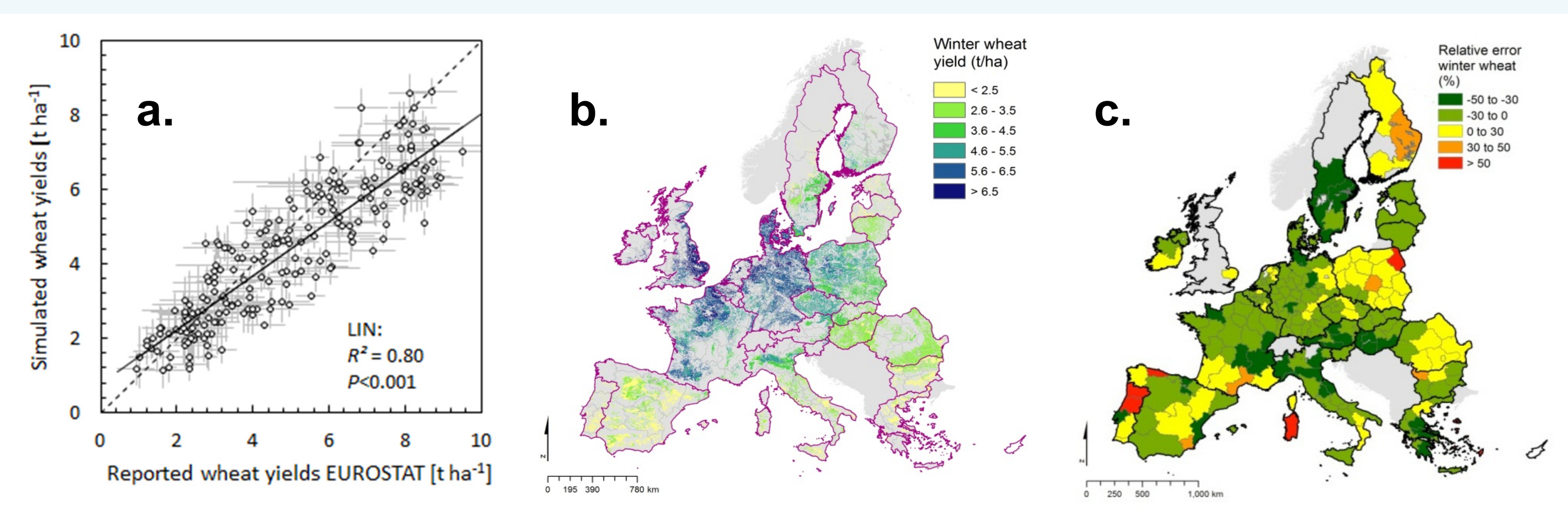

Fig. 2. (a) scatter plot with means and +/- SD of simulated versus observed regional yields (average of 1997-2007), (b) simulated WWHT yields in t ha^{-1}, (c) relative estimation error in %

SOC changes

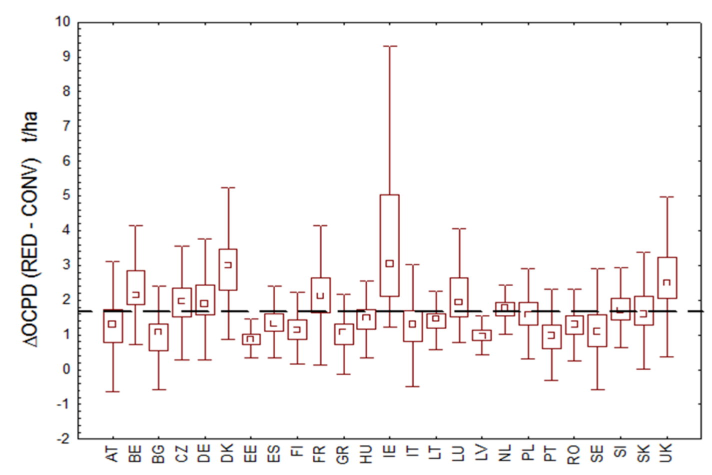

Fig. 3. Average annual change in the total topsoil SOC (OCPD) when converting from conventional to reduced tillage (dashed line denotes the EU average).

The reduced tillage management increased the topsoil SOC stock (OCPD) by about 4% (+1.7 t/ha) on average for whole of Europe (the *P* value for the paired *t*-test < 0.001) compared to the conventional tillage. The average annual increase was about 1% (328 kg/ha), 0.5% (86 kg/ha), 22.6% (340 kg/ha) and 24.7% (930 kg/ha) for SOC in passive humus, slow humus, metabolic litter and structural litter, respectively. The labile SOC pools were affected more than the slow and passive SOC. However, the simulated SOC changes vary by regions (Fig. 3) depending on different climatic, site and nutrient-input conditions.

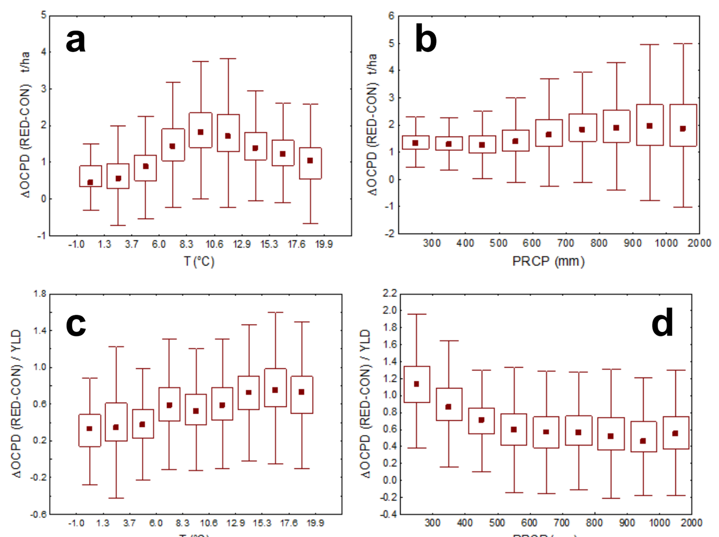

Fig. 4. Impact of mean annual temperature and precipitation on (a, b) OCPD change and (c, d) the OCPD change relative to 1 t/ha yield when converted from conventional to reduced tillage

Temperature (T) and precipitation (PREC) are major climatic drivers affecting the SOC dynamics. Higher PREC together with moderate T promote SOC accumulation in conservation CRM (Fig. 4 a-b). It is because these conditions increase the accumulation of wheat biomass and thus crop residue inputs. Since OCPD, and especially its structural litter component, are intensively transformed into CO_2 or more resistant SOC under these conditions, EPIC expects a decrease in ΔOCPD with increasing PREC when evaluated relative to a unit wheat yield (Fig. 4c), indicating that the net increase in ΔOCPD relative to PREC in Fig 4b. is caused by an increase in crop biomass.

Soil erosion

Soil erosion causes a substantial loss of soil material on European cropland as indicated by the MUSLE method in EPIC. The distribution of annual soil erosion under conventional winter wheat production system is presented in Fig. 5. In addition, the EPIC simulations enable identifying hot-spots with a high probability of extreme erosion events (Fig. 6). Reduced tillage can significantly decrease the SOC losses with soil sediments (YOC) compared to conventional tillage (Fig. 7).

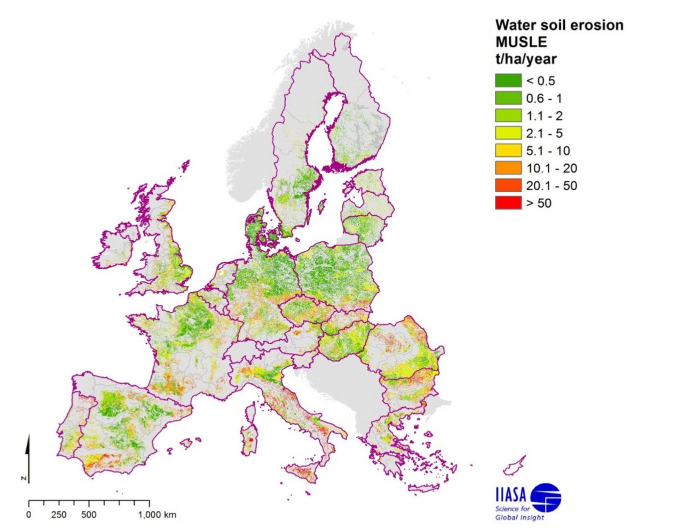

Fig. 5. Average annual soil loss by water erosion under a wheat production system (MUSLE, conventional tillage)

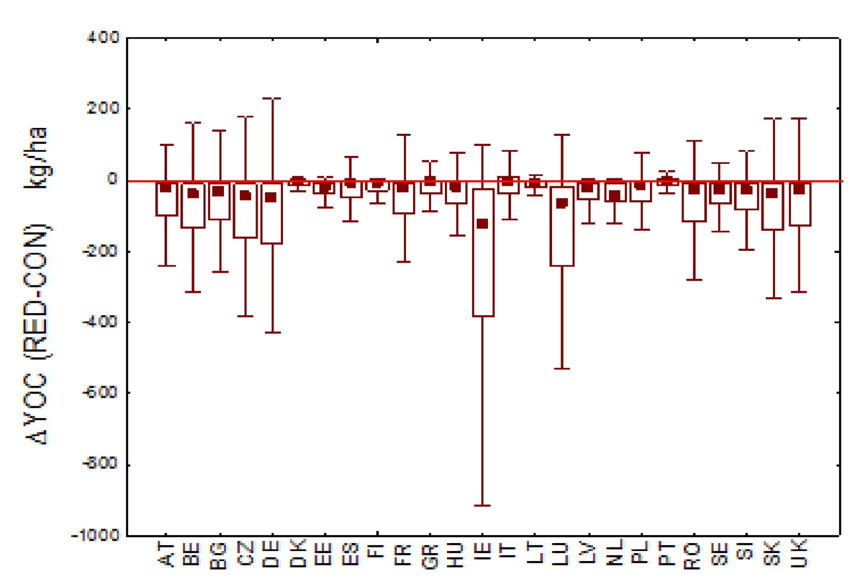

Fig. 7. Average annual change in the annual SOC loss with sediments when converting from conventional to reduced tillage

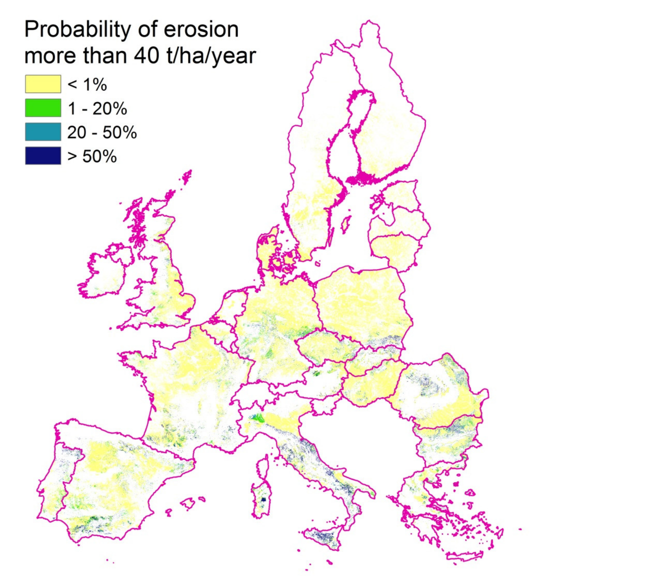

Fig. 6. Probability of an extreme erosion event (MUSLE, conventional tillage)

Conclusions

Conservation tillage practices may enhance SOC sequestration and help to control SOC losses with sediments. Fig. 8 demonstrates the SOC stock gained from the reduced tillage relative to the conventional tillage for the winter wheat production system. Reduced tillage was identified as an effective measure to control both erosion and SOC stocks in agricultural soils.

The European EPIC implementation is a useful tool to asses environmental impacts of alternative crop management strategies in the agricultural sector.

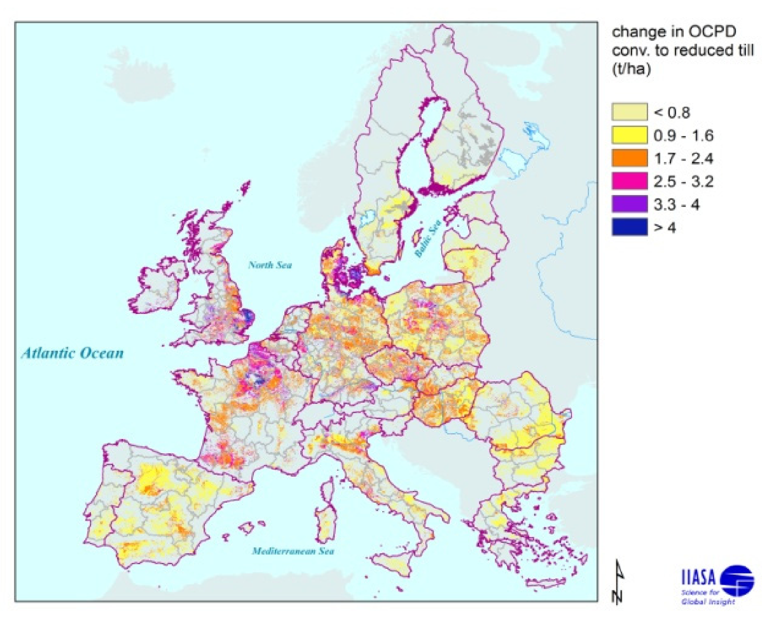

Fig. 8. Average annual change in OCPD in agricultural soils under winter wheat production system when converting from conventioanl to reduced tillage.

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