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Carbon Sink Enhancement in Soils of Europe: Data, Modeling, Verification

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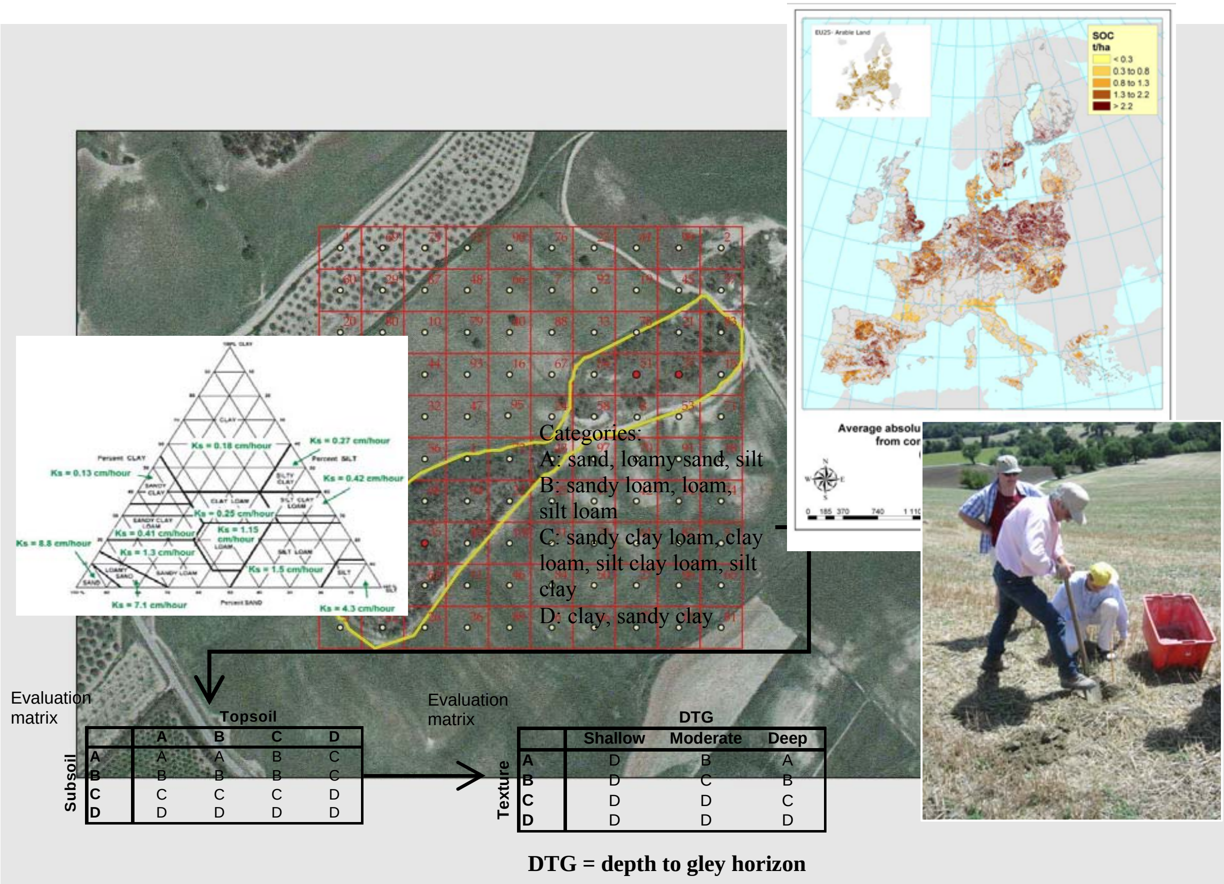
L. Montanarella
P. Panagos



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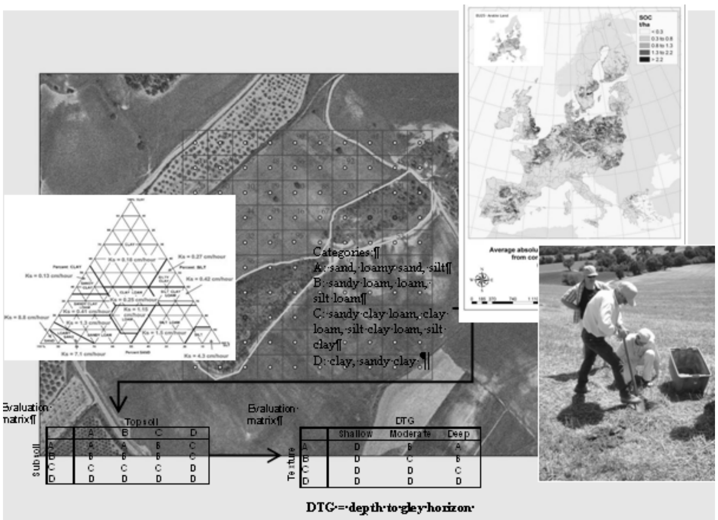

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Foreword

This book is a result of the 6^{th} Framework Programme project on Integrated Sink Enhancement Assessment (INSEA) (EC Contract no.: SSP1-CT-2003-503614 (INSEA)). The overall objective of the INSEA project was to develop an analytical tool to assess economic and environmental effects for enhancing carbon sinks on agricultural and forest land. This goal has been achieved through several Work Packages (WP). Activities within WP 3000 'Data and Database Strategy' were centered on: 1) selection and development of necessary data and, 2) integration/harmonization of various data to support a baseline module on cost landscapes, validation, assessment and scenario analysis. The work carried required the analysis of raw and prcessed data derived from various sources. In some cases, these data were needed as model inputs, while in the other cases, model outputs were to be connected with spatially explicit information. The main deliverables from WP 3000, together with the summary of the principle findings, are included in this publication.

Continuous improvement of the INSEA database, as well as regional/local verification, is available in the form of a web map portal (http://www.iiasa.ac.at/Research/FOR/INSEA/).

Executive summary

The biophysical data available for the EU25 (i.e. soils, land cover, digital elevation model, etc.) are sufficient to meet the needs of the field-scale Environmental Policy Integrated Climate (EPIC) model. The data allow for the sophisticated analysis of climate mitigation and adaptation practices in line with the implementation of the LULUCF activities of the Kyoto Protocol. However, available data should be adapted and fitted to the models requirements.

The soil organic carbon (SOC) content database in of the EU25 at the scale of 1:1,000,000 has been developed based on an advanced pedo-transfer functions (PTF). However, the validations of these data should be performed using measured soil profile analytical data from different geographical locations of Europe and across the entire range of land cover types. The analysis of the topsoil SOC content shows that data significantly overestimate carbon resources of arable land in Slovakia. Preparatory bio-physical process simulations using EPIC may help to correct SOC stocks at NUTS2 level.

A newly developed Area-Frame Randomized Soil Sampling (AFRSS) method makes the verification of the changes of SOC stock in mineral soils of the EU simple, transparent and economically efficient. The method allows easy programming and computation of the sampling procedure. Reproducibility test assists the establishing of a minimum detectable amount of SOC change.

The bio-physical process modelling with INSEA data estimate impacts on SOC under alternative tillage systems, which are relatively consistent with impacts being simulated from national data sources. The effects on SOC from a change in conventional tillage practices to reduced or minimum tillage systems are, in relative terms, similar between the Slovakian soil database and the INSEA database for Slovakia.

The impact analysis of alternative tillage systems shows that there are substantial potentials to sequester SOC through conserving tillage (i.e. reduced and minimum tillage). In particular, additional SOC could be sequestered when changing towards reduced tillage of 0.11 t/ha/yr, or when changing towards minimum tillage of 0.18 t/ha/yr.

Crop yields are reduced by 3% (reduced tillage) and 8% (minimum tillage) compared to conventional tillage. Furthermore, there is strong evidence that the alteration of tillage systems will lead to other environmental side-effects such as more pesticide or fertilizer applications, which should be also accounted for in evaluating the environmental performance of alternative tillage systems.

The calculation procedure for N_2O-N emissions from food crop production on arable lands in EU25 results in 'direct' N_2O-N emissions of 5.3 kg/ha/yr, or 511.9 Gg/yr in total and in 'indirect' N2O-N emissions of 0.9 kg/ha/yr, or 91.7 Gg/yr in total. Taking the assumptions on computing fertilization rates, 104 kg/ha of nitrogen is applied for crop production on arable lands on average. Consequently, almost 6% of fertilized nitrogen is 'direct' and 'indirect' N2O-N emissions, which also includes background N_2O-N emissions. In addition, a tillage change would lead to reduced 'direct' and 'indirect' N_2O-N emissions on average, exhibiting gain/loss effects locally.

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Soil database in the context of INSPIRE

L. Montanarella, V. Stolbovoy, P. Panagos and Marc Van Liedekerke

1. Introduction

The Soil Geographical Database of Europe (SGDBE) corresponds to geographical scale 1:1,000,000 and is part of the European Soil Information System (EUSIS). It is developed by collaborative efforts of all the European Union and neighboring countries. This database represents diversity and spatial variability of the soils. The methodology used to differentiate and name the main soil types is based on the terminology of the United Nations Food and Agricultural Organization (FAO) legend for the Soil Map of the World at Scale 1:5,000,000. This terminology has been refined and adapted to take account of the specificities of the landscapes in Eurasia. It is itself founded on the distinction of the main pedogenetic processes leading to soil differentiation: brunification, lessivage, podzolisation, hydromorphy, etc.

The database contains a list of Soil Typological Units (STU). Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils: for example the texture, the water regime, the stoniness, etc. (Appendix 1.1). The geographical representation was chosen at a scale corresponding to the 1:1,000,000. At this scale, it is not feasible to delineate the STUs. Therefore they are grouped into Soil Mapping Units (SMU) to form soil associations and to illustrate the functioning of pedological systems within the landscapes (Figure 1).

Harmonization of the soil data from the member countries is based on a dictionary providing the definition for each occurrence of the variables. Considering the scale, the precision of the variables is limited. Furthermore these variables were estimated over large areas by expert judgment rather than measured on local soil samples. This expertise results from synthesis and generalization tasks of national or regional maps published at more detailed scales, for example 1:50,000 or 1:25,000 scales. Delineation of the SMUs is also the result of expertise and experience. The spatial variability of soils is very important and is difficult to express at the continental levels of precision. Quality indices of the information (purity and confidence level) are included with the data in order to guide the usage.

As a result, the SGDBE consists of both a geometrical dataset (polygons) and a semantic dataset (set of attribute files) which are linked together as it is illustrated in the figure 1 below.

The Joint Research Centre of the European Commission (JRC) has developed a CD-ROM with full documentation of the European Soil Database. The detailed documentation contains:

- Brief introduction
- Metadata (general description of the database (purpose, history, etc.).
- Database dictionary (implementation details of the database structure in the ArcInfo GIS software environment)
- Attribute coding (detailed description of the database attribute values)

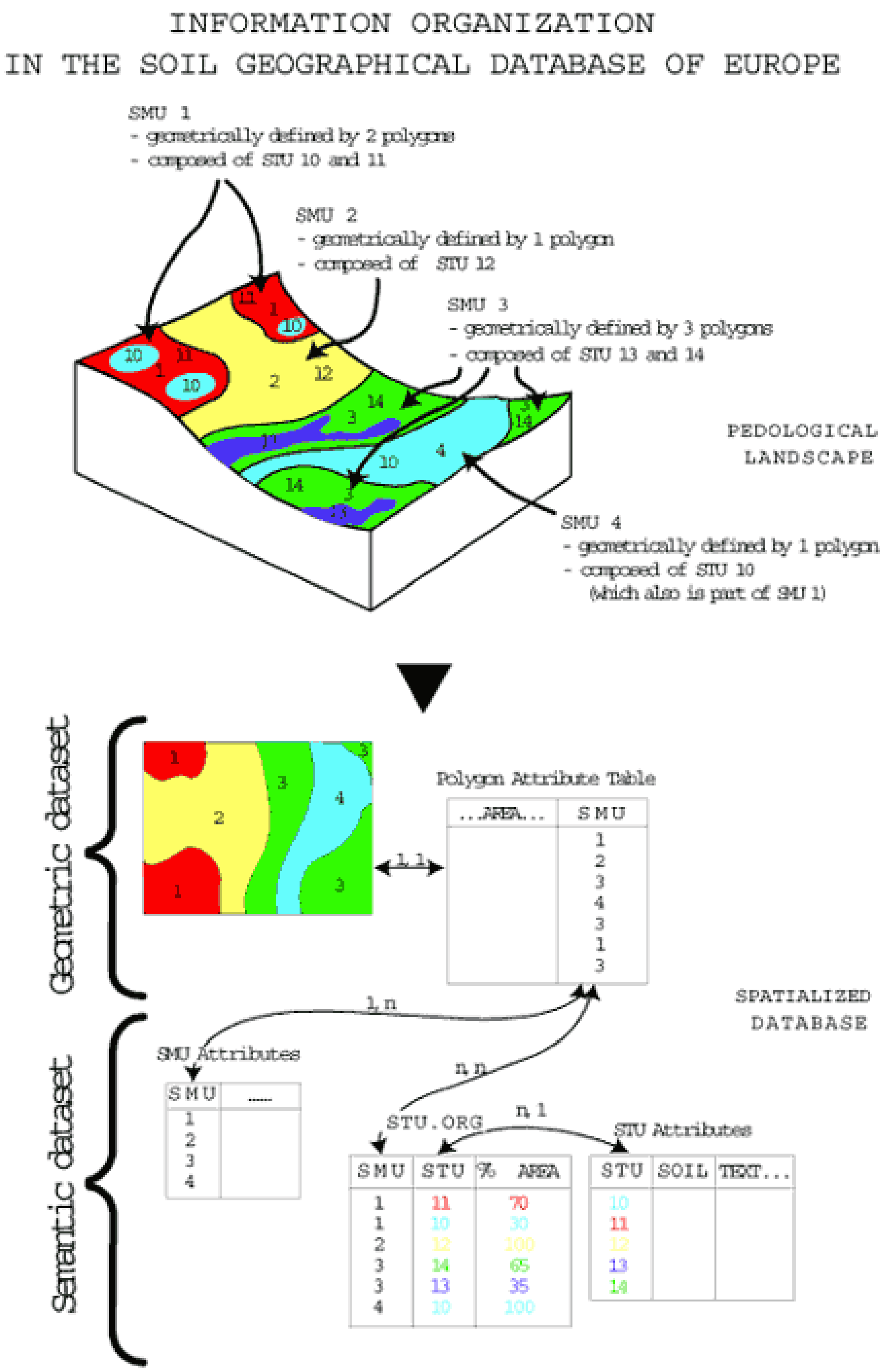

Figure 1: Organizing soil information in a geographical information system

The documentation is provided in 2 levels of details:

- Easy Access to the Soil DB (for all the users)
- Advanced Access to the Soil DB (for experts users)

This detailed documentation can be found on-line in:

http://eusoils.jrc.it/ESDB_Archive/ESDBv2/index.htm

2. Raster Library

The SGDBE (Soil Geographical Database) v2 Raster Library contains raster data files (ESRI GRID format for 73 attributes of the SGDBE and PTRDB databases of the European Soil Database (distribution version 2). Cell sizes are both of **1km x 1km** and **10km x 10km** and each grid is aligned with the reference grid recommended during the 1st Workshop on European Reference Grids in the context of the INSPIRE (Infrastructure for Spatial Information in Europe) initiative. The grids are in the ETRS89 Lambert Azimuthal Equal Area (ETRS_LAEA) co-ordinate system.

Raster values have been derived using the "features to raster" tool in the Spatial Analyst extension of ArcGIS, the feature layer being a shape file created from the SGDBE geometrical database to which attributes from SGDBE and PTRDB have been linked according to the "dominant value" principle (more details about this principle can be found in the link: http://eusoils.jrc.it/msapps/Soil/SoilDB/ABOUT_ms/purity.htm)

Additionally, there is the European Soil Data Base v2 Raster Library that contains all the above-mentioned Grids in another co-ordinate system (standard GISCO Lambert Azimuth co-ordinate system). Cell sizes are 10km x 10km aligned with the 50km x 50km reference grid from the MARS database (reference grid is defined in the GISCO reference database in theme "lr/ci" (land resources / climate interpolated), coverage "cieu" ; the extent is also the same as the one of the MARS raster.

The raster attributes correspond to the attributes represented in the maps of the Eurasian Soil Data Base Map Archive (published on http://eusoils.jrc.it) as “a collection of maps” which represent all attributes which are present in the in the Soil Geographical Database of Eurasia at scale 1:1,000,000 - version 4 beta (For more details see Table 1) and the PedoTransfer Rules Data Base - version 2.0 (For more details see Table 2). All maps are in PDF format(A3)", sizes typically between 1 and 2 MB.

In the location below there is an explanation of the names of the raster’s:
http://eusoils.jrc.it/ESDB_Archive/raster_archive/description_of_raster_layers.htm

In the location elow there is the whole list of possible attribute values for SGDBE derived raster's: http://eusoils.jrc.it/ESDB_Archive/raster_archive/SG_attr.htm

In the location below there is the whole list of possible attribute values for PTRDB derived raster's:
http://eusoils.jrc.it/ESDB_Archive/raster_archive/pt_attr.htm

It has been given free public access to this degraded data (10km x10km Grids) and Autheticated access to the 1km x 1km Grids. The internet user has the following options to download the Grids:

- 10km x 10km Grids in the ETRS89 Lambert Azimuthal Equal Area (ETRS_LAEA) co-ordinate system: http://eusoils.jrc.it/ESDB_Archive/etrs_laea_raster_archive/all_grids_laea.zip (14 MB). A zipped version of all raster's in native GRID format; Unzipping this file results in 74 directories (one info directory and 73 grid directories (one for each raster) referring all to the same info directory) and 73 *.aux* files, which contain projection information needed by ArcGIS. (Total size 96 MB)

- 10km x 10km Grids in the GISCO Lambert Azimuth co-ordinate system: http://eusoils.jrc.it/ESDB_Archive/raster_archive/rasters/all_rasters_native.zip (40 MB): A zipped version of all raster's in native GRID format; unzipping this file results in 76 directories: one info directory and 73 grid directories (one for each raster) referring all to the same info directory (total size 205 MB).

- 1km x 1km Grids in the in the ETRS89 co-ordinate system: http://eusoils.jrc.it/ESDB_Archive/ESDB_data_1k_raster_intro/ESDB_1k_raster_data_intro.html In order to obtain access to those raster data an authentication mechanism (Username / Password) has been set up which requires the registration of the user.

In the structure of the database and in STU table, each STU has a number of attributes: an overview of these attributes is given below. For each one of these attributes, a raster has been developed (see table 1):

Name of raster	Original attribute name in SGDBE	Description (for possible attribute values: see SGDBE_rasters_attributes_classes.txt)
AGLIM1	AGLIM1	Code of the most important limitation to agricultural use of the STU.
AGLIM2	AGLIM2	Code of a secondary limitation to agricultural use of the STU.
FAO85FU	FAO85-FULL	Full soil code of the STU from the 1974 (modified CEC 1985) FAO-UNESCO Soil Legend
FAO85LV1	FAO85-LEV1	Soil major group code of the STU from the 1974 (modified CEC 1985) FAO-UNESCO Soil Legend.
FAO85LV2	FAO85-LEV2	Second level soil code of the STU from the 1974 (modified CEC 1985) FAO-UNESCO Soil Legend.
FAO85LV3	FAO85-LEV3	Third level soil code of the STU from the 1974 (modified CEC 1985) FAO-UNESCO Soil Legend.
FAO90FU	FAO90-FULL	Full soil code of the STU from the 1990 FAO-UNESCO Soil Legend.
FAO90LV1	FAO90-LEV1	Soil major group code of the STU from the 1990 FAO-UNESCO Soil Legend.
FAO90LV2	FAO90-LEV2	Second level soil code of the STU from the 1990 FAO-UNESCO Soil Legend.
IL	IL	Code for the presence of an impermeable layer within the soil profile of the STU.
PARMADO	PAR-MAT-DOM	Code for dominant parent material of the STU.
PARMADO1	PAR-MAT-DOM1	Major group code for the dominant parent material of the STU.
PARMADO2	PAR-MAT-DOM2	Second level code for the dominant parent material of the STU.
PARMADO3	PAR-MAT-DOM3	Third level code for the dominant parent material of the STU.
PARMASE	PAR-MAT-SEC	Code for secondary parent material of the STU.
PARMASE1	PAR-MAT-SEC1	Major group code for the secondary parent material of the STU.
PARMASE2	PAR-MAT-SEC2	Second level code for the secondary parent material of the STU.
PARMASE3	PAR-MAT-SEC3	Third level code for the secondary parent material of the STU.
ROO	ROO	Depth class of an obstacle to roots within the STU.
SLOPEDO	SLOPE-DOM	Dominant slope class of the STU.
SLOPESE	SLOPE-SEC	Secondary slope class of the STU.
TXDEPCHG	TEXT-DEP-CHG	Depth class to a textural change of the dominant and/or secondary surface texture of the STU.
TXSRFDO	TEXT-SRF-DOM	Dominant surface textural class of the STU.
TXSRFSE	TEXT-SRF-SEC	Secondary surface textural class of the STU.
TXSUBDO	TEXT-SUB-DOM	Dominant sub-surface textural class of the STU.
TXSUBSE	TEXT-SUB-SEC	Secondary sub-surface textural class of the STU.
USEDO	USE-DOM	Code for dominant land use of the STU.
USESE	USE-SEC	Code for secondary land use of the STU.

WM1	WM1	Code for normal presence and purpose of an existing water management system in agricultural land on more than 50% of the STU.
WM2	WM2	Code for the type of an existing water management system.
WR	WR	Dominant annual average soil water regime class of the soil profile of the STU.
WRBADJ1	WRB-ADJ1	First soil adjective code of the STU from the World Reference Base (WRB) for Soil Resources.
WRBADJ2	WRB-ADJ2	Second soil adjective code of the STU from the World Reference Base (WRB) for Soil Resources.
WRBFU	WRB-FULL	Full soil code of the STU from the World Reference Base (WRB) for Soil Resources.
WRBLV1	WRB-LEV1	Soil reference group code of the STU from the World Reference Base (WRB) for Soil Resources.
ZMAX	ZMAX	Maximum elevation above sea level of the STU (in meters).
ZMIN	ZMIN	Minimum elevation above sea level of the STU (in meters).

Table 1. List of fields provided by Soil Geographical Database of Eurasia (SGDBE)

Pedotransfer rules define how to infer values for an output attribute based on a set of values from a number of input attributes. Within the Soil Database, the input attributes are selected among the attributes in the STU table from the SGDBE. The following list contains the new attributes for which rules have been defined. For each one of these attributes, a raster has been developed (see table 2):

Name of raster	Original attribute name in PTRDB	Description (for possible attribute values: see PTRDB_rasters_attributes_classes.txt)
AGLI1NNI	AGLIM1NNI	Dominant limitation to agricultural use (without no information).
AGLI2NNI	AGLIM2NNI	Secondary limitation to agricultural use (without no information).
ALT	ALT	Elevation
ATC	ATC	Accumulated temperature class.
AWC_SUB	AWC_SUB	Subsoil available water capacity.
AWC_TOP	AWC_TOP	Topsoil available water capacity.
BS_SUB	BS_SUB	Base saturation of the subsoil.
BS_TOP	BS_TOP	Base saturation of the topsoil.
CEC_SUB	CEC_SUB	Subsoil cation exchange capacity.
CEC_TOP	CEC_TOP	Topsoil cation exchange capacity.
CRUSTING	CRUSTING	Soil crusting class.
DGH	DGH	Depth to a gleyed horizon.
DIFF	DIFF	Soil profile differentiation.

DIMP	DIMP	Depth to an impermeable layer.
DR	DR	Depth to rock.
EAWC_SUB	EAWC_SUB	Subsoil easily available water capacity.
EAWC_TOP	EAWC_TOP	Topsoil easily available water capacity.
ERODI	ERODIBILITY	Soil erodibility class.
HG	HG	Hydrogeological class.
MIN	MIN	Profile mineralogy.
MIN_SUB	MIN_SUB	Subsoil mineralogy.
MIN_TOP	MIN_TOP	Topsoil mineralogy.
OC_TOP	OC_TOP	Topsoil organic carbon content.
PD_SUB	PD_SUB	Subsoil packing density.
PD_TOP	PD_TOP	Topsoil packing density.
PEAT	PEAT	Peat.
PHYSCHIM	PHYS-CHIM	Physi-chemical factor of soil crusting & erodibility.
PMH	PMH	Parent material hydrogeological type.
STR_SUB	STR_SUB	Subsoil structure.
STR_TOP	STR_TOP	Topsoil structure.
TD	TD	Rule inferred subsoil texture.
TEXT	TEXT	Dominant surface textural class (completed from dominant STU).
TXCRUST	TEXT-CRUST	Textural factor of soil crusting.
TXEROD	TEXT-EROD	Textural factor of soil erodibility.
USE	USE	Regrouped land use class.
VS	VS	Volume of stones.

Table 2. List of fields provided by Pedotrasferring Rules Database (PTRDB)

3. Maps for attributes

Based on the SGDBE dataset attributes which are present in the Soil Geographical Database of Eurasia at scale 1:1,000,000 (version 4 beta), a number of Static maps (PDF Format, A3) have been created which allow the user to have an overview of the distribution of soil characteristics in a spatial way.

All maps are "dominant value" maps. The name of the parameter and its short description for each of these maps is given below. For each attribute, a "dominant value" and corresponding purity map has been built; if a "confidence level" for the attribute is available in the database, then a "confidence level" map has been computed.

T: Thematic map for the attribute;

P: Purity map for the attribute;

C: Confidence level map for the attribute.

There are 12 groups of SGDBE attribute maps:

3.1 Soil Classification WRB

WRB-FULL: Full soil code of the STU from the World Reference Base (WRB) for Soil Resources. (T,P,C)
WRB-LEV1: Soil reference group code of the STU from the World Reference Base (WRB) for Soil Resources. (T,P,C)
WRB-ADJ1: First soil adjective code of the STU from the World Reference Base (WRB) for Soil Resources. (T,P,C)
WRB-ADJ2: Second soil adjective code of the STU from the World Reference Base (WRB) for Soil Resources. (T,P,C)

3.2 Soil Classification FAO

FAO90-FULL: Full soil code of the STU from the 1990 FAO-UNESCO Soil Legend. (T,P,C)
FAO90-LEV1: Soil major group code of the STU from the 1990 FAO-UNESCO Soil Legend. (T,P,C)
FAO90-LEV2: Second level soil code of the STU from the 1990 FAO-UNESCO Soil Legend. (T,P,C)
FAO85-FULL: Full soil code of the STU from the 1974 (modified CEC 1985) FAO-UNESCO Soil Legend. (T,P,C)
FAO85-LEV1: Soil major group code of the STU from the 1974 (modified CEC 1985) FAO-UNESCO Soil Legend. (T,P,C)
FAO85-LEV2: Second level soil code of the STU from the 1974 (modified CEC 1985) FAO-UNESCO Soil Legend. (T,P,C)
FAO85-LEV3: Third level soil code of the STU from the 1974 (modified CEC 1985) FAO-UNESCO Soil Legend. (T,P,C)

3.3 Texture

TEXT-SRF-DOM: Dominant surface textural class of the STU. (T,P,C)
TEXT-SRF-SEC: Secondary surface textural class of the STU. (T,P,C)
TEXT-SUB-DOM: Dominant sub-surface textural class of the STU. (T,P,C)
TEXT-SUB-SEC: Secondary sub-surface textural class of the STU. (T,P,C)

TEXT-DEP-CHG: Depth class to a textural change of the dominant and/or secondary surface texture of the STU. (T,P,C)

3.4 Parent Material

PAR-MAT-DOM: Code for dominant parent material of the STU. (T,P,C)

PAR-MAT-DOM1: Major group code for the dominant parent material of the STU. (T,P,C)

PAR-MAT-DOM2: Second level code for the dominant parent material of the STU. (T,P,C)

PAR-MAT-DOM3: Third level code for the dominant parent material of the STU. (T,P,C)

PAR-MAT-SEC: Code for secondary parent material of the STU. (T,P,C)

PAR-MAT-SEC1: Major group code for the secondary parent material of the STU. (T,P,C)

PAR-MAT-SEC2: Second level code for the secondary parent material of the STU. (T,P,C)

PAR-MAT-SEC3: Third level code for the secondary parent material of the STU. (T,P,C)

3.5 Land Use

USE-DOM: Code for dominant land use of the STU. (T,P,C)

USE-SEC: Code for secondary land use of the STU. (T,P,C)

3.6 Limitation to agricultural use

AGLIM1: Code of the most important limitation to agricultural use of the STU. (T, P, C)

AGLIM2: Code of a secondary limitation to agricultural use of the STU. (T, P, C)

3.7 Obstacle to roots

ROO: Depth class of an obstacle to roots within the STU. (T,P,C)

3.8 Impermeable Layer

IL: Code for the presence of an impermeable layer within the soil profile of the STU. (T,P,C)

3.9 Soil Water Regime

WR: Dominant annual average soil water regime class of the soil profile of the STU. (T,P,C)

3.10 Water Management System

WM1: Code for normal presence and purpose of an existing water management system in agricultural land on more than 50% of the STU. (T,P,C)

WM2: Code for the type of an existing water management system. (T,P,C)

3.11 Altitude

ZMAX: Maximum elevation above sea level of the STU (in meters). (T,P,C)

ZMIN: Minimum elevation above sea level of the STU (in meters). (T,P,C)

3.12 Slope

SLOPE-DOM: Dominant slope class of the STU. (T,P,C)

SLOPE-SEC: Secondary slope class of the STU. (T,P,C)

4. Maps for attributes included in the PedoTransfer Rules Database

Based on the attributes which are present in the in the PedoTransfer Rules Data Base (PTRDB)(version 2.0), a number of Static maps (PDF Format, A3) have been created which allow the user to have an overview of the distribution of soil characteristics in a spatial way.

All maps are "dominant value" maps. The name of the parameter and its short description for each of these maps are given below. For each attribute, a "dominant value" and corresponding purity map has been built; if a "confidence level" for the attribute is available in the database then a "confidence level" map has been computed.

T: link to thematic map for the attribute;
P: link to purity map for the attribute;
C: link to confidence level map for the attribute.

There are 5 groups of PTRDB attribute maps:

4.1 Primary properties

TEXT: Dominant surface textural class (completed from dominant STU). (T,P,C)

OC_TOP: Topsoil organic carbon content. (T,P,C)

PEAT: Peat. (T,P,C)

ALT: Elevation (T,P,C)

4.2 Chemical properties

DIFF: Soil profile differentiation. (T,P,C)

MIN: Profile mineralogy. (T,P,C)

MIN_TOP: Topsoil mineralogy. (T,P,C)

MIN_SUB: Subsoil mineralogy. (T,P,C)

CEC_TOP: Topsoil cation exchange capacity. (T,P,C)

CEC_SUB: Subsoil cation exchange capacity. (T,P,C)

BS_TOP: Base saturation of the topsoil. (T,P,C)

BS_SUB: Base saturation of the subsoil. (T,P,C)

4.3 Mechanical properties

DR: Depth to rock. (T,P,C)

VS: Volume of stones. (T,P,C)

TD: Rule inferred subsoil texture. (T,P,C)

STR_TOP: Topsoil structure. (T,P,C)

STR_SUB: Subsoil structure. (T,P,C)

PD_TOP: Topsoil packing density. (T,P,C)

PD_SUB: Subsoil packing density. (T,P,C)

4.4 Hydrological properties

PMH: Parent material hydro-geological type. (T,P,C)

DGH: Depth to a gleyed horizon. (T,P,C)

DIMP: Depth to an impermeable layer. (T,P,C)

HG: Hydro-geological class. (T,P,C)

AWC_TOP: Topsoil available water capacity. (T,P,C)

EAWC_TOP: Topsoil easily available water capacity. (T,P,C)

AWC_SUB: Subsoil available water capacity. (T,P,C)

EAWC_SUB: Subsoil easily available water capacity. (T,P,C)

4.5 Applications

AGLIM1NNI: Dominant limitation to agricultural use (without no information). (T,P,C)

AGLIM2NNI: Secondary limitation to agricultural use (without no information). (T,P,C)

USE: Regrouped land use class. (T,P,C)

ATC: Accumulated temperature class. (T,P,C)

TEXT-CRUST: Textural factor of soil crusting. (T,P,C)

PHYS-CHIM: Physi-chemical factor of soil crusting & erodibility. (T,P,C)

CRUSTING: Soil crusting class. (T,P,C)

TEXT-EROD: Textural factor of soil erodibility. (T,P,C)

ERODIBILITY: Soil erodibility class. (T,P,C)

5. European Soil Documents Repository

The collection of soil related documents is available on-line and the public user can download a series of research reports:
http://eusoils.jrc.it/ESDB_Archive/eusoils_docs/doc.html

The Repository has the following features:

- Contains the contents of useful CD-ROMS like:
    - The Contents of the Summers Schools (since 2003)
    - The Soil Thematic Strategy
    - The GroundWater Resources in Europe
- There are some multilingual versions of reports. For example the Manual of Procedures is published in English (EN), French (FR), Italian (IT), and Spanish (ES).
- The user can Preview the cover page, navigate the contents and download the document.

ESBN Research Reports is a collection of soil related documents available from the European Soil Bureau Network (ESBN)

ESBN Research Reports

No.	Title	Preview
21	NEW Status and prospect of soil information in south-eastern Europe: soil databases, projects and applications Hengl, T., Panagos, P., Jones, A. and Toth, G. (eds) 2007. Status and prospect of soil information in south-eastern Europe: soil databases, projects and applications. EUR 22646 EN Scientific and Technical Research series, Office for Official Publications of the European Communities, Luxemburg, 187 pp. Download document: (Size: 15 MB) Preview FrontPage:	
20	Common Criteria for Risk Area Identification according to Soil Threats This report presents an overview of common criteria and approaches to identify risk areas for the threats Soil Organic Matter (SOM) Decline, Soil Erosion, Soil Compaction, Salinization and Landslides. Wolf Eckelmann, Rainer Baritz, Stanislav Bialousz, Pavel Bielek, Florence Carré, Beata Houšková, Robert J.A. Jones, Mark Kibblewhite, Josef Kozak, Christine Le Bas, Gergely Tóth, Tibor Tóth, György Várallyay, Markku Yli Halla,Marko Zupan. European Soil Bureau Research Report No.20, EUR 22185 EN, 94pp. Office for Official Publications of the European Communities, Luxembourg (2006). Download document: (Size: 4.1 MB) Preview FrontPage:	
19	SPADE-2: The Soil Profile Analytical Database for Europe (version 1.0) John M. Hollis, Robert J.A. Jones, Charles J. Marshall, Ann Holden, Jan Renger van de Veen and Luca Montanarella (2006). EUR 22127 EN Download document: (Size: 2.7 MB) Preview FrontPage:	
18	DRIS, MDRIS and CND Bivariate and multivariate analyses tools for monitoring the soil and plant nutrient imbalances Senthil-Kumar Selvaradjou, Luca Montanarella and Aruna-Geetha (2005). EUR 21505 EN Navigate the Contents: Download document: (Size: 0.8 MB) Preview FrontPage:	
17	THE MAP OF ORGANIC CARBON IN TOPSOILS IN EUROPE: VERSION 1.2 - SEPTEMBER 2003 Explanation of: Special Publication Ispra 2004 No.72 S.P.I.04.72 Robert J.A. Jones, Roland Hiederer, Ezio Rusco, Peter J. Loveland and Luca Montanarella. EUR 21209 EN Download report : (Size: 0.2 MB) Preview FrontPage :	
16	Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J. and Huting, J.(2004). European Soil Bureau Research Report No.16, EUR 21176, 18pp. and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg. Download report : (Size: 1.2 MB) Preview FrontPage: Download Map : (Size: 10 MB)	
15	Organic Matter in the Soils of Southern Europe. Pandi Zdruli, Robert J.A. Jones and Luca Montanarella (2004). EUR 21083 EN, 16pp. Office for Official Publications of the European Communities, Luxembourg. Download document: (Size: 1.4 MB) Preview FrontPage:	

Figure 2: European Soil Documents Repository

6. Infrastructure for spatial information in Europe (INSPIRE)

The SGDBE follows all European tendencies to harmonize different spatially explicit databases. The INSPIRE is a major tool to approach this goal. The initiative originates from the difficulty to identify access and use available spatial information in Europe. It is caused by the fragmentation of datasets and sources, gaps in availability, lack of harmonization between datasets at different geographical scales and duplication of information collection. The implementation of the INSPIRE initiative within INSEA is a major challenge of the WP3000 due to complementary to related policy, such as the Commission proposal for a Directive on the re-use and commercial exploitation of Public Sector Information.

6.1 Objectives

The INSPIRE intends to trigger the creation of a European spatial information infrastructure that delivers to the users integrated spatial information services. These services should allow the users to identify and access spatial or geographical information from a wide range of sources, from the local level to the global level, in an inter-operable way for a variety of uses. The target users of INSPIRE include policy-makers, planners and managers at European, national and local level and the citizens and their organizations. Possible services are the visualization of information layers, overlay of information from different sources, spatial and temporal analysis, etc.

The INSPIRE initiative is based on the following principles:

1. Data should be collected once and maintained at the level where this can be done most effectively

2. It must be possible to combine seamlessly spatial data from different sources across the EU and share it between many users and applications

3. It must be possible for spatial data collected at one level of government to be shared between all levels of government

4. Spatial data needed for good governance should be available on conditions that are not restricting its extensive use

5. It should be easy to discover which spatial data is available, to evaluate its fitness for purpose and to know which conditions apply for its use.

6.2 Technical Tools

In the framework of INSPIRE, two sets of guidelines are foreseen: the INSPIRE Technical Guidelines, and the INSPIRE Cookbook for Spatial Interest Groups.

INSPIRE Technical Guidelines is coordinated by the Joint Research Centre of the European Commission. Technology is changing, and all the areas of technology relevant to SDIs are in continuous development. The incorporation of future developments must be viewed from a user perspective. In order to accommodate changes in standards and specifications which are judged useful today, This will be a living document providing all the necessary details, and is to evolve into the authoritative reference for the implementation of INSPIRE.

The INSPIRE Technical Guidelines is based on the INSPIRE Architecture and Standards Position Paper, and is available since middle 2004.

INSPIRE Cookbook is to provide guidance to the network of spatial interest groups in issues that go beyond the purely technical issues. Examples include templates for data licenses and best practice in data documentation. A draft version of the Cookbook should be available in early 2004.

6.3 Standardization Initiatives

The INSPIRE EU Geo-Portal is developed based on International standards and specifications, as laid down in the INSPIRE Guidelines, in order to attain the interoperability of data and services in support of the architecture. There are currently two major standardization initiatives in the field of geographic information and geomatics. These are ISO/TC211 and the OpenGIS Consortium Ltd. (OGC). The standards produced by these initiatives may specify methods, tools and services for data management, acquiring, processing, analyzing, accessing, presenting and transferring such data between different users, systems and locations. The INSPIRE profile and guidelines for the implementation shall be based on the ISO 19100 series of standards for geographic information, and where necessary and appropriate, results of other standardization initiatives can be considered (e.g., Dublin Core Dublin Core, OGC). ISO 19100 series of base standards are implementation neutral. Some of these may be used by the market directly (like ISO 19113 Quality principles, ISO 19109 Rules for Application Schema, ISO 19103 Conceptual Schema Language, etc) while others need to be implemented as software components. Implementation specifications has been mainly been developed by OGC, more and more taking the ISO 191xx implementation neutral base standards as the basis for platform specific implementations (CORBA, COM/OLE, SQL, XML, etc.). This process may result in amendments to the base standards, submitted to ISO, either as technical corrigendum or as new ISO standards, either IS or possibly PAS (Public Available Specifications). In this way, ISO/TC 211 and OGC complement each others efforts to ensure interoperable solutions to GIS. European industry has a role in fostering this co-operation.

6.4 Mapping services and applications

A number of mapping services have been developed in order to serve the public user. The SOMIS (**SO**il **M**ap **I**nternet **S**ervice) is a Standalone web-based application for the navigation of soil related maps. This map service has the following features:

- It is a dynamic Internet application to European Soil Database and allows interaction with the user

- Presentation of all attributes (73) as map layers ; all attributes are taken from the Soil Geographical Database (v4 beta) and associated Pedo Transfer Rules Database (v2) grouped in 14 categories
- The user can execute on-line almost all the mapping operations: Zoom in, Zoom out, Full Extent, Previous Extent, Panning, Panning to 4 directions, Query data, Identify, Select Features by Line/Polygon, Advanced Printing capabilities.
- The user is allowed to view, navigate and inspect soil data but cannot download (due to ownership data status)
- The application is like a GIS Tool and there is no need for specific S/W(only web browser)
- The data contents are fully documented and On Line Help Button is provided
- Combine layers of maps located in different Map servers all around the World (According to INSPIRE principles)

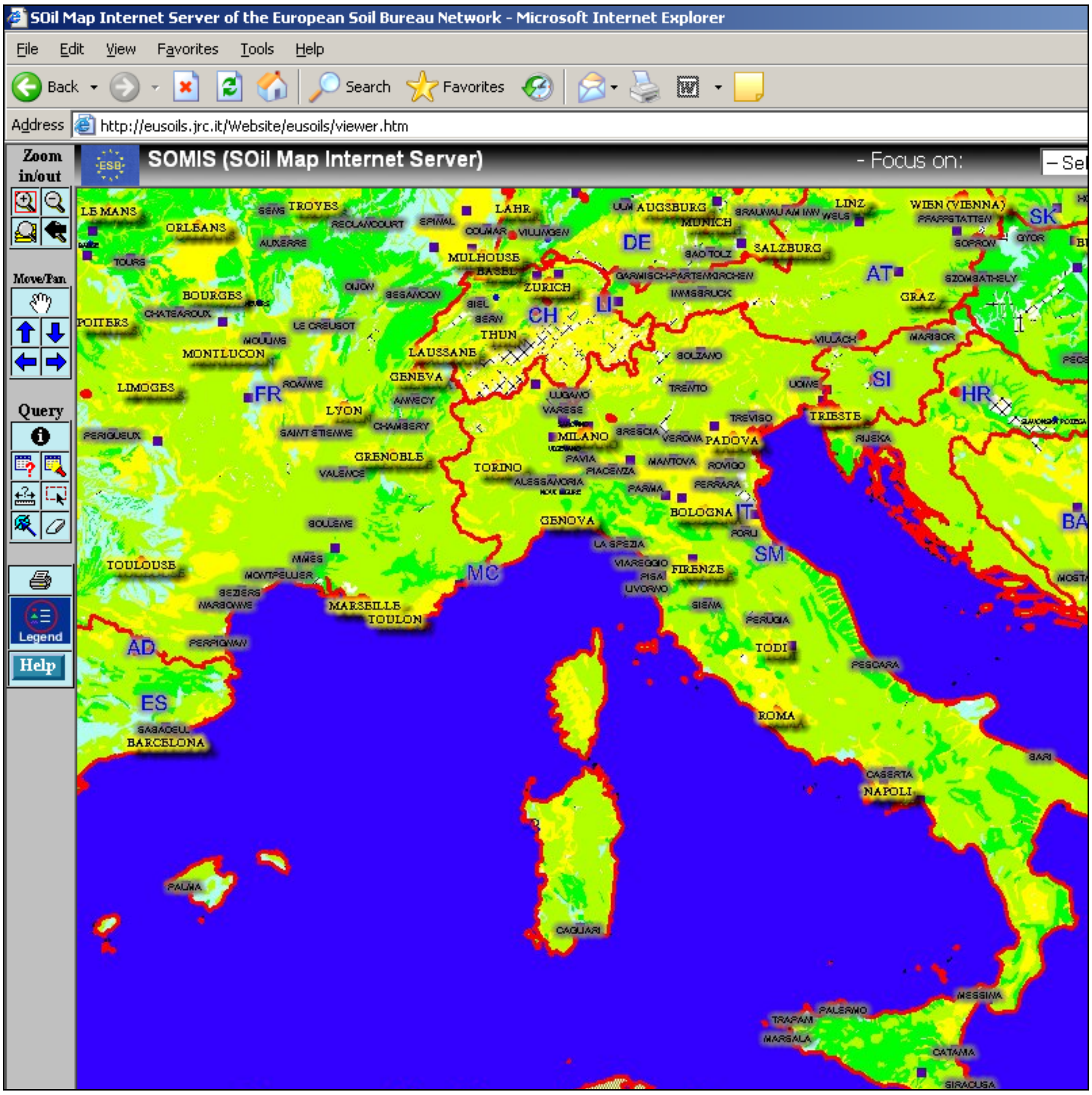

Figure 3: Example of the SOMIS (Soil Mapping Interner Service)

7. Metadata Standards

The ISO 19115:2003 standard for geographic information metadata was released in January 2003. Work on this standard has brought together the experiences of the FGDC, the CEN Technical Committee 287, which had developed a pre-standard on GI metadata in 1997, and similar activities that have taken place in Australia-New Zealand and Canada. All together 33 countries and 12 observer organizations participated in the development of the standard. It defines the schema required to describe geographic information and services and provides information about the identification, extent, quality, spatial reference and distribution of digital geographic data.

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The European Soil Portal, EUR 22186 EN, 69pp. Office for Official Publications of the European Communities, Luxembourg. Panos Panagos, Marc Van Liedekerke and Luca Montanarella

Appendix. Explanatory notes on soil parameters

To operate with SGDBE successfully general understanding of origin and meaning of soil parameters is needed. This section provides general knowledge necessary to work with soil DB.

A 1.1 Origin of Data

The soil data might come from real analytical measurements and actual profile descriptions or be modal or even expert guesses - because of lack of information. This diversity falls under following categories:

i. average of a number of profiles;
ii. from a single representative profile;
iii. prediction derived from mathematical functions;
iv. prediction derived from relationships between horizons and class functions (e.g. texture and density class);
v. expert judgment.

A 1.2 Explanation on soil parameters

A 1.2.1 Soil Name

The name of the soil type is indicated inclusive of the texture class. For example: Be-4,Lo-2. Some soil types do not have a texture class, i.e. Histosols.

A 1.2.2 Groundwater Level

The mean highest and mean lowest permanent or perched groundwater table is indicated. It is the mean of at least 10 years. Generally such information is lacking and so it mostly is an estimate or guess (expert guess) values provided by following classes:

1: groundwater table between: 0-50cm
2: groundwater table between: 50 -100 cm
3: groundwater table between: 100-150cm
4: groundwater table between: 150 -200 cm
5: groundwater table below: 200 cm

For example, if mean groundwater level in winter estimated to be 70 cm and in summer 190 cm, it is recorded:

Highest: 2

Lowest: 4

A 1.2.3 Landuse

This will be agriculture for dominantly agricultural units but record any non-agricultural use for units which are not used for agriculture.

A 1.2.4 Horizon

Names of different horizons according to the FAO system. For example: the horizon sequence of a Luvisols: Ap, E, Bt, C.

A 1.2.5 Texture

The percentage of different particle sizes (<2mm) to the nearest integer (or whole' number i.e. without giving decimals). For example: clay 28%, not 27.8%. The contents of all the texture grades add up to 100%

A 1.2.6 Stones + Gravel

The percentage of estimated stones and gravel in the soil is recorded by following codes:

Code	Class	
1:	very few	< *5%* by volume
2:	few	5 - *15%* by volume
3:	frequent or many	15 - 40% by volume
4:	very frequent, very many	40 - 80% by volume
5:	dominant or skeletal	> 80% by volume

A 1.2.7 Organic Matter (OM)

Organic matter content (%) {not the organic carbon content} in each horizon to one decimal place, e.g. 3.8%.

Codes for methods:

Al Method of Walkley and Black

A2 Leco Method Tabatabai and Bremner (1970)

A3 Other

A 1.2.8 Total Nitrogen (N)

Records are given to one decimal place with indication of the following methods:

A4 Wet digestion (Kjeldahl method) (%)

A5 Other

A 1.2.9 Carbon/Nitrogen (C/N) Ratio

The C/N ratio is rounded to the nearest whole number.

A 1.2.10 $CaCO_3$ and $CaSO_4.2H_2O$

The calcium carbonate equivalent ($CaCO_3$) and gypsum content ($CaSO_4.2H_20$) are given to the nearest integer i.e. 36.

Methods for $CACO_3$:

A6 Calcimeter method (%) [measures CO_2 emitted]

A7 Other

Methods for $CaSO_4.2H_20$:

A8 For soils with small quantities of gypsum: By water extraction: USDA Handbook No 60, Diagnosis and Improvement of Saline and Alkaline Soils *(1954)*.

A9 For highly gypsiferous soils: By loss of crystallization water between 40 & 110 °C.

Al0 Other

A 1.2.11 Active $CaCO_3$

The method of Druineau (1942) modified by Gehu-Frank (1959) is used. A 10 g subsample of soil is shaken (for 2h) in 250m1 of ammonium oxalate. A 20 ml aliquot of filtrate is then treated with acidic potassium permanganate (60-70°C). Active calcium carbonate is then determined from the following equation:

$$\text{Active } CaCO_3 (\%) = (A - B)\ N\ 50\ (0.125)$$

Where: A ml KMnO4 in the blank (oxalate only)

B = ml KMnO4 in sample

N = normality

50 = equivalent weight of $CaCO_3$

A 1.2.12 pH (H_20)

pH measured in water, soil: water ratio 1:2.5. The pH - values are given to one decimal place, i.e. 5.9.

A 1.2.13 Acidity pH

Code of methods:

All 1:l water(H20)

A12 1:2.5 water (H_20)

A13 1:2.5 0.01 M Calcium Chloride (CaCl2)

A14 1:2.5 TM Potassium Chloride (KC1)

A15 Other

A 1.2.14 Electrical Conductivity (EC)

The EC value in dS m^1. Codes of methods:

A17 In extract from sample saturated in water

A18 Other

A 1.2.15 Exchangeable Bases

The exchangeable bases are given for an extraction with 1M NH_4AOc at pH 7.0. The values are rounded to one decimal place only except when the values are lower than 0.1 cmol+/kg.

A 1.2.16 Cation Exchange Capacity (CEC) and Base Saturation (BS)

CEC is given to one decimal place for each horizon as the sum of exchangeable bases and the exchangeable acidity at pH 8.1. Base saturation is calculated as the percentage of the CEC taken up by exchangeable bases:

BS = (TEB/CEC) 100

TEB - total exchangeable bases

BS is expressed as an integer (mass)

(or whole number).

Methods for Cation Exchange Capacity (CEC)

A21 Distillation method (cmol+/kg)

A22 Total Exchangeable Bases (TEB) + Exchange Acidity

A23 Other

Base Saturation (BS) follows codes:

A24 TEB/CEC (%)

A25 Other

A 1.2.17 Porosity and Bulk Density

The porosity (%) is given to the nearest integer; the bulk density is rounded to two decimal places.

Codes for techniques:

A28 Soil core in lab, g/cm^3

A29 Wet measurement in the field, g/cm^3

A30 Other

A 1.2.18 Root Depth

The effective root depth is defined as the depth of soil in which the plant available water (field capacity - permanent wilting point) is equal to the amount of soil water utilized by the plants until wilting occurs due to lack of water. The mean total root depth is self evident. Depths are given for the different types of crops/vegetation, which grow on the soil type.

The depth of soil available for rooting is recorded to 2 m (200 cm); the depth in cm (to nearest integer) to rock is recorded under D_Rock and the depth (cm) to any other obstruction, such as a compact layer, under D_Oth_Obs.

Mapping Organic Carbon Content for European Topsoils

R. Hiederer and R. J. A. Jones

1. Introduction

A very pronounced decline in soil organic carbon (SOC) contents was observed mainly during the second half of the 20th century. Susceptible to a loss of SOC were in particular areas under agriculture, but concern was also raised for areas of organic soils and non-agricultural land cover types. The development of SOC was derived primarily from the analysis of point observations from soil surveys with very diverse intensity and local extent. A regional estimate of the status of SOC at European level was needed to evaluate the response of SOC to changes in land use and climatic conditions.

The study project aimed at providing a spatial data layer of estimated organic carbon contents (%) in topsoils in Europe. The layer is intended to be used as baseline information to support the development of strategies for soil protection at regional level. The estimates of soil organic carbon content can also form a basis for improving estimates of the organic carbon stocks in the soils of Europe.

The procedure applied takes into account the strong effect of vegetation and land use on soil organic carbon. The effect of temperature on the organic carbon estimates has been included using an accumulated temperature data set. By varying land cover and temperature according to projected changes in those parameters the procedure elaborate in the study has the added potential to be used to model various scenarios of the progression of soil organic carbon content.

2. Methodology

Several attempts have been made to estimate carbon stocks at regional level in Europe (Howard *et al.,* 1995; Batjes, 1996; Smith *et al*., 2000; Arrouays *et al*., 2001). The studies mainly aimed at estimating the quantity of organic carbon in the soil stratum primarily to evaluate the potential of soils to sequester carbon as part of global change research. The starting point for this study is the information provided by the European Soil Database (King *et al*., 1995; Heineke *et al*., 1998). The database contains a spatial domain of vector data with the location of Soil Mapping Units (SMUs). Soil characteristic are stored in two tables with various attributes. The attributes are combined to typical characteristics in form of Soil Typological Units (STUs). The number of measured or observed attributes is increased by collection of Pedo-Transfer Rules (PTRs). Daroussin and King, (1997) describe the general methodology for applying these PTRs to widen the thematic scope of the database.

Information on land cover was taken from a geographically extended CORINE land cover data set for 1990. Using only the area covered by CORINE data would have limited the spatial extent of the estimates. Land cover data from the USGS Global Land Cover Characterization (GLCC) project were processed to cover the full spatial extent of the soil data. The land cover legend was adjusted to comply with the CORINE level 3 legend by a series of cross-classifications matrices. For the appreciation of the temperature effect data from the Global Historical Climatology Network (GHCN) (Easterling *et al.*, 1996) were employed. The station data were gridded to a spatial layer and data from 1960 to 1990 were integrated to produce the average annual accumulated temperature (AAAT) for that period.

The organic carbon PTRs of the soil database (Van Ranst *et al.*, 1995) were revised to include rules for soils and conditions of high organic content. The whole set of rules were further adjusted to be consistent with the substitution of the land cover criterion by a spatial layer and the temperature criterion by a function. The temperature function was developed according to the principle that, within belts of uniform moisture conditions and comparable vegetation, the average total organic matter in soils increase by two to three times for each 10º C fall in mean temperature (Buckman and Brady, 1960). From the AAAT of the reference period 1960–1990 a temperature coefficient ($TEMP_{cor}$) was defined by a sigmoidal function of the type:

$$TEMP_{cor} = f * \cos(t_{AAAT})^n + c\,.$$

The estimates of soil organic carbon content were calculated by combining the revised PTR with the spatial layer of land cover and adjusting the results by the temperature coefficient.

All data, including the PTR, were coded as standard spatial layers with a 1km regular grid spacing. The layers are projected conform to the GISCO Lambert Azimuthal Equal Area definition. All raster data were geometrically and thematically harmonized to the layers of the Catchment-based Information System (Hiederer, 2001).

3. Results

The final spatial layer of estimated organic carbon content in the topsoil layer in Europe is shown in Figure 1. A first qualitative assessment of layer was carried out by analyzing the distribution of SOC based on expert knowledge. Areas of low SOC content are located predominantly in southern Europe with values ranging between 0 and 1%. The map also shows the prevalence of organic soils in northern Europe.

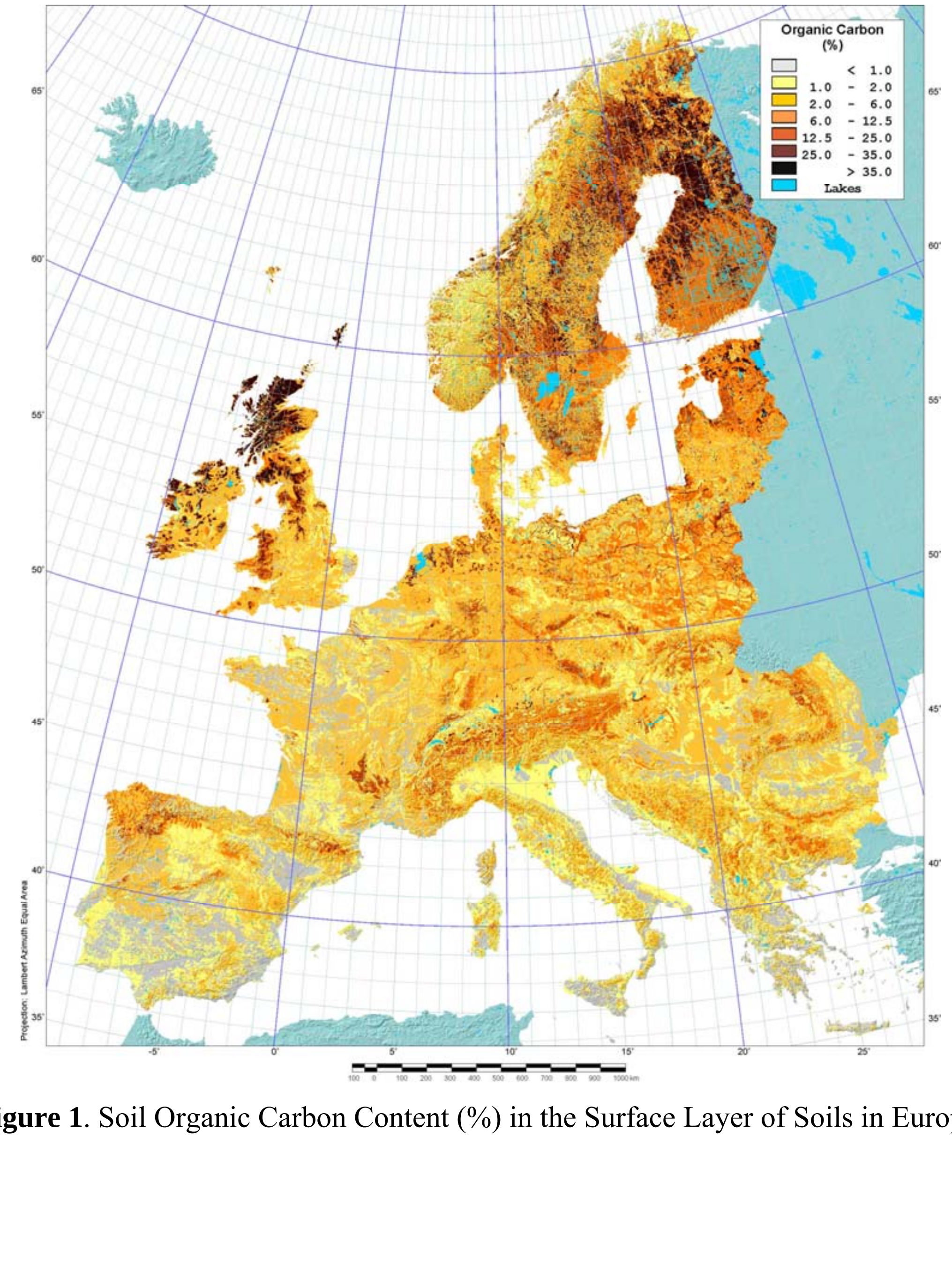

Figure 1. Soil Organic Carbon Content (%) in the Surface Layer of Soils in Europe.

A quantitative validation of the data layer was performed by comparing the estimates with measured data from soil surveys. The ground data available for this validation exercise originate from surveys conducted in the UK (England and Wales) and Italy. Data from England and Wales originate from the National Soil Inventory (NSI) made during the period 1979-1983 (McGrath and Loveland, 1992). The sampling was conducted on a regular grid of 5km spacing irrespective of land cover, with the exception of some urban areas. The measured data for Italy originate from a survey, which used a random or deliberate method for positioning sample sites and was restricted to agricultural land. The use of the data from Italy was further restricted by the integer format used to record the measurements.

For the validation, the estimates and the ground data were aggregated to NUTS Level 2 units. Due to the local variation of SOC and the grid size of the spatial layer a comparison of grid point-to-ground sample was found to be unsuited for the purpose. For the UK data a linear relation of: $OC\_TOP_{FIELD} = 1.01 * OC\_TOP_{MODEL} - 0.68$ was calculated for the aggregated units with a coefficient of determination greater than 0.9.

For Italy the field data do not permit calculating a meaningful and generally applicable coefficient of correlation between ground observations and modelled values, because the sample sites were restricted to agricultural areas. Yet, the data are very useful for verifying the temperature coefficient function for areas with low SOC in southern Europe.

4. Discussion and Conclusions

Previous studies on producing a spatial layer of SOC estimates for Europe were largely based on extrapolating measured values from ground surveys or on assigning what were considered values representative for a particular soil type to larger spatial units (Howard *et al.*, 1995; Smith *et al.*, 2000 and Arrouays *et al.*, 2001).

A quite different approach was taken in this study. It is based on refining the estimates of SOC for larger areas to more precise and geographically detailed estimates.

The method thus accounts for the strong local variation of soil organic carbon contents within pedologically defined soil units (Batjes, 1996, 1997). The study further improves upon the spatial resolution of the data layer to the most detailed (1km) and provides a unique pan-European coverage at this resolution.

With a large number of ground measurements available for the UK and Italy the estimates could be validated for two very different regions of SOC content in Europe. Still, these areas are not considered fully representative for all situations across Europe and measured data from other European areas under all land cover types are ultimately needed to validate the estimates. Further research into refining the temperature coefficient by soil type could improve the estimates of SOC content.

Acknowledgements

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Field soil sampling to detect the changes of organic carbon stock in mineral soil

V. Stolbovoy, L. Montanarella, N. Filippi, A. Jones and J.Gallego

1. Introduction

Soil Organic Carbon (SOC) is a measure of the total amount of organic carbon (C) in soil, independently of its origin or decomposition. Interest in SOC is common among soil scientists and related practitioners because of the importance for principle physical, chemical and biological soil ecological functions and because SOC is a universal indicator of soil quality. Consequently, as variations in SOC levels can have serious implications on many environmental processes such as soil fertility, erosion and greenhouse gas fluxes, the need to estimate SOC changes has become central to several pan-European and global environmental policies.

At a European level, SOC is considered in many policies and strategies of the European Union (EU). The Sixth Environment Action Programme[1] required the European Commission to prepare a Thematic Strategies on Soil Protection. The resulting Communication (COM(2006) 231[1], adopted by the European Commission on 22/09/2006) sets out the overall objectives through a proposal for a Framework Directive (COM(2006) 232[1]) that establishes common principles for protecting soil functions against a range of threats. One of the key goals of the Strategy is to maintain and improve SOC levels. The Directive is supported by an Impact Assessment (SEC (2006) 1165[1] and SEC(2006) 620[1]) that contains an analysis of the economic, social and environmental consequences of the different options for soil protection. The assessment reveals that the cost of not taking any additional action to improve the management of SOC stocks (i.e. maintaining the *status quo*) were significantly higher than the costs of measures to protect soil.

At the international level, all the various Conventions arising from the 1992 United Nations Conference on Environment and Development in Rio (e.g. Climate Change, Biodiversity and to Combat Desertification) have the issue of SOC levels at their core.

[1] documents are available at http://ec.europa.eu/environment/soil/index.htm

The Kyoto Protocol (UNFCCC, 1998), in particular, allows the use of biospheric carbon sinks and sources originating from human-induced activities to meet the Countries' commitments of greenhouse gas emissions reduction. These activities, listed in Article 3.3 (afforestation, reforestation and deforestation since 1990) and Article 3.4 (forest management, cropland management, grazing land management, re-vegetation) of the Kyoto Protocol, are collectively named "Land Use, Land-Use Change and Forestry" (LULUCF) activities[2]. The soil is among the mandatory carbon pools to be reported for these activities under the Kyoto Protocol[3] and it is certainly one with the highest potential, both in terms of enhancement of C sink and reduced C emission[4]. The procedures for estimating changes in SOC under the Kyoto Protocol are described by the International Panel on Climate Change report 'Good Practice Guidance for LULUCF' (IPCC, 2003). However, as this document mainly addresses general principles – with a focus on the approaches to be applied at the Country scale depending on the level of methodological complexity ("Tier") -, a more specific protocol for estimating SOC changes even at the plot level (e.g., agricultural field, pasture or forest stand) would be very useful.

In order to meet this challenge, a new method referred to as the "Area-Frame Randomized Soil Sampling" (AFRSS) has been developed by the European Commission's Directorate General Joint Research Centre (JRC) in Italy (Stolbovoy et al., 2007; Stolbovoy et al., 2005a). Although this methodology mainly addresses the need of a cost-effective estimation of SOC change arising from specific projects or regional/national policies aimed at increasing soil carbon, potentially it may be used also to support country-level reporting under the Kyoto Protocol, through the improvement of specific components of the IPCC's default methodologies (e.g., by estimating detailed stock change factors).

This paper discusses the AFRSS including: technical specification, data acquisition and accuracy control. It also provides working examples of the method application.

2. Standard norms

[2] While the reporting and accounting of Art. 3.3 activities is mandatory, each of the Art. 3.4 activity is eligible for accounting or not.
[3] Reporting SOC changes is mandatory except if "transparent and verifiable information is provided that this pool is not a source"

The Protocol follows the general requirements of the International Standard (ISO/FDIS 10381-1:2002(E)) (ISO, 2002a) and is particularly relevant to ISO 10381-4 (ISO, 2002b) which is devoted to "Sampling to support legal or regulatory action", covering the requirements to establish baseline conditions prior to an activity which might affect the composition or quality of soil.

Sampling strategies included in the Protocol are consistent with the general principles of the IPCC Good Practice Guidance, which requests quality assurance and quality control data and information to be documented, archived and reported, quantification of uncertainties at the source or sink category level and for the inventory as a whole (IPCC, 2003, p.1.6).

Laboratory analysis are based on Italian guidelines and standards (e.g. *Ministero per le Politiche Agricole,* 1997; *Ministero per le Politiche Agricole*, 2000; IPLA, 2006).

3. Technical specification

3.1 Template description

At the core for the AFRSS method is a randomized sampling template that represents a grid of 100 cells that enables a 'modified' random sample collection with a distance threshold to be carried out. The numeration of the sampling cells is selected at random with particular care being placed to prevent a previously sampled cell being too close to subsequent ones, which can occur for pure random sampling plans. Sampling plans that avoid points too close to each other, give a lower variance than simple random sampling (Bellhouse, 1977); this happens in particular for systematic sampling (Bellhouse, 1988). The sampling scheme used in this approach behaves approximately like a systematic sampling plan in the sense that points too close to each other are avoided and is more flexible than systematic plans to adjust a small sample size in areas with an irregular shape.

[4] For a more detailed discussion on the agricultural and forestry activities having potential for C sink or for emissions reduction, see results of the European Climate Change Programme (ECCP) - Topic Group Agriculture and Forestry (http://ec.europa.eu/environment/climat/pdf/eccp/review_agriculture.pdf)

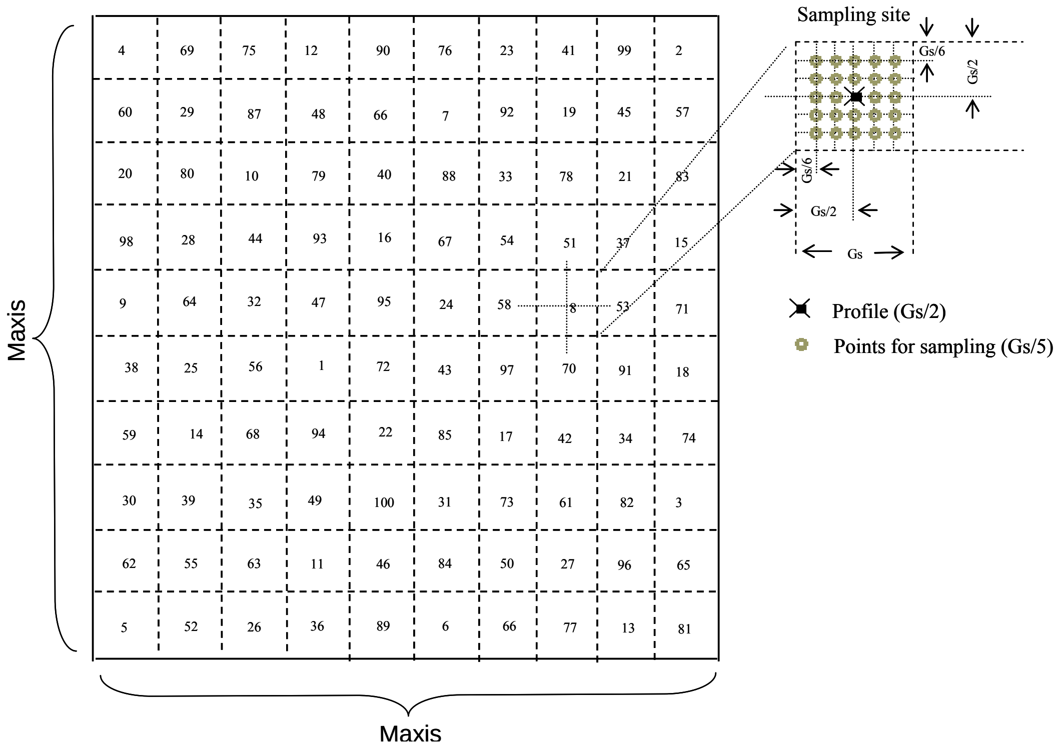

Figure 1. Area-frame randomized template and its parameterization (for explanation see text).

The spatial parameters of the template are flexible and adjusted to the size and geographical coordinates of the sampling plot (e.g. a field/pasture/forest). To define the dimension of the template, the longest X or Y axis (Maxis) of the plot should be found (Figure 1). The grid size (Gs) is calculated by dividing Maxis by 10. This grid is matched with the plot and is applied to position the sampling sites. The amount of the latter is defined by the plot area (Table 1). Each sampling site comprises a number of sampling points for collecting the composite soil samples and soil profile. Following ISO recommendations (ISO, 200a), the number of sampling points for the composite soil sample should be 25[(5)]. To define the distances between sampling points, Gs is divided into a 5 x 5 grid, which is Gs/6. The central sampling point within the grid is assumed to be the position of the soil profile and is found by dividing Gs by 2. Soil description, collection of undisturbed cylinder samples for bulk density[6], litter and coarse debris[7] should be taken in this point.

[5] There is a proposal from the field surveyors in Italy that the number of the sampling points for the composite soil sample can be reduced to nine. However, this suggestion currently lacks experimental data and cannot be taken at present.
[6] The undisturbed cylinder samples are not accurate enough for bulk density measurements and cannot be taken easily in the dry season. Most surveyors prefer using local pedo-functions which provide more reliable data. We

3.2 Adaptation of the template

For effective implementation of the randomised sampling template (Figure 1), the user has to:

- Represent the plot (field/pasture/forest) margins in X and Y coordinates of the standard local projection used for topographic or cadastral maps.
- Define the X and Y extents of the plot and take the longest axis (Maxis). Setup a square frame having Maxis size and match it with the plot. The coordinates of the corners of this square frame should be preferably integer values.
- Overlay the template with 100 grids numbered from 1 to 100, as represented in Figure 1.
- Determine the number (n) of sampling sites (grids) that is conditioned by the plot area and the need to minimise costs (Table 1).
- Select the first sampling site (grid) having the lowest number within the plot. If the next site (grid) falls outside the plot, the next sampling site (grid) must be selected until ‘n’ sites (grids) will be identified.

The amount of the sampling sites follows general rules for the field inspection densities, i. e. “one inspection per one square centimetre” of the intended scale of the map (e.g., Soil Survey Division Staff, 1993). By computation it can be found that one observation will cover:

- 0.25 ha at the scale of 1: 5000;
- ha at the scale 1:10000;
- 625 ha at the scale of 1:25000;
- 2500 ha at the scale of 1:50000.

Some national soil survey manuals (e.g., Gavrilyk, 1981) suggest the number of field observations being dependent on the soil heterogeneity and the scale of the survey (Figure 2). As can be seen from the figure, one observation of the territory with relatively homogeneous

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suggest relying on the experience of the local specialists to select either direct field cylinder sampling or make use of available pedo-functions to define soil bulk density.

[7] High stone content might be a constraint for the widespread application of the AFRSS method in the stony soil. This is especially relevant for mountainous regions with fragmented soil cover and abundant rock outcrops.

soils will cover more area then that of heterogenic soils. In addition, the area covered by one observation will be larger for the less detailed soil survey.

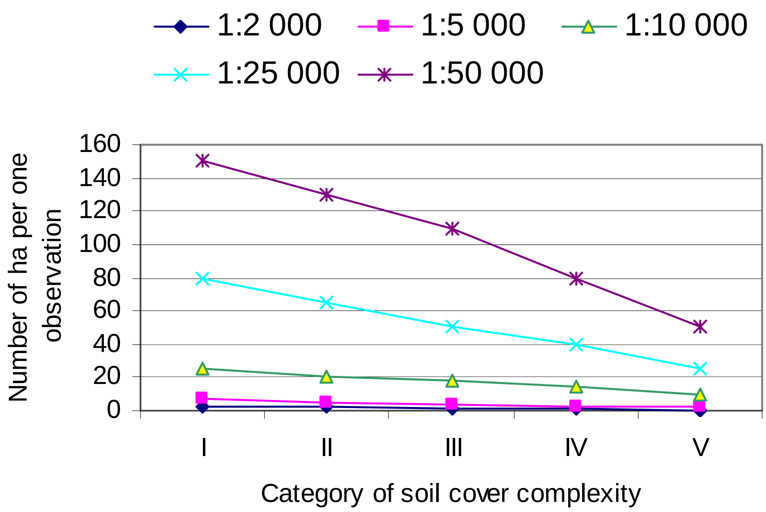

Figure 2. Area (in ha) per one soil observation depending on the category of soil complexity ranging from homogeneous (category I) to heterogeneous (category V).

For the scale 1:2000 the area per one observation is: 3.0, 2.0, 1.5, 1.0 and 0.5 ha for the categories from I to V respectively. For these categories at the scale of 1:5000, the area is: 7.0, 5.0, 4.0, 3.0, 2.0 ha (Sources: based on Gavrilyk, 1981).

Table 1 contains the suggested for the AFRSS number of the sampling sites for the field areas from less <5.0 ha to more than 25 ha. The minimum number of inspections enables determination of the average SOC stock and variances of variables for a specified soil parameter. Randomization avoids bias regardless of the structure of the spatial variation (de Gruijter, 1999).

Size of the plot	Number of sampling sites (n)
< 5 ha	3
5 - 10 ha	4
10-25 ha	5
> 25 ha	6

Table 1. Recommended number of sampling sites depending on the plot area.

3.3 Sampling location

Following the adaptation procedure, the geographical position of the plot (field/pasture/forest), together with the location of the sampling sites and soil profiles are presented in the local coordinate system. To keep a consistent register of each sampled field, pasture or forest plot at EU level, the geographical positions should be fixed in the European Coordinate Reference Systems (CRS identifier ERTS89, Ellipsoidal CRS) (Boucher and Altamini, 1992). The position should be recorded as precise as possible by means of Global Positioning Systems (GPS) to enable return visits to the sampling site. Data can be downloaded to a portable or office computer for registration and combination with other layers of information for spatial analysis.

3.4 Pedological details

A record of the sampled sites and points should be kept. In order to reduce temporal variations, sampling should be confined to periods with low biological activity, such as the winter or during the dry season. Any resampling should be carried out in the same period (season) as for the initial sample for all sites. The sampling dates should be reported.

For the determination of bulk density, an undisturbed sample with a minimum volume of 100 cm^3 cylinder should be taken from non-stony soil. For every sampling site, composite samples should be taken and analyzed in the laboratory. The composite soil samples from the sampling sites should be of equal weight, except for situations where the subsoil is shallow. In such cases (e.g. an indurate horizon within the depth range of the sampled layer), the weight of each sub sample is function of the thickness of the sampled layer. The minimum weight of each composite sample should be at least 500 g to provide sufficient material to perform all necessary analysis and for future storage.

3.4.1 Cropland

A soil profile under cropland can be schematized by two principal horizons: topsoil (the plough layer) and the underlying subsoil (Figure 3a).[8]

The plough horizon or layer indicates regular anthropogenic disturbance and physical mixing of soil material (e.g. application of organic and mineral fertilizers, addition of soil

[8] If no-till or no-plough land management practices are adopted, the soil profile will exhibit a gradual change of soil characteristics with depth. In this case, the soil sampling scheme should follow that of pasture land.

improvers, etc.). The plough horizon hosts the largest proportion of root biomass and incorporates surface crop residues that contribute to the change in SOC content. The plough horizon is seldom stratified due to regular tillage. As the thickness of the plough horizon differs according on cultivation practices, then the AFRSS methodology proposes to keep the sampling depth in accordance to the existent thickness of the plough layer. One sample should be taken from the middle of the plough horizon (e.g., at 10-20 cm depth if plough horizon is 30 cm thick as illustrated in Figure 3a). An undisturbed soil sample with the cylinder to determine the bulk density should be taken at the same depth.

3.4.2 Pasture

Soil under pasture is exposed to limited anthropogenic disturbances and a reduction in organic inputs because of biomass consumption through grazing. The soil profile under such land use displays a gradual change of soil characteristics with depth. For these soil types the IPCC Good Practice Guidance (IPCC, 2003) suggests detecting changes of SOC stock in the upper 30 cm topsoil. This sampling strategy is illustrated by Figure 3b.

The AFRSS methodology follows the IPCC rules and proposes a column soil sampling procedure at 10 cm intervals. However, to reduce costs, the column soil samples should be combined into a single composite sample for laboratory analysis. In a similar manner to the undisturbed cylinder samples for bulk density, the ‘disturbed’ samples, taken at three comparable sampling depths, should be combined into a composite sample.

3.4.3 Forests

General rules for soil sampling in the forests of Europe are specified by the ICP Manual (UNECE, 2003) and can be partly adapted, for measurements of SOC (e.g., sampling points should be 1 m distant from tree stems and should avoid animal holes and disturbances such as wind-thrown trees and trails). However, the ICP Manual centers on details (e.g. litter fractions) that are unnecessary for detection changes in total SOC stock.

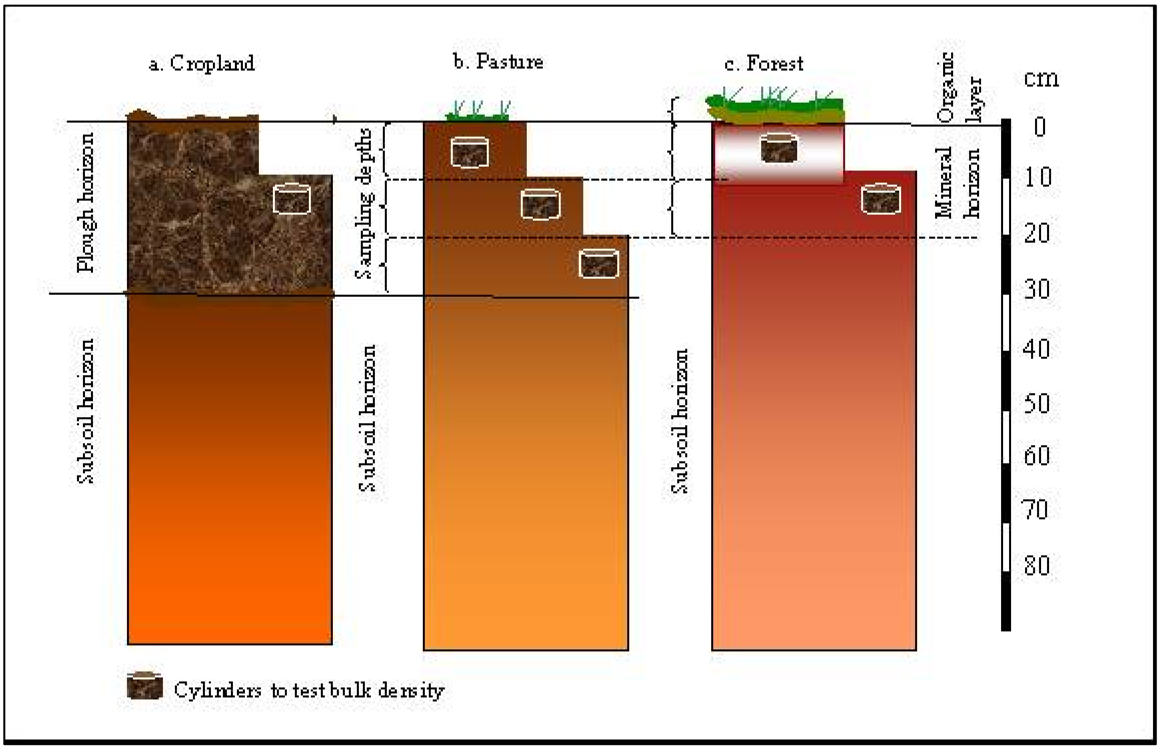

Figure 3. Principal structure and the scheme of soil profile sampling.

As illustrated by Figure 3c, when sampling soil in the forest, the organic (litter) topsoil is sampled as a whole and accompanied by an indication of the total thickness of the layer. A frame of 25 cm by 25 cm is recommended for collecting forest litter. In the field, the total fresh weight of the forest litter should be determined. A sub-sample is collected for the determination of moisture content (% weight) in the laboratory to calculate total dry weight (kg/m^2).

Mineral layers should be sampled at exactly the same locations (i.e. underneath the litter that has already been removed for sampling). Sampling should be done at fixed depths. The top of the mineral soil corresponds to the zero level for depth measurements. The entire thickness of the predetermined depth should be sampled and not only the central part of the layer. Auguring is preferred and pits are allowed, especially in case of stony soil where auguring is usually difficult and sometimes impossible.

To determine the bulk density of each mineral layer (0-10 and 10-20 cm) of non-stony mass a cylinder of undisturbed samples should be taken.

4. Algorithms

According to the Good Practice Guidance (IPCC, 2003), the SOC account should be measurable, transparent and verifiable. The AFRSS method follows this recommendation. Estimates of SOC changes derived from models are complimentary and valuable for defining the potential for carbon change in the soil.

It is important to emphasize that the goal of the AFRSS is the verification of the changes in SOC stock and its standard error. The SOC change is a relative term for which an absolute SOC value is insignificant. This makes the procedure of By applying spatial grids for the sampling, the method ensures a reproducibility and accuracy of the measurements for the geographically fixed sampling sites.

4.1 Computation

The computation of SOC stock is based on a few parameters that must be measured in the field, determined in laboratory or taken from other sources (e.g. cadastral information on the plot location and area). The list of parameters includes: the carbon content in soil, bulk density, the thickness of the soil layer, the content of coarse fragments and the area of the plot. The computation routine follows the steps outlined below:

Step 1: Soil organic carbon density (SCD) for sampling site

$$SCD_{site} = \sum_{layer=1}^{j} (SOC_{content} * BulkDensity * Depth * (1 - frag)) \quad (1)$$

Where:

$SOC_{content}$ is a SOC content, % of mass $\left(\frac{kgC}{kgSoil} X100 \right)$;

$BulkDensity$ is a soil bulk density, $\left(\frac{kgSoil}{dm^3} \right)$;

$Depth$ is a thickness of the sampled layer, dm;

$frag$ is volume of coarse fragments, % of mass or $\left(\frac{m^3 Stone}{m^3 Soil} \right)$.

The SCD_{site} provides an average value for the sampling site, which is derived from a composite sample (Figure 2).

Step 2: Mean (arithmetic average) soil carbon density ($\overline{SCD}$) for plot

$$\overline{SCD}_p = \frac{1}{n}\sum_{site=1}^{n} SCD_{site} \tag{2}$$

Where:

SCD_{site} is as indicated in Equation 1;

n is a number of sampled sites within the plot.

Step 3: Reference soil organic carbon ($SOC_{reference}$) stock for plot

$$SOC_{reference} = \overline{SCD}_p * A_p \tag{3}$$

Where:

$\overline{SCD}_p$ as indicated in Equation 2;

A_p is an area of the plot.

Step 4: Changes in organic carbon stock[9] (ΔSOC_{stock}) for plot

$$\Delta SOC_{stock} = SOC_{new} - SOC_{refstock} - f_{org} - f_{\lim} \tag{4}$$

Where:

$SOC_{refstock}$ is as indicated in Equation 3;

SOC_{new} is a new (determined during subsequent field campaign) SOC stock;

f_{org} is C with organic fertilizers (if applied);

f_{lim} is C with lime (if applied).

[9] This equation describes the changes of SOC due to sequestration from the atmosphere.

4.2 Uncertainty

The IPCC Good Practice Guidance (IPCC, 2003) defines uncertainty as a parameter associated with the result of measurement that characterizes the dispersion of the values that could be reasonably attributed to the measured quantity. The uncertainty of the changes in SOC stock for the plot can be characterized by the standard error of the changes as computed by the following steps:

Step 5: Standard error of mean soil carbon density ($s(\Delta S\overline{C}D_p)$) for plot

$$s(\Delta S\overline{C}D_p) = \sqrt{\frac{1}{n(n-1)}\sum_{site=1}^{n}\left(\Delta SOC_{site} - \Delta S\overline{O}C_p\right)^2} \tag{5}$$

Where:

$\Delta SOC_{site} = SCD_{new} - SCD_{reference}$ is a change in SOC stock for the sampling site;

$\Delta S\overline{O}C_p$ is the average of ΔSOC_{site} for the plot;

n is the number of sampling sites within the plot.

Step 6: Standard error of organic carbon stock ($s(\Delta SOC_{stock})$) for plot

$$s(\Delta SOC_{stock}) = s(\Delta S\overline{C}D_p) * A_p \tag{6}$$

Where:

$s(\Delta S\overline{C}D_p)$ is as indicated in Equation 5;

A_p is the area of the plot.

Step 7: Result

$$\Delta SOC_{stock} \pm s(\Delta SOC_{stock}),\ \text{where} \tag{7}$$

ΔSOC_{stock} is the weight of the SOC stock change and $s(\Delta SOC_{stock})$ is the standard error of the latter. Expressing the inaccuracy of the result in terms of standard error does not require normality assumptions but does not give a specific level of confidence.

5. Work examples

To bring any new method into practice requires considerable validation efforts. It is essential to adopt the method into a practical tool for field surveyors, set up boundary conditions and evaluate the economic cost. In order to validate the AFRSS methodology, a number of test sites were selected in different soil conditions across the EU (see http://eusoils.jrc.ec.europa.eu). This document presents the results of the validation exercise carried out in the Piemonte Region of Northern Italy (Stolbovoy et al., 2006).

The main objective of this section is to provide work examples for the AFRSS method implementation including:

- Sampling parameterization;
- Computation;
- Economic effectiveness.

5.1 Sampling parameterization

5.1.1 Cropland

The geographic coordinates of the cropland plot are given in Table 2. The Xmax value is 2175 and Xmin is 1899. By computation (Xmax - Xmin) the difference is 276.0m. Applying the same operation to the Y coordinates, the difference (Ymax – Ymin) is 209.0 m. The longest axis value (Maxis) is 276 m which defines the size of the template square (Figure 1). Based on this Maxis value, the Gs value is 276/10 = 27.6 m. Consequently, the distance between sampling points (Gs/6) is 4.6 m. The poison of the soil profile (Gs/2) is 13.8 m in the grid.

Based on the cropland plot area, the number ‘n’ of sampling sites can be defined (Table 1). As the area of cropland plot is less than 5 ha, the number of sampling sites should be 3. Following the procedure described in the methodology section, the 1st, 8th and 22nd grids have been selected (Figure 4).

Plot coordinates	X (meters)	Y (meters)
North	2175,000	828,000
South	1978,107	749,007
West	1899,000	852,000
East	2098,094	958,052

Table 2. Geographical coordinates of the cropland plot (values in bold indicate coordinates of the plot – see Fig 4).

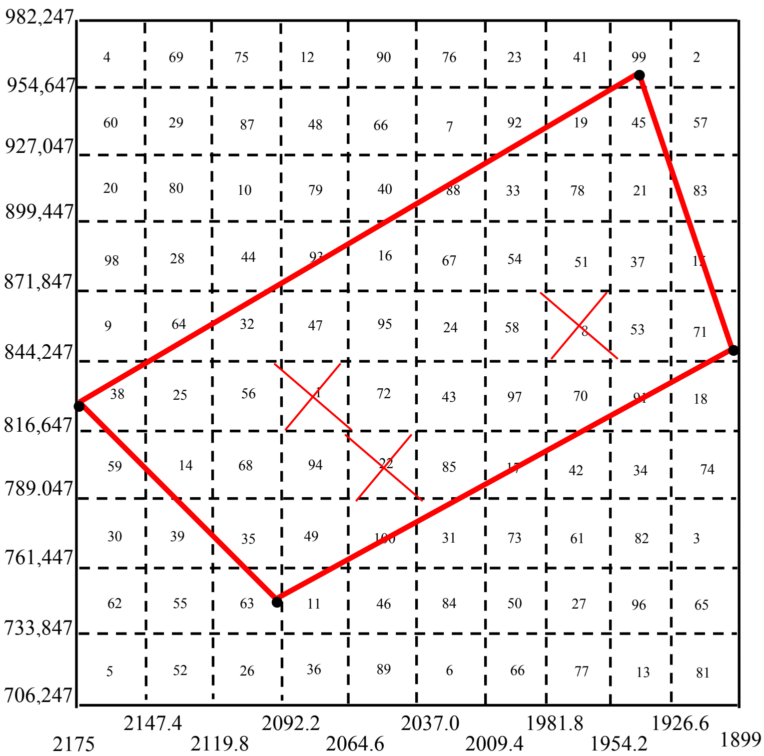

Figure 4. Adaptation of the template to the cropland plot and soil profiles positioning (red crosses).

5.1.2 Pasture

The geographic coordinates of the pasture plot are given in Table 3. The Xmax value = 376255 and Xmin = 375917. By computation (Xmax - Xmin), the difference is 338 m. Applying the same calculation to the Y coordinates, the difference (Ymax – Ymin) is found to be 343 m and as the longest value corresponds to the Maxis, which defines the dimensions of the template square (Figure 1). Based on the Maxis value, the Gs value is 343/10=34.3 m. Consequently, the distance between sampling points (Gs/6) is 5.7 m. The position of the soil profile (Gs/2) is 17.1 m in the grid.

Axis Coordinate	X (meters)	Y (meters)
North	6026	669
South	6162	326
West	5917	521
East	6255	513

Table 3. Geographical coordinates of the pasture plot (values in bold indicate coordinates of the plot – see Fig 4).

The procedure to identify the number (n) of sampling sites was already described in the cropland section. The same operation in this case results in three sampling sites and the respective positioning of the soils profiles are given in Figure 5.

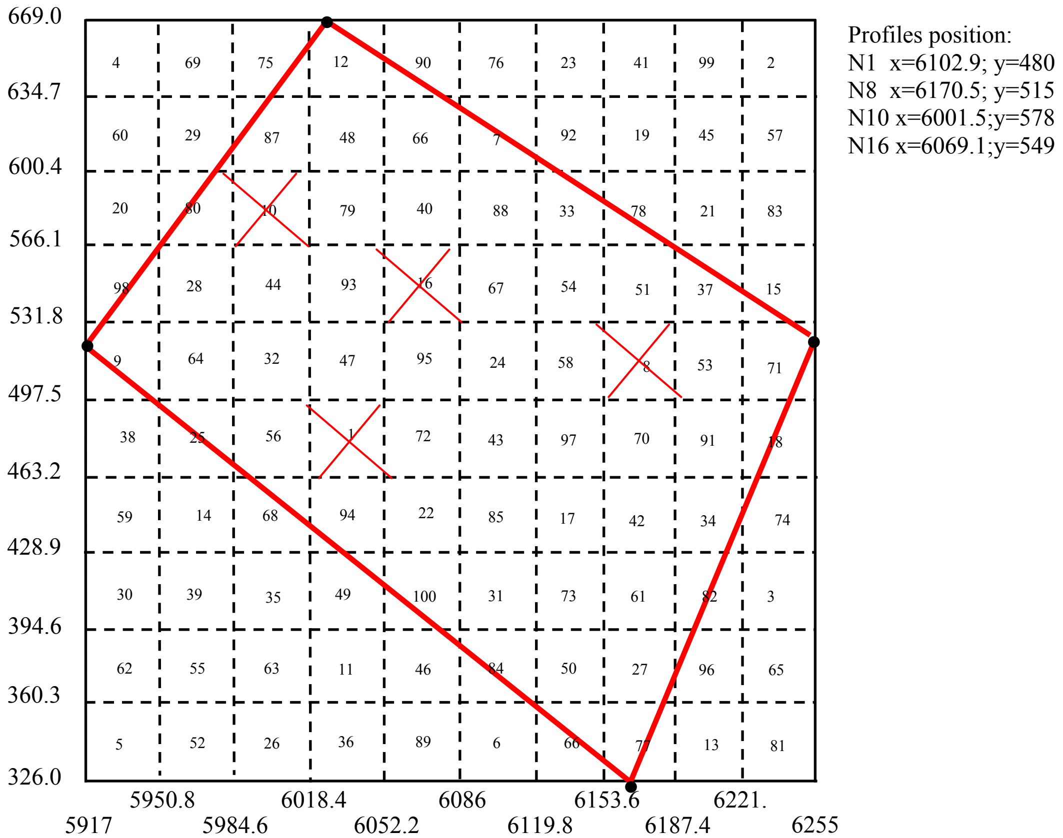

Figure 5. Adaptation of the template to the pasture plot and soil profiles positioning (red crosses).

5.1.3 Forest

The geographic coordinates of the forest plot are given in Table 4. The Xmax value = 929 and Xmin = 514. By computation (Xmax - Xmin), the difference is 415 m. Applying the same operation to the Y coordinates, the difference (Ymax – Ymin) is found to be 131 m. The longest value (Maxis) is 415 m and is used to define the dimensions of the template square (Figure 1). Based on the Maxis, the Gs value is 415/10 = 41.5 m. The distance between sampling points (Gs/6) is 6.9 m. The poison of the soil profile (Gs/2) is 20.7 m in the grid.

By calculation, the number of the sampling sites is 3 and their position and geographical coordinates are given in Figure 6.

Axis Coordinate	**x**	**y**
North	514	737
South	929	733
West	917	606
East	597	678

Table 4. Geographical coordinates of the forest plot (values in bold indicate coordinates of the plot – see Figure 6).

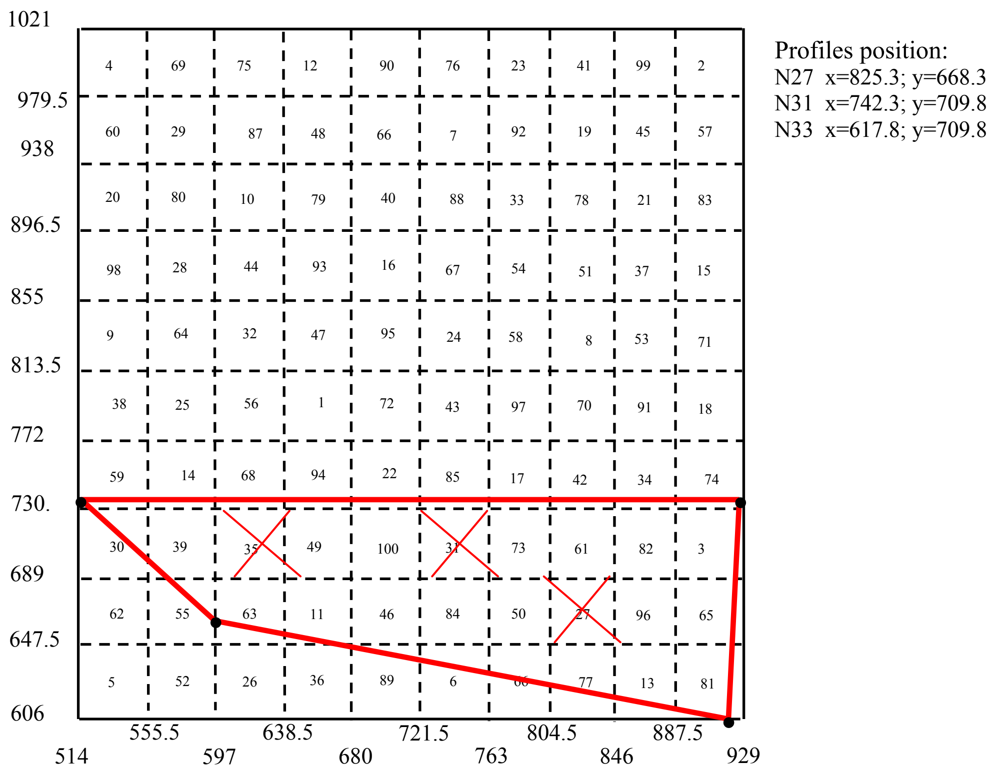

Figure 6. Adaptation of the template to the forest plot and soil profiles positioning (red crosses).

5.2 Computation

Reference soil organic carbon stock (SOC_{stock})

The reference SOC stock is the initial (baseline) amount of the total SOC of the field, pasture or forest plot. The computation follows three steps described in the algorithms section. A summary of the soil characteristics is given in Table 5.

Profile, N	Depth, cm	C, %	Bulk density, g/cm3	Soil carbon density, kgC/m3	Carbon content for profile, tC/ha	Soil carbon stock, tC (area 4 ha)	Average soil carbon stock, tC (area 4 ha)	Difference in average carbon stocks between samplings, %
Cropland *Skeletic Cambisol*, first sampling								
C1S	0-25	2.43	1.29	7.86	n.a.*	314.4		
C22S		2.16	1.43	7.72	n.a.	308.8	301.1	
C8S		2.04	1.37	7.00	n.a	280.0		
Cropland *Skeletic Cambisol*, second sampling								3
C1Ss	0-25	1.99	1.52	7.60	n.a.	304.0		
C22Ss		2.00	1.40	7.00	n.a.	280.0	292.0	
C8Ss		1.55	1.25	4.85	n.d.**	n.d.		
Pasture *Dystric Leptosol*, first sampling								
P8S	0-10	7.38	1.07	7.90	181.0	723.8		
	10-20	8.36	1.22	10.20				
P1OS	0-10	8.00	0.43	3.44	111.1	444.5	516.2	
	10-20	5.60	1.37	7.67				
PIS	0-10	6.97	0.77	5.37	95.1	380.3		
	10-20	5.75	0.72	4.14				
Pasture *Dystric Leptosol, s*econd sampling								3
P8Ss	0-10	6.73	0.91	6.1	163.2	652.9		
	10-20	8.36	1.22	10.2				
P1Oss	0-10	7.60	0.68	5.2	128.4	513.6	532.7	
	10-20	5.60	1.37	7.7				
PISs	0-10	6.71	0.83	5.6	107.9	431.5		
	10-20	6.14	0.85	5.2				

*n.a. = not applicable; **n.d. = not defined

Table 5. Basic soil characteristics and reproducibility of the results of the carbon detection for cropland and pasture in Piemonte region.

Soil organic carbon density (SCD) for sampling site

The calculation of the SCD follows eq. 1 (hereafter the numeration of equations follows the section that described the algorithms). The SCD refers to carbon concentration in $\left(\frac{kgC}{m^2}\right)$ or $\left(\frac{tC}{ha}\right)$ related to a layer of soil (e.g., 0-0.3 m, 0-0.5 m, 0-1.0 m, 0-2.0 m). The SCD should not be confused with the carbon (C) content of soil. The latter is a relative fraction of C by weight of soil expressed in percentage $\left(\frac{kgC}{kgSoil}X100\right)$. This value does not show an absolute C mass in soils and is inconvenient to use for soil comparisons. The mass of C dependence on the soil bulk density (e.g., soil with a low percent of C and high value of bulk density may contain more mass of C than soil with a high content in C and low value of bulk density).

The example for the calculation of the SCD is given for the *Skeletic Cambisol* cropland (site C1S, Table 5) in the Piemonte region. The soil has the following measured parameters:

$SOC_{content}$ is 2.43 %;
BulkDensity is 1.29 kg/dm^3;
Depth of ploughed layer is 2.5 dm (0-25 cm);
frag is none.

Introduction of these parameters into eq. 1 gives:

SCD = 2.5 (dm) X 2.43 (kgC/kgSoilX100) X 1.29 (kgSoil/dm^3)X 100 = 7.86 kgC/m^2,

where units are given in brackets and, 100 is to converted dm^2 into m^2.

Mean (arithmetic average) soil organic carbon density ($S\overline{C}D_{plot}$) for plot

The calculation of the mean $S\overline{C}D_{plot}$ follows eq. 2. For the above-mentioned cropland *Skeletic Cambisol,* values of the SCD for the three identified sampling sites were defined as 7.86 kgC/m^2; 7.72 kgC/m^2 and 7.00 kgC/m^2 (Table 5).

The introduction of these values in to eq. 2 gives:

$$S\overline{C}D_{plot} = (7.86+7.72+7.00)/3 = 7.53 \text{ (kgC/m}^2\text{) or } 75.3 \text{ (tC/ha)}$$

Soil organic carbon stock (SOC_{stock}) for plot

Calculation of the SOC stock follows eq. 3. The SOC stock refers to the total amount of C captured by a certain layer of soil having a certain area. The SOC stock is named "reference" for the initial (first time) sampling. For the cropland *Skeletic Cambisol,* the ploughed layer is 0.25 m, which is accounted by the eq.2. The area of the tested cropland is 6.96 ha. The introduction of these values in to eq. 3 gives:

$$SOC_{reference} = 75.3 \text{ (tC/ha) X } 6.96 \text{ (ha)} \sim 524.1 \text{ (tC)}$$

Changes of soil organic carbon stock (ΔSOC)

To detect the changes of SOC stock time series observations are needed. These data is not available for the study. Nevertheless, an opportunity was exploited to simulate the SOC stock change on the results obtained from the forest test site. The planting scheme in the forest follows rows in which the rows with trees are covered by a dark plastic sheet isolating soil from litter. The rows without trees are lacking plastic sheet and open to littefall. This makes the input of organic residuals in soils different and causes a difference in the SOC content between the covered (with trees) and bare rows. The sampling template was designed in such a way that the first set of samples was collected from the rows with trees and the second set of samples from bare soil. The two sets are examined to define the difference between SOC stocks in the forest plot, which is interpreted as a SOC stock change. In order to simplify the calculations the area of the forest plot is taken as 4 ha.

<table>
<tr><th>ID</th><th>Soil carbon density by sites, tC/ha</th><th>Mean soil carbon density for forest, tC/ha</th><th>Soil carbon stocks (4ha forest plot), tC</th><th>Difference (changes) in soil carbon stocks, tC</th></tr>
<tr><td colspan="4">Rows with trees covered by plastic sheet</td><td rowspan="9">108.4</td></tr>
<tr><td>F27S</td><td>50.68</td><td></td><td rowspan="3">181.2</td></tr>
<tr><td>F31S</td><td>47.51</td><td>45.3</td></tr>
<tr><td>F35S</td><td>37.75</td><td></td></tr>
<tr><td colspan="4">Rows with bare soil open to litterfall</td></tr>
<tr><td>F27Ss</td><td>74.1</td><td></td><td rowspan="3">289.6</td></tr>
<tr><td>F31Ss</td><td>70.2</td><td>72.4</td></tr>
<tr><td>F35Ss</td><td>72.9</td><td></td></tr>
</table>

Table 6. Difference in soil organic carbon contents between rows with trees (covered by plastic sheet) and rows without trees open to litterfall in the forest plot.

Table 6 illustrates the calculation of the difference in the SOC stock following the eq. 4:

$$\Delta SOC_{forest} = \left|289.6 - 181.2\right| = 108.4 \text{ (tC)}$$

Standard error of the changes of soil organic carbon (SOC) stock

An example of the calculation of the standard error for the difference between SOC stocks in rows with trees and that with bare soils is given in Table 7.

First sampling	Second sampling	Difference (ΔSOC_{site})	Average of diffeences ($\Delta SOC_{site}/3$)	Standard error of the differences ($s(\Delta S\overline{C}D_{site})$)	Standard error of the Changes estimate for the forest plot (4ha) ($s(\Delta S\overline{C}D_{site}) \times 4$)
50.68	74.1	23.42			
47.51	70.2	22.69	27.01	4.03	~16.1
37.75	72.9	35.15			

Table 7. The standard error of the difference (changes) of the SOC stocks (tC ha).

The calculation of the error uses eq. 5 (in the uncertainty section). The values for the calculations are given in Table 7.

$$s(\Delta S\overline{C}D_{site}) = \sqrt{\frac{1}{3(2-1)}\sum_{site=1}^{3}((74.1-50.68)-27.1)^2 + ((70.2-47.51)-27.1)^2 + ((72.9-37.75)-27.1)^2} = 4.03$$

(tC)

Standard error of soil organic carbon stock changes ($s(\Delta SOC_{stock})$) for forest plot

The standard error of the difference for the forest plot follow eq. 6:

$$s(\Delta SOC_{stock}) = 4.03 \times 4 = 16.12 \approx 16.1 \text{ (tC)}$$

Result of the verification of soil organic carbon stock changes (ΔSOC_{stock}) for forest plot

The overall result will be in line with eq. 7:

$$\Delta SOC_{stock} = 108.4 \pm 16.1 \text{ tC}$$

5.3 Reproducibility

The reproducibility (RP) of the AFRSS method establishes the minimum detectible value of the $\Delta SOCstock$. The RP sums inaccuracies originate from soil heterogeneity and are caused by short distance variability of soil characteristics attributed to any soil plot. With some reservations the RP Mostly might be a measure of the plot specific sensitivity of the AFRSS method. The sensitivity is lower for the plots with the higher soil variability. In other words, the RP of the AFRSS method with highly deviated soil characteristics is small. An example of the RP test is illustrated by a parallel soil samplings of the same plot (e.g. if two GPS devices are used to establish position of the sampling sites).

Technically, the RP can be defined as follows: 1) the sampling at the sampling campaign is described above; 2) the parallel soil sampling can be done in repositioned sampling sites established with another GPS device. The difference in sites positioning will be within few meters depending on the GPS quality, satellite location, etc. If the second GPS device is unavailable the repositioning of the sampling sites can be done arbitrarily. The procedure of the parallel soil sampling is similar to that of the initial one. Additional computational steps would be:

Step: Difference (absolute) in averages of soil organic carbon stock (ΔSOC_{plot}) between initial (stok1) and parallel (stok2) samplings for a plot

$$\Delta SOC_{plot} = \left| S\overline{O}C_{stock1} - S\overline{O}C_{stock2} \right| \tag{8}$$

where

$S\overline{O}C_{stock1}$ and $S\overline{O}C_{stock2}$ are average SOC stocks for the initial and parallel sampling campaigns within a given plot.

Step: Reproducibility (RP_{plot}) of sampling result for plot

3.4.4

$$RP_{plot} = \frac{\Delta SOC_{plot}}{S\overline{O}C_{stock1}} \times 100 \tag{9}$$

where

RP_{plot} is given in percent.

5.4 Computation of reproducibility

The test of the RP is based on the parameters defined for cropland and pasture (Table 5). From Table 5, these parameters cover all measurements essential to calculate the SOC stock in cropland and pasture soils. The SOC stock varies in the range from 280 tC (C22Ss site) to 314 tC (C1S site) in cropland *Gleyic Luvisol*s and from 380 tC (PIS site) to 724 tC (P8S site) in the pasture *Dystric Leptosol* Based on these data, the RP is computed using eq. 8:

$$RP_{cropland} = \frac{(301.1 - 292.0)}{301.1} \times 100 \approx 3\,\%$$

while the calculation for the pasture gives:

$$RP_{pasture} = \frac{(532.7 - 516.2)}{516.2} \times 100 \approx 3\,\%$$

The comparison of the RP between cropland and pasture shows that in spite of the considerable variation in SOC contents in soils of cropland (9%) and pasture (15%) (Table 8), the AFRSS method provides a RP value at practical level (within 3%) illustrating applicability of the method to wide range of soil conditions.

Land use	Number sites	Average C, %	Coefficient of variation, %
Cropland	5	2.13	9
Pasture	12	6.71	15
Forest	12	1.55	23

Table 8. Average soil organic carbon content and its variation in the tested plots.

6. Economic effectiveness

6.1 Number of samples

The cost of the sampling to assess SOC consists of different components which include the number of samples collected and the laboratory price to determine the SOC content. In this study, cost comparisons for the conventional IPCC (IPCC, 2003) and the AFRSS sampling approaches are made. The IPCC procedure recommends that nine soil points are tested for each plot, each containing three sampled depths (0-10 cm, 10-20 cm and 20-30 cm). These samples are required to study the spatial variability of the soil parameters for the initial sampling. On the basis of these data, the number of the soil samples needed for a second sampling is estimated. IPCC propose to detect the changes in the SOC stock with a confidence level of 95%.

The CV of SOC content in the soil of the cropland, pasture and forest are 9%, 15% and 23% respectively (Table 8). If the value $CV(SOC) = 0.09$ (i.e. 9% SOC stock) is taken, as an example, then the standard error of the measured average SOC is $s\left(S\overline{O}C\right) = 0.09 \times SOC$. The values for pasture and forest plots will be: $s\left(S\overline{O}C\right) = 0.15 \times SOC$ and $s\left(S\overline{O}C\right) = 0.23 \times SOC$ respectively.

Thus, to calculate the required number of samples needed to estimate the SOC with a confidence semi-interval of 1.5 tC/ha (suggested average annual C accumulation in agricultural soil in Europe, corresponding to approximately 2% of the average SOC) and with a 95% confidence level, the coefficient of variation of the estimate is required to be:

$$CV\left(S\overline{O}C\right) = \frac{s\left(S\overline{O}C\right)}{S\overline{O}C} = \frac{0.02}{t_{95}} \quad \Rightarrow \quad s\left(S\overline{O}C\right) = \frac{0.02 \times S\overline{O}C}{t_{95}},$$

where $t_{95} = 1.96$ (as taken from Student's t Table) if the sample size is large enough but can be above 2 for a moderate sample size, especially if the distribution of SOC is not Gaussian. For a lower confidence level $t_{65} \approx 1$ or $t_{90} \approx 1.7$ if the distribution of SOC is assumed to be normal.

In a simple random sampling, the standard deviation of the SOC estimate is:

$$s\left(S\overline{O}C\right) = \frac{s(SOC)}{\sqrt{n}}$$

Therefore, the required sample size to achieve certain accuracy with a given confidence level with simple random sampling in the cropland is:

$$n = \left(\frac{CV(SOC) \times SOC}{s(S\overline{O}C)} \right)^2 = \left(\frac{CV(SOC) \times SOC \times t_{95}}{0.02 \times S\overline{O}C} \right)^2 \approx \left(\frac{CV(SOC) \times t_{95}}{0.02} \right)^2 \approx \left(\frac{0.09 \times 2}{0.02} \right)^2 = 81$$

Figure 7 illustrates the considerations in general form for the average soil conditions of Europe. For example, the range of SOC density varies from 50 to 100 tC/ha and average change of carbon in soil is 1.5 tC/ha. The figure shows that in order to meet the IPCC requirements the amount of the samples is rather large even for relatively homogeneous soil (e.g. CV for cropland soil is 9%). This amount should be further increased by a factor of 3 because of the recommendation by IPCC 3 layers sampling of the 30 cm topsoil. This multiplication results in 243 samples in total for cropland, 675 samples for pasture and 1587 samples for forest (Table 9).

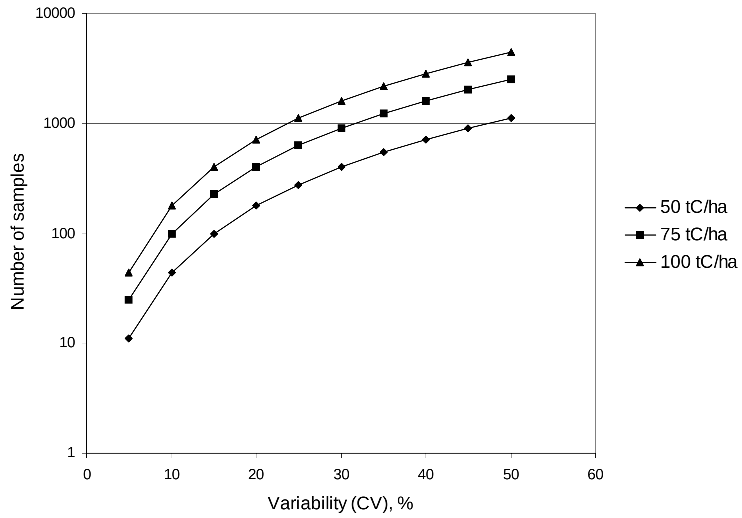

Figure 7: Number of samples for simple random sampling depending on the SOC variability and the average SOC (minimum detectable changes of 1.5 tC/ha, 95% confidence).

6.2 Carbon detection costs

Multiplying the number of samples by the cost of the analysis of one sample calculates the total cost of the laboratory treatment. For example, the price to determine C in commercial laboratories in Europe varies from €6 to €16, where the lowest price (€6) is taken from CARBOEUROPE project (see www.carboeurope.org) and highest price (€16) is indicated by EU BIOSOIL project (see http://inforest.jrc.it/activities/ForestFocus/biosoil.html). Following these laboratory prices, the cost of a single sampling campaign for a 4 ha agricultural field ranges from 18€ to 48€. Setting an average annual C sequestration rate of 1.5 tC for agricultural soil in the EU, the total C accumulation in the test plot would be 6 tC, which gives a cost for C detection of 3-8€ per 1 tC for cropland and pasture and of 6-16€ per 1 tC for forest. In tCO_2_eqv units the costs will be 0.82 - 2.18€ for cropland and pasture and 1.64 - 4.40€ for forest. This amount will not change for the second time observation and can be less if the laboratory price is decreased due to technological improvements. It is important to notice, that for the longer accumulation period and the larger fields the cost for C detection will be considerably less making the AFRSS method economically efficient.

In comparison, the cost of the analysis for a single sampling campaign based on the IPCC recommendations is different. The initial number of he sampling population is 27, which corresponds to 9 sampling sites containing 3 sampling depths each. The laboratory expenses would be 162€ and 432€ that are costs of C detection in the range of 27-72€ per 1 tC. This reference SOC detection is based on the assumption that the rate of the C accumulation is 6 tC. The verification cost for the second time observation will be substantially larger due to increase of the number of soil samples to meet a required by IPCC confidence level (P=0.95). The number of the soil samples (Table 9) is derived from Figure 7. The costs of C detection for the second time observation would be 241-643€ per 1 tC for cropland, 675-1800€ for pasture and 1587-4332€ per 1 tC for forest (Table 9). Clearly, these high costs make the routine verification of C changes in soil impractical with the risk that the role of soil in carbon management issues will not be considered by policy and decision makers.

Land cover	Coefficient of variation of carbon content, %	Conventional (IPCC, 2003)				Area-Frame Randomized Soil Sampling		
		Reference sampling		Second time sampling				
		Number of samples	Cost per 1 tC	Number of samples	Cost per 1 tC	Coefficient of variation of carbon content, %	Number of samples (reference and second time)	Cost per 1 tC
Cropland	9	27	27-72	241	241-643	n.a.*	3	3-8
Pasture	15	27	27-72	675	675-1800	n.a	3	3-8
Forest	23	27	27-72	1587	1587-4232	n.a.	6	6-16

*n.a. = not applicable

Table 9. The laboratory costs of carbon detection. Conditions: the average carbon change is 6 tC for the 4 ha plot; the laboratory price of the carbon determination is in the range of 6-16€ per 1 sample.

6.2 Plot area and carbon detection cost

Figure 8 provides a tentative laboratory cost of carbon detection for a single sampling campaign depending on the area of the plot. As can be seen from the figure, the cost is less for the larger size of the sampling plot (e.g., the cost to detect 1 tC in a field of 1 ha is nearly €35). This cost would be about €0.13 for the cropland plot of 50 ha. This cost corresponds to the one year accumulation period. For the longer duration of C accumulation the cost will be less.

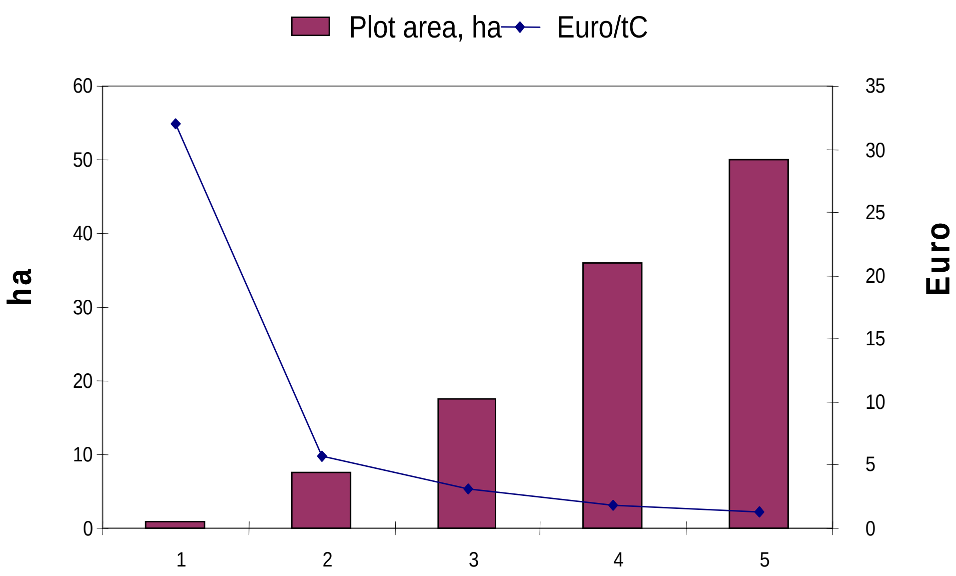

Figure 8. Dependence of the laboratory cost for carbon detection on the plot area.

Conditions: average carbon sink in agricultural soils is 1.5 tC/ha; the laboratory cost of carbon detection is 16 Euro.

7. Conclusions

A new AFRSS method for the detection of the changes of organic carbon stock has been introduced. The method exploits area-randomized template with a distance threshold to define sampling sites and composite soil sampling. The number of the sampling sites allows to define an average SOC stock and its standard error. Instrumental record of the site position makes soil resampling during the follow up observations easy. The AFRSS is fully transparent. It allows computer programming of the sampling strategy and is technologically sound.

Field test has shown that the AFRSS method is economically efficient and can be easy adapted by a practical soil survey.

Further development will be testing of the AFRSS in different sloil conditions to define boundary conditions of the method implementation.

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Annex. Description and laboratory data on soil

Cropland plot

Geographic distribution and pedolandscape

The soil type is characteristic on parts of almost flat alluvial cones, formed by coarse gravelly and sandy deposits, with a deep groundwater such as its effects on the soil hydrology are not evident. The parent material is not calcareous but rich in greenstones. The soil use is mainly agricultural with prevalence of rotated cultivations and grasslands.

Soil series: FOGLIZZO coarse-loamy over sandy-skeletal, gravelly.

Soil properties: soil is characterised by a loamy or silty-loam texture and by a low macroporosity due to iron oxides (mottling and concretions). Consequently drainage is moderate as well as oxygen availability.

Main feature is the root restricting depth at 45-50 cm, due to highly gravelly layers. Oxigen availability is good, drainage is moderately high and saturated hydraulic conductivity moderately high, as they are influenced by coarse texture and gravels

Profile: brown topsoil, sandy-loam, 15% gravel, acid or subacid pH; yellowish brown subsoil with some reddish shade, sandy-loam with gravel over 35%, subacid pH. The substratum is constituted by gravels and sands. Ca/Mg ratio is lower due to greenstones and reduces soil chemical fertility.

Profile code: LIQU0050
Profile location: Malanghero (S.Maurizio – province of Turin)

Profile classification:

Soil Taxonomy: Dystric Eutrudept, coarse-loamy over sandy-skeletal, mixed, nonacid, mesic
WRB: Skeletic Cambisol

Slope: 0°
Exposition: no.
Elevation: 230 m s.l.m.
Soil use: rotated wheat
Lithology: serpentine
Morphology: alluvial plain

Photo: the soil profile LIQU0050, characterised by sandy-loam texture
with evident presence of pebbles from alluvial gravel deposits of Stura river

Photo: the plot site from a satellite image

Layer Ap: 0 - 25 cm; dark brown (10YR 3/3); sandy-loam; 25 % gravels, of rounded shape, with average diameter 30 mm and maximum diameter 150 mm, slightly altered; structure fine granular of moderate degree; roots 20/dmq, with average dimensions 3 mm; non calcareous.

Layer A2: 25 - 45 cm; dark yellowish brown (10YR 3/4); sandy-loam; 35 % gravels, of subrounded shape, with average diameter 40 mm and maximum diameter 150 mm, slightly altered; structure subangular medium poliedric of moderate degree; roots 5/dmq, with medium dimensions 2 mm; non calcareous.

Layer Bw: 45 - 65 cm; dark yellowish brown (10YR 3/4); sandy-loam; 70 % gravels, of subrounded shape, with average diameter 60 mm and maximum diameter 200 mm, slightly altered; structure incoherent; roots 2/dmq, with average dimensions 2 mm, non-calcareous.

Layer C1: 65 - 90 cm; dark yellowish brown (10YR 3/6 and 10YR 3/5); loamy-sand; 70 % subrounded gravels, with average diameter 100 mm and maximum 300 mm, altered; structure: incoherent; non calcareous.

Layer C2: 90 - 120 cm; brown (10YR 5/3); secondary colour yellowish brown (10YR 5/6); mottles very dark gray (10YR 3/1); loamy-sand; 90 % subrounded gravels, with average diameter 150 mm and maximum 350 mm; structure incoherent; non calcareous.

Physical-chemical analyses of the *Skeletic Cambisol* (cropland soil profile)

	Ap	A2	Bw	C1
Upper boundary cm	10	30	45	65
Lower boundary cm	20	40	55	80
pH in H2O	5,5	5,4	6,1	6,4
Coarse sand %	20,6	24,3	35,6	75,5
Fine sand %	32,6	32,9	34,3	14,2
Very fine sand %	-	-	-	-
Coarse silt %	18,9	15,1	13,0	3,9
Fine silt %	23,9	24,0	14,4	5,3
Clay %	4,0	3,7	2,7	1,1
CaCO3 %	0,0	0,0	0,0	0,0
Organic carbon %	2,69	2,34	1,45	1,03
N %	0,259	0,252	0,129	0,101
C/N	10,0	9,0	11,0	10,0
Organic matter %	0,00	0,00	0,00	1,77
C.S.C. meq/100g	18,20	18,40	6,90	15,30
Ca meq/100g	4,75	4,12	2,98	1,30
Mg meq/100g	3,08	2,83	2,58	2,29
K meq/100g	0,36	0,27	0,16	0,09
Na meq/100g	0,18	0,15	0,20	0,15
P available ppm	51,0	39,0	23,0	25,0
Basic saturation %	-	-	-	-

Pasture plot

Geographic distribution and pedolandscape

The heading of the Tesso valley, where this site is located, is a good example of slope and ridge morphologies over glacial morphologies which are completely stabilised at low altitude. Around the glacial circle, occupied by Monastero lake, is therefore possible to recognise sloping and ridge morphologies, moraine accumulations, bucked backs and nival valleys.

Soil series

Not defined

Soil properties

The studied site is characterised by alternance of deeper soils with an A-AB-Bw-BC-C layers sequence and shallow soils characterised by the presence of only two layers: the first is few centimetres deep and in rich in organic matter, the second is the interface with the rocky substratum. The pedon is characterised by a high anisotropy due to variability of microrelief which brings different depth and percentage of rock fragments. Consequently the herbaceous cover and root development are to be considered irregular in depth and quantity.

Profile

A sequence of three layers Ah-BC-C. Layer Ah is brown (10YR 4/2); loamy-sand; 2% of rock fragments ; fine structure of granular shape Layer BC is brown (10YR 4/3); loamy-sand; 25 % of rock fragments, of irregular shape. Layer C is dark brown (10YR3/3), sandy, 60% of rock fragments.

Profile code: LANZ0069

Profile location: Slope and ridge morphologies, Monastero Lake, Lake Alp, Chiaves

Profile classification:

Soil Taxonomy: Lithic Cryorthent, coarse-loamy, mixed, acid, frigid

WRB: Dystric Leptosol

Slope: 30°

Exposition: 270°

Elevation: 230 m s.l.m.

Soil use: alpine pasture

Lithology: serpentine

Morphology: slope with rocky leaps

Layer Ah: 0 -10 cm, humid, dark greyish brown (10YR 4/2), secondly very dark greyish (10YR 3/2); loamy-sand; 2% irregular skeletal; fine structure of granular shape and moderate strength; common macro pores of medium dimensions 1-5 mm; roots 40/dmq, of medium dimensions of 1 mm and maximum dimensions of 3 mm, oriented in every plane; rooting 90%; consistence: slightly resistant; very slightly cemented; non-sticky; non-plastic; non- calcareous; no concentrations ; no coats; lower boundary clear and wavy

Layer BC: 10 -20 cm; humid; brown (10YR 4/3); loamy-sand; 25 % of rock fragments, of irregular shape, with 10 mm of medium diameter and 100 mm of maximum diameter, highly altered; fine subangular polyedric structure of moderate strength; few macropores, with medium dimensions of less than 1 mm; roots 5/dmq, of medium dimensions of 1 mm and maximum dimensions of 2 mm, oriented in horizontal planes; rooting 60 %, consistence: slightly resistant; very slightly cemented; non-sticky; non-plastic; non-calcareous; no concentrations ; no coats; lower boundary clear and wavy

Layer C: > 20 cm; humid; dark brown (10YR 3/3); sandy; 60 % of rock fragments, of irregular shape, with 10 mm of medium diameter and 300 mm of maximum diameter, highly altered; incoherent structure; few macropores, , with medium dimensions of less than 1 mm; no roots; rooting 30%; consistent: slightly resistant; very slightly cemented; non-sticky; non-plastic; non- calcareous; no concentrations ; no coats; lower boundary: unknown.

Physical-chemical characteristics of the *Dystric Leptosol* (pasture soil profile)

	Ah	AB	Bw	BC
Upper boundary cm	0	10	35	70
Lower boundary cm	10	35	70	120
pH in H_2O	4,4	4,6	5,0	5,1
Gravel %	2	10	10	25
Coarse sand %	29,4	39,8	38,9	50,1
Fine sand %	51,6	28,2	28,6	32,4
Coarse silt %	10,8	8,9	8,0	8,2
Fine silt %	6,0	16,2	17,2	7,6
Clay %	2,1	7,0	7,2	1,7
$CaCO_3$ %	0,0	0,0	0,0	0,0
Organic carbon %	6,90	1,18	0,92	2,74
N %	0,416	0,138	0,098	nd
C/N	17	8,6	9,4	nd
Organic matter %	11,87	2,04	1,58	4,71
C.S.C. meq/100g	17,56	9,32	10,26	nd
Ca meq/100g	1,06	0,12	0,10	nd
Mg meq/100g	0,50	0,17	0,07	nd
K meq/100g	0,04	0,02	0,01	nd
P available ppm	17,6	nd	nd	nd
Basic saturation %	9	3	2	nd

Photo: profile LANZ0069 in the maximum depth

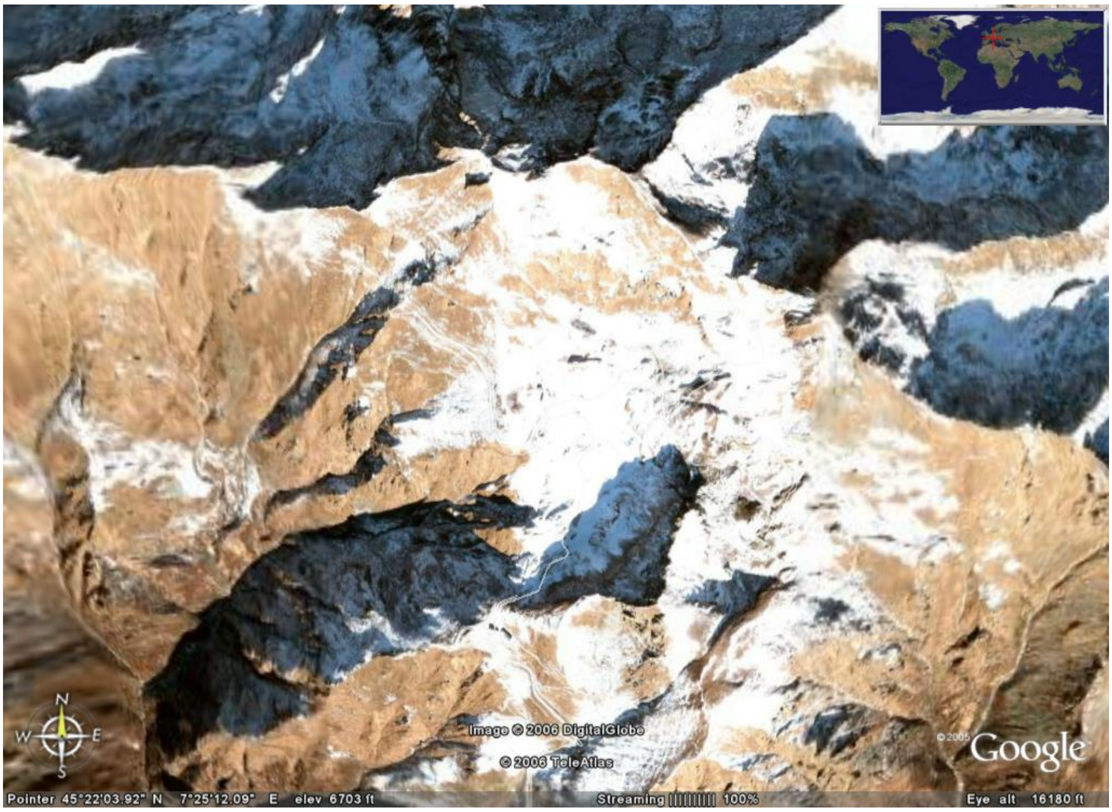


Photo: satellite image of the mountain site morphology

Forest plot

Geographic distribution and pedolandscape
The more diffused soil type is a Luvisol (WRB), which covers the lower level of the old terrace in the Partecipanza of Trino (Vercelli province). Wavy surface constituted by eroded parts of an old terrace formed on a substratum made by gravely deposits rich in fine sands and, secondly, by clay. The sampling site is placed at 150 m a.s.l., 20 m higher than the main plain. The original slopes are slightly recognizable due to rice-chambers arrangement. Surface stoniness is very low. Land use is rice-growing.

Soil series: RAMEZZANA fine-silty, typic

Soil properties: soil is characterised by a loamy or silty-loam texture and by a low macroporosity due to iron oxides (mottling and concretions). Consequently drainage is moderate as well as oxygen availability. Soil variability is sharpened by two factors: irregular distribution of organic matter due to plastic films used in wood arboriculture and irregular patterns of soil texture and bulk densities due to mixing of soil layers in rice-field arrangements for water submersion.

Profile: it is composed by a loamy topsoil with acid pH, often conditioned by sub merged cultivation,, and by a subsoil constituted by a sequence of eluvial-illuvial layers with loamy texture, neutral pH and evidence of clay coats. Below 160 cm C layers are well recognisable with much more gravel and colours vary from olive-brown to yellowish-brown with evident mottles all along the depth.

Profile code: ASTA0006
Profile location: Crescentino (province of Vercelli)
Profile Classification:
Soil Taxonomy: Aquic Haplustalf, fine-silty, mixed, nonacid, mesic
WRB: Gleyic Luvisol

Slope: 0°
Exposition: - °
Elevation: 160 m slm
Land use: rice-growing
Lithology: silty sediments
Morphology: lower part of ancient terrace

Photo: the soil profile of a rice-field near the Trino arboricolture plot

Photo: the arboricolture plot of Trino (VC)

Layer Ap1 : 0 - 7 cm; humid, light olive brown (10YR 3/1); loamy; 15% of mottles (4 mm medium size) with clear boundaries, dominant colour yellowish brown (10YR5/6), secondary colour greenish gray (1 for gley 6/3); non gravely, clod structure, few macropores (less than 1 mm medium size), no roots, rooting 90%, consistence: moderately resistant; very slightly cemented; slightly sticky; moderately plastic; non- calcareous; no concentrations ; no coats; lower boundary clear and wavy.

Layer Ap2:15 - 30 cm; humid, greenish gray (1 FOR GLEY 5/3), colour type: reducted; loamy;; non gravelly, clod structure, few macropores (less than 1 mm medium size), no roots, rooting 90%, consistence: moderately resistent; very slightly cemented; slightly sticky; moderately plastic; non- calcareous; no concentrations ; no coats; lower boundary clear and wavy.

Layer EB: 30 - 60 cm; humid; light olive brown (2,5Y 5/4); colour type: variegated; mottles: quantity 25%, average size 7 mm, clear boundaries, primary yellowish brown (10YR 5/6), secondary light brownish gray (2,5Y 6/2); other mottles: dark yellowish brown (10YR 4/4); loamy; non gravelly; structure: massive; common macropores of 1-5 mm medium size; rooting 50%; consistence: very slightly cemented; slightly sticky; moderately plastic; non-calcareous; 5 % iron-manganese nodules, 2 mm medium size in the matrix; lower boundary gradual and smooth.

Layer Bt1: 60 - 100 cm; humid; dominant colour yellowish brown (10YR 5/4); secondary colour dark yellowish brown (10YR 4/4); colour type: variegated; mottles: quantity: 25 %, average size 5 mm, clear boundaries, primary light brownish gray (2,5Y 6/2), secondary yellowish brown (10YR 5/6); loam; non gravely; weak structure with coarse subangular polyedric shape; many macropores, with average dimensions greater than 5 mm; rooting 50%; consistence: slightly resistant, very slightly cemented; moderately sticky; slightly plastic; non calcareous; 4 % iron-manganese nodules, 2 mm medium size in the matrix; 3 % iron-manganese masses, with average dimensions 15 mm, in the matrix; 2% clay coats in the matrix; gradual and linear lower boundary.

Layer Bt2: 100 - 160 cm; humid; light olive brown (2,5Y 5/3); peds faces brown (7,5YR 4/4); colour type: variegated; mottles: quantity: 20 %, average size 4 mm, abrupt boundaries, primary light brownish gray (2,5Y 6/2), secondary yellowish brown (10YR 5/6); loam; non gravely; weak structure with medium angular polyedric shape; common macropores, with average dimensions greater than 5 mm; rooting 30%; consistence: slightly resistant, very slightly cemented; slightly sticky; slightly plastic; non calcareous; 2 % iron-manganese nodules, 2 mm medium size in the matrix; 2 % iron-manganese masses, with average dimensions 2 mm, in the matrix; 20% clay coats in the matrix; gradual and linear lower boundary.

Layer C: 160 - 170 cm; humid; gravel 70 %, of subrounded shape, with average diameter 50 mm and maximum 80 mm, very much altered.

Physical-chemical characteristics of the *Gleyic Luvisol* (forest soil profile)

	Ap1	Ap2	EB	Bt1	Bt2
Upper boundary cm	0	20	40	80	130
Lower boundary cm	10	30	50	90	140
pH in H2O	6,5	6,4	7,6	7,2	7,0
Coarse sand %	3,4	3,3	5,1	6,5	13,0
Fine sand %	20,1	20,0	3,1	5,9	6,7
Very fine sand %	-	-	22,6	21,5	25,7
Coarse silt %	32,0	32,5	27,0	28,1	22,0
Fine silt %	27,9	26,7	19,3	18,2	15,2
Clay %	16,7	17,7	23,0	19,8	17,4
CaCO3 %	0,0	0,0	0,0	0,0	0,0
Organic carbon %	1,20	1,30	-	-	-
N %	0,148	0,156	-	-	-
C/N	8,1	8,3	-	-	-
Organic matter %	2,06	2,24	-	-	-
C.S.C. meq/100g	20,00	18,60	-	-	-
Ca meq/100g	6,60	6,55	-	-	-
Mg meq/100g	1,58	1,58	-	-	-
K meq/100g	0,51	0,38	-	-	-
Na meq/100g	-	-	-	-	-
P available ppm	10,5	9,1	-	-	-
Basic saturation %	44	46	-	-	-

Data processing

J. Balkovič, E. Schmid, E. Moltchanova, R. Skalský, K. Poltárska, B. Müller and R. Bujnovský

1. Introduction

The purposes of the data processing are to meet requirements and format of input parameters for the bio-physical and economic models. In general, the data processing includes: extraction and adaptation needed input parameters from existing/available data sources, aggregation of existing data to produce secondary parameters, manipulation with the existing data and/or secondary parameters to develop a new data sets based on a model specific data processing, formatting of the input parameters to make them readable by the principle EPIC model, etc. procedure covers data subsets, re-processing of data-structure, treatment of values, various ways of data up- and down-scaling and so on. Pre-processing leads to formulating the final structure of a database, where data are stored respecting the target scale of biophysical modelling, i.e. HRU and NUTS2 level. Data gathered within the initial stage, and which were described above, were harmonised with aim to create a consistent and compromise GIS-based workspace for EPIC modelling. All the processing respects that the modelling (i) is representative for the scale 1:1,000,000, (ii) is geographically explicit for the coverage of homogeneous response units as basic physical delimitation of landscape, (iii) is geographically explicit for different types of land cover as a basis for different land management, (iv) is geographically explicit for NUTS2 administrative regions as a basis for integration into INSEA model cluster, and (v) is a compromise that have appeared under different requirements given by economic models as target users of biophysical modelling. In following subchapters, different partial steps to process and prepare data are described.

2. Adaptation of existing data

2.1 GIS coverage of NUTS2 regions

The system of coding NUTS regions in AGISCO database in some cases differs from that, which is used in official EUROSTAT (New Cronos) statistical database. It was necessary to define a comparing converter that enables linking the statistical auxiliary information to AGISCO coverage. AGISCO code was used for the final dataset. The rules of the converter are defined in the Table 19 in the appendix.

2.2 Nitrogen depositions from atmosphere

To include EMEP data (Monitoring and evaluation of long-range transmission of air pollution in Europe; http://www.emep.int/) into INSEA, the geographic reference system was changed to one used in INSEA GIS archive (Lambert-Azimuthal), see Figure 1. Afterwards, the average N-depositions were calculated for NUTS2 regions from the grid maps of EMEP database. Following attributes were appended to the database at NUTS2 level:

- NHXDEPOS (average depositions of NHx from atmosphere, NUTS2 level, in kg/km^2), and
- NOXSEPOS (average depositions of NOx from atmosphere, NUTS2 level, in kg/km^2).

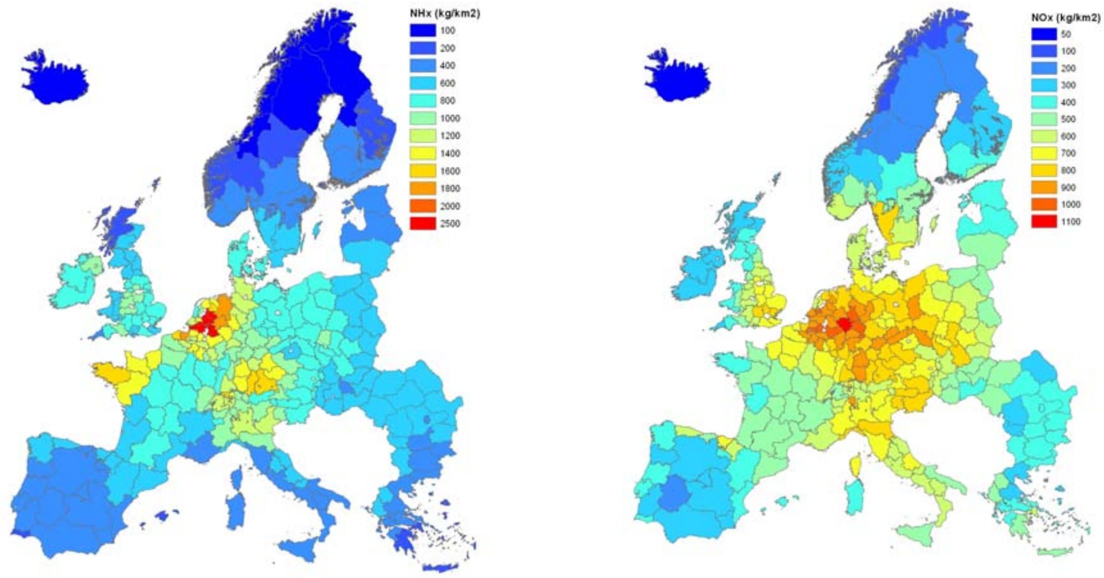


Figure 1. Atmospheric depositions of NHx (left) and NOx (right) (source: EMEP).

2.3 Pedotransfer Functions (PTF)

Single-parameter soil maps of SGDBE and PTRDB with Lambert-Azimuthal projection were used, of which a subset of grids covering the spatial extent of EU25 were created. In the next step, these maps were checked for attribute consistency, and if needed, they were adjusted accordingly.

A direct use of raster single-parameter maps from SGDBE and PTRDB does not sufficiently fulfil the minimum requirements for EPIC inputs. Some additional pedotransfer functions from European sources were mobilised to derive additional necessary soil parameters. A set of PTFs basically integrates expertise of JRC (especially PTRDB), which are not further described in detail. For more information see http://eusoils.jrc.it/ESDB_Archive /ESDBv2/fr_intro.htm/

Except the maps from SGDBE and PTRDB, additional soil parameters, which were estimated by PTFs, are summarised in Table 1.

Parameter	Description	Unit
VS_sub	Volume of stones in the subsoil	vol %
BD_top	Bulk density in the topsoil	$g.cm^{-3}$
BD_sub	Bulk density in the subsoil	$g.cm^{-3}$
SOB_top	Sum of base ions in the topsoil	$cmol_+.kg^{-1}$
SOB_sub	Sum of base in the subsoil	$cmol_+.kg^{-1}$
WP_top	Wilting point in the topsoil	$cm^3.cm^{-3}$
WP_sub	Wilting point in the subsoil	$cm^3.cm$
FWC_top	Field water capacity in the topsoil	$cm^3.cm$
FWC_sub	Field water capacity in the subsoil	$cm^3.cm$
KS_sub	Saturated conductivity in the topsoil	$mm.hour^{-1}$
KS_sub	Saturated conductivity in the subsoil	$mm.hour^{-1}$
pH_top	Soil reaction in the topsoil	pH_{KCl}
pH_sub	Soil reaction in the subsoil	pH_{KCl}
HYDROGR	Hydrological Soil Group	A, B, C, D

Table 1. Soil parameters derived with pedotransfer functions.

2.4 Volume of stones in subsoil (VS)

The volume of stones in subsoil was estimated by an expert co-interpretation matrix being applied on PTRDB raster maps of (i) depth to rock, (ii) character of the parent material, and (iii) volume of stones in the top-soil. It includes a re-classification of soil depth into shallow (<40 cm), moderate (40-80 cm), deep (80-120 cm), and very deep (>120 cm) classes. Parent material (paramdo2.grd as a part of ESDBv2 Raster Archive) was reclassified into three classes according to a potential for soil stoniness (rocks, mixed, fine), and the final matrix evaluates all combinatorial occurrences of soil depth, parent material and volume of stones in the top-soil respecting an opinion of INSEA expert board (figure 19 in appendix).

2.5 Bulk density (BD)

To fill the gaps in data availability, bulk density (BD) was estimated in two consecutive steps.

(i) If package density information was available, then bulk density was estimated from package density (PTRDB) using the formula provided to INSEA by JRC:

BD_TOP = PD_TOP − (CLAY_TOP × 0.009)

BD_SUB = PD_SUB − (CLAY_TOP × 0.009)

(ii) Otherwise, bulk density was estimated form textural composition of soils and organic carbon content using the pedotransfer function as it was published by Lettens et al. (2004):

BD = 100 / {(SOM/VOM)+(100−SOM)/VMF},

where SOM = OC_TOP × 1.32 × 2 (OC for subsoil was set to 0.1% by default), VOM = 0.224 g/cm^3, VMF is the density of mineral material, which is readable form the following triangle (Figure 2):

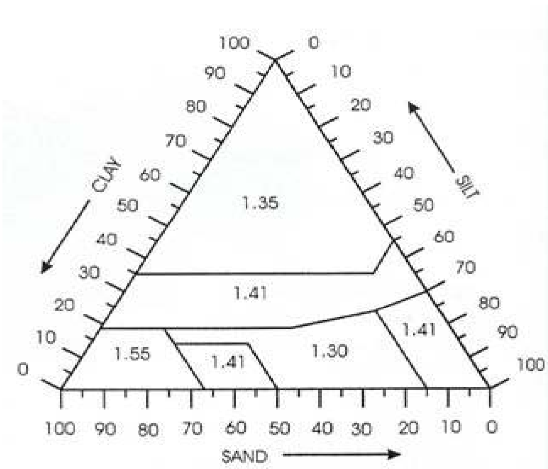


Figure 2. The triangle of density of soil mineral fraction (VMF).

2.6 Sum of base cations (SOB)

Sum of base cations is calculated from base saturation and cation exchange capacity, which are on the list of data that is available form ESDBv2 Raster Archive.

2.7 Saturated conductivity (KS), Wilting point (WP) and Field water capacity (FWC)

Parameters of saturated hydraulic conductivity, wilting point and field water capacity were estimated by PTF equation of HYPRES (Wösten et al. 1998, 1999), being calculated over data of PTRDB. Following relations were used for European datasets:

THS = 0.7919 + 0.001691 × CLAY - 0.29619 × BD - 0.000001491 × SILT^ 2 + 0.0000821 × (OC × 1.724) ^ 2 + 0.02427 × CLAY^(-1) + 0.01113 × SILT^(-1) + 0.01472 × Log(SILT) / Log(2.71828182) - 0.0000733 × OC × 1.724 × CLAY - 0.000619 × BD × CLAY - 0.001183 × BD × OC × 1.724 - 0.0001664 × 1 × SILT

LN_ALPHA = -14.96 + 0.03135 × CLAY + 0.0351 × SILT + 0.646 × OC × 1.724 + 15.29 × BD - 0.192 × 1 - 4.671 × BD ^ 2 - 0.000781 × CLAY ^ 2 - 0.00687 × (OC × 1.724) ^ 2 + 0.0449 × (OC × 1.724) ^ (-1) + 0.0663 × (Log(SILT) / Log(2.71828182)) + 0.1482 × (Log(OC × 1.724) / Log(2.71828182)) - 0.04546 × BD × SILT - 0.4852 × BD × (OC × 1.724) + 0.00673 × 1 × CLAY

LN_N = -25.23 - 0.02195 × CLAY + 0.0074 × SILT - 0.194 × (OC × 1.724) + 45.5 × BD - 7.24 × (BD) ^ 2 + 0.0003658 × (CLAY) ^ 2 + 0.002885 × (OC × 1.724) ^ 2 - 12.81 × (BD) ^ (-1) - 0.1524 × (SILT) ^(-1) - 0.01958 × (OC × 1.724) ^ (-1) - 0.2876 × (Log(SILT) / Log(2.71828182)) - 0.0709 × (Log(OC × 1.724) / Log(2.71828182)) - 44.6 × (Log(BD) / Log(2.71828182)) - 0.02264 × BD × CLAY + 0.0896 × BD × (OC × 1.724) + 0.00718 × 1 × CLAY

IF CLAY < 18% and SAND > 65% Then THR = 0.025 Else THR = 0.01

where THS is θ_s, THR is θ_r, LN_ALPHA is natural logarithm of α, LN_N is natural logarithm of n, while θ_s, θ_r, α and n are parameters of van Genuchten (1980) equation of a retention curve:

$$\theta_e = \frac{\theta - \theta_r}{\theta_S - \theta_r} = \left[\frac{1}{1 + \left(\alpha \left| h_W \right|\right)^n} \right]^m$$

Pressure (*hw*) was set to 1500 kPa for wilting point, and 33 kPa for field water capacity. The routine was calculated for both topsoil and subsoil layers, while organic carbon content in subsoil was set to 0.1 by default as we do not have information on subsoil organic carbon. Similarly, HYPRES function was used to estimate saturated hydraulic conductivity for both topsoil and subsoil (LN_KS is natural logarithm of Ks):

LN_KS = 7.755 + 0.0352 × SILT + 0.93 × 1 - 0.967 × BD ^ 2 - 0.000484 × CLAY ^ 2 - 0.000322 × SILT ^ 2 + 0.001 × SILT ^ (-1) - 0.0748 × (OC × 1.724) ^ (-1) - 0.643 × (Log(SILT) / Log(2.71828182)) - 0.01398 × BD × CLAY - 0.1673 × BD × (OC × 1.724) + 0.02986 × 1 × CLAY - 0.03305 × 1 × SILT

2.8 Soil acidity

Soil acidity appeared as problematic to estimate by a PTF, because it is highly variable and depends on many factors and natural process. Nevertheless, it was estimated by a regression function of base saturation. However, it is an approximation only for arable land, and for the middle European region, because it was calibrated with KPP dataset (database of Slovakian agricultural soils, refer to Bielek et al. 2005). For forests it needs to be adjusted by expert opinions. A relatively comprehensive dataset of soil samples (nearly 15 800 soil samples of arable land, pastures, meadows, orchards and vineyards for topsoil and more than 38 000 soil samples for subsoil) provides statistical regressions, where coefficients of determination reach 50% (linear regression model) for topsoil horizons and 76% for subsoil horizons (polynomial regression model), $p<0.001$ (Figure 3). Following equation was finally applied to calculate pH for both topsoil and subsoil (representing pH as measured in 1M KCl):

pH = $6E\text{-}06 \times BS^3 - 0.0004 \times BS^2 + 0.0179 \times BS + 4.1731$ ($R^2 = 0.76$, $p<0.001$),

where BS is base saturation.

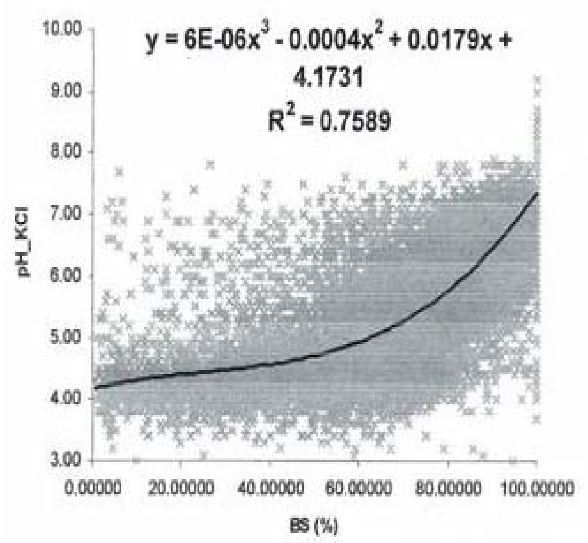


Figure 3: Scatter plot of pH (pH in 1M KCl) as a function of base saturation (BS) estimated from KPP Dataset of Slovakian agriculture soils.

3. Hydrological Soil Group

Hydrological soil group categorically defines bottom boundary determining water movements in soil profile. It was derived as a result of interpretation of two different expert matrices in two steps (for more information see figure 20 in appendix):

Step 1. Co-evaluation of textural soil composition and mean saturated conductivity both for topsoil and subsoil, whereas higher weight was given to subsoil.

Step 2. Co-evaluation of step1 with depth-to-clay-horizon parameter.

The Hydrological Soil Group is subdivided from A to D reflecting some expected runoff potentials.

- **A -** Low Runoff Potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sand or gravels. These soils have a high rate of water transmission.
- **B** - Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

- **C** - Soils having slow infiltration rates when thoroughly wetted and consisted chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
- **D** - High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay-pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

4. Topography

SRTM90 digital elevation model with 90 m resolution (http://www.mapmart.com /DEM/InternationalDEMBundle.htm) was processed to obtain slope (in percentages) using Spatial Analyst for ArgGIS™ (McCoy et al. 2002). Slope map has the same resolution as SRTM90. Slope is considered to be of very high importance for biophysical process modelling because it affects most natural processes, such as erosion, water movement, carbon losses an so forth. Since biophysical process modelling for INSEA is built on GIS information with 1 km resolution, we are not able to employ the entire potential of the high-resolution SRTM90. Therefore, SRTM90 elevation and slope maps were purposely built-in to 1km grid of Lambert-Azimuthal projection. Mean elevation and most frequent slope (Figure 4) were calculated for each 1×1 km cell using zonal statistic toolkit of ArcInfo, which yields the rasters of elevation and slope in percentages (1km cell resolution). For Scandinavia, of which we missed SRTM90 data, GTOPO30 digital elevation model was used for elevation and slope data, so topography data is coarser there.

For some specific purposes, GTOPO30 was processed in order to obtain specific elevation categories, which were used in further evaluation, e.g. for delineation of homogeneous response units, or for studying some response functions of crops along elevation gradients. Elevation was classified in four categories:

- lowlands (altitude <300 m),
- uplands (300-600 m),
- mountains (600-1100 m),
- high mountains (>1100 m).

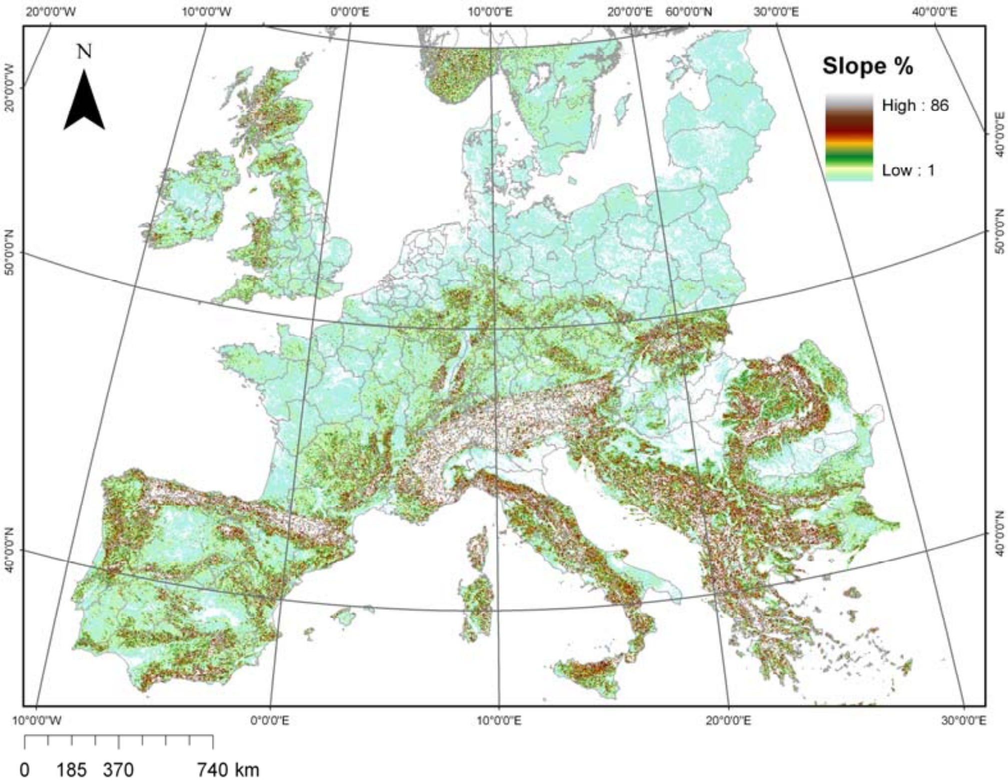


Figure 4. Major slope gradients in percent (SLSRTM_PERC.grd) to convert SRTM90 into INSEA GIS workspace (1 km cell resolution). Scandinavia is not covered with SRTM90.

5. Land cover

The CORINE-PELCOM data (place of origin: European Topic Centre on Land Cover (ETC/LC) - European Environment Agency (EEA)) were classified to two different raster maps. First-level classification delineates the target area of EU25 according to main land cover categories (Table 2). This coverage is used for masking homogeneous response units by land cover information such that initial inputs for the simulation can be calculated. Hence, this coverage respects the biophysical process modelling framework. The first level defines strategic land covers, for which land use and land-use changes could be specified. The second-level map carries more precise information on land cover, and it is used for some specific reasons.

Land cover categories Level 1		Land Cover categories Level 2	
10	Artificial	10	Artificial
21	Arable Land	211	Non-irrigated Arable Land
22	Permanent Crops	212	Permanently Irrigared Land
23	Pastures	213	Rice Fields
24	Heterogenous agric. Areas	221	Vineyards
311	Broad-leaved Forest	222	Fruit Trees and Berry Plantations
312	Coniferous Forest	223	Olive Groves
313	Mixed Forest	231	Pastures
32	Shrubs and Herbaceous Vegetation	241	Annual Crops with Permanent Crops
33	Open spaces with little vegetation	242	Complex Cultivation Pattern
41	Inner Wetlands	243	Agric. + signif. Area of Natural Veg.
42	Maritime Wetlands	244	Agro-Forestry
50	Water Bodies	311	Broad-leaved Forest
		312	Coniferous Forest
		313	Mixed Forest
		321	Natural Grasslands
		322	Moors and heathlands
		329	Shrubs and Seminatural Vegetation
		339	Open spaces with little vegetation
		41	Inner Wetlands
		42	Maritime Wetlands
		50	Water Bodies

Table 2. Main land cover categories for level 1 (left) and level 2 (right) of CORINE-PELCOM dataset.

First, it was used for spatial allocation of irrigated arable land (where irrigation systems occur). It was also used to calculate auxiliary information on acreage of different land covers.

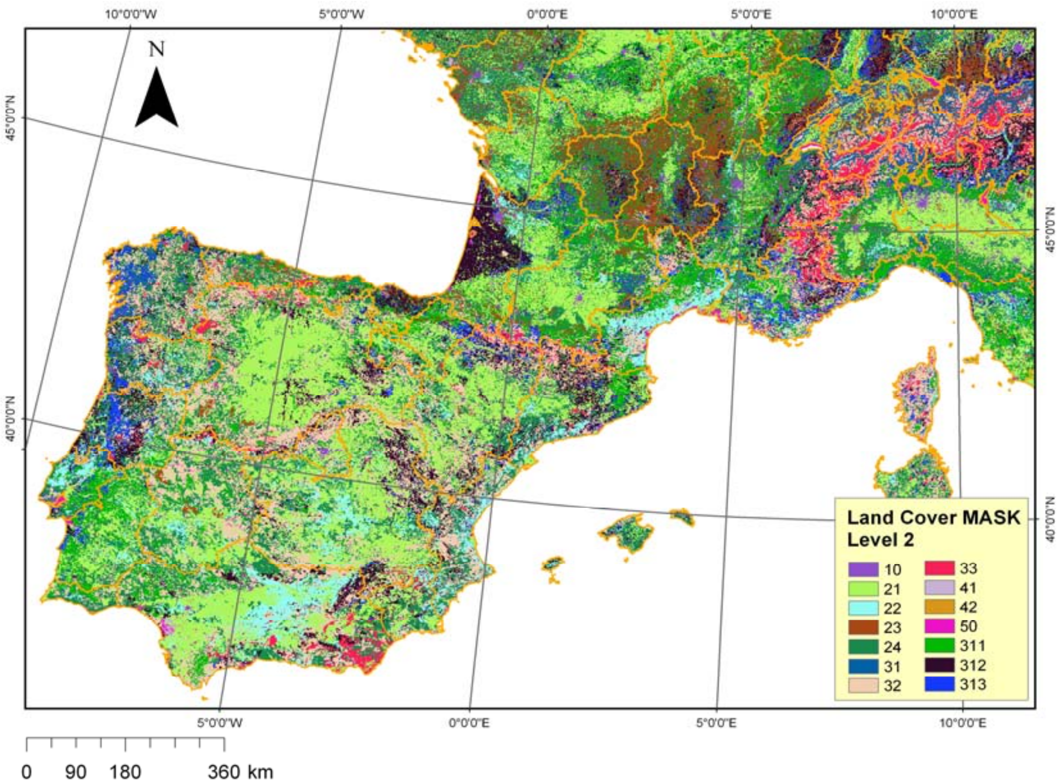


Figure 6. Main categories of land covers from the CORINE and PELCOM dataset, which is used to mask homogeneous response units with specific land cover categories (1 km cell resolution) – an example view. (source: CORINE and PELCOM).

The list of land-cover categories obtained from CORINE and PELCOM for both levels are graphically illustrated in Figure 5. It represents an example on the distribution of main land categories, which is used to mask HRUs with land cover categories to calculate initial soil parameter values for each individual simulation unit.

6. Agricultural statistics

The New Cronos dataset (see EC, EUROSTAT 2004) is a major source of information for land use activities. Since it is NUTS0-2 specific, in some cases it was processed in a way to downscale the information if possible. The entire base-run land use management in biophysical process modelling is designed to replicate NUTS2 crop share statistics, which are simulated over a moderate time horizon. Crop shares are used to calibrate the crop rotation lengths, and frequencies, and yields are adequately used to validate fertilization rates and the maturing of crops (adjustment of heat units).

The pre-processing of the database mainly includes adjustments of the attributes to consistently align with the architecture of the biophysical process modelling framework i.e. to specify a list of crops usable in EPIC, and to adjust the crop share data for each NUTS2 regions, (tables 12 to 14 in appendix). For instance, the shares of crops at NUTS2 level should yield 100%, so that optimisation algorithms, which specify typical crop rotations by NUTS2 region are working properly. The pre-processing of New Cronos datasets includes (i) integration of crops and land cover in a common platform, and (ii) aggregation of information for NUTS2 level, or NUTS1 level if NUTS2 level information is not available (e.g. UK).

Integration of crops and land cover includes aggregation of crops and their coding, and the crop dataset obtained from LUCAS sources (EC 2003). An integrative platform for crops in biophysical process modelling is presented in Table 19 in the appendix.

Crop shares were calculated CROP = 100 × CROP / ARABLELAND, where CROP is the harvested area. Average crop shares are calculated from 14 years of statistics. Due to some inconsistencies in New Cronos, following treatments were applied:

IF OCER < 0% Then OCER = 0% (only some small inconsistencies), IF OOIL < 0% Then OCER = 0% (only some small inconsistencies),

IF OOIL < 0% Then OOIL= 0% (only some small inconsistencies),

IF SUM < 90% Then OCRP = 100 – SUM,

which ensures that the sum of harvested area is 100%. If it is less than 90%, like in Finland, Ireland, Spain etc., then green fodders or fallow is used on arable land. If SUM is between 90 and 100 %, (and also if SUM is between 100 and 105 %) we consider it as small error, and all categories were proportionally rescaled. IF SUM > 110 % Then FALW = FALW – (SUM – 100) – in some Spain and Greece regions, where FALW acreage is higher than the total of ARABLELAND despite it is declared to be a subset of ARABLELAND. For all crop categories, average yields (14 year average) were calculated from New Cronos database. It uses the same coding system as identified before.

Information on fertilization was adopted from the “Environment and energy section” of New Cronos. It offers data of nitrogen balances from which the information on consumption of N-mineral fertilisers and organic manure (in kg/ha) were downloaded (only NUTS-1 level for EU15). In addition NUTS0 data of N, K, P fertilizer consumptions (in tonnes of active ingredient) were collected from years 1997–2001. Crop specific consumptions of mineral fertilizers in individual countries were processed from FAO dataset (IFA-IFDC-IPI-PPI-FAO 2002). So far, we do not have developed a sufficient algorithm to allocate fertilization to individual crop rotations. The information available seems much aggregated to make it geographically specific, and link it to the level of HRUs. We use country data, i.e. crop specific N, P, K fertilizers of FAO dataset and country specific organic manure allocated to root crops and maize by default, and set them default for whole countries (NUTS0). We use a feed-back approach to recalibrate fertilization schedule if yields from simulations are not appropriate.

LUCAS is the only source of statistical data, which is truly geographically explicit. It is therefore considered as very important for allocation of crops on agricultural lands. It was used for downscaling crop shares along elevation classes to support the definition of crop rotations for each HRU. The pre-processing itself includes a treatment that enables to gain the benefit of LUCAS in further geographical analyses. The coordinates and geographical projection were transformed consistently to INSEA GIS Archive (Lambert-Azimuthal projection). After appending all SSU files to predefined point structure, data records were joined to spatial coordinates. Resulting data were converted to an ESRI Database.

7. Data archive

The data for EPIC application at EU25 level was divided into three different archives: (i) GIS archive of original datasets, (ii) DBF archive of EPIC input parameters, and (iii) GIS interface for publishing EPIC output indicators.

7.1 The GIS archive

This archive stores datasets with direct geographical reference and own geometry. It was designed to support geographical analyses. In some extent, it is also a tool of how outputs from EPIC simulations could be presented to audience. The GIS archive is divided into two subsets: (i) ESRI vectors and (ii) ESRI grids with 1 km cell resolution. Both are harmonised to 'Lambert Azimuthal Equal Area' geographical projection system and GCS 'Sphere_ARC_INFO' (Table 19 in appendix). A brief description of GIS archive items is listed in Table 20 in the appendix.

7.2 The DBF archive for EPIC input parameters

This archive stores records, which contain input parameters for EPIC. It is stored in MS Access environment (MDB architecture of database). Basically two different MDBs were prepared respecting different origin and organisation of data.

The first one (INSEA_HRUs.mdb) contains physical data being organised at the level of the Individual Simulation Units (ISU). Physical data consists of soil, climate and topography information for each original combination of NUTS2 region, land cover category (level 1), HRU, and irrigation class. Each individual simulation unit is coded by a primary key (ID2 = NUTS2_LandCat_SoilClass_Irrig), resulting in 57,594 individual simulation units for EU25. The list of attributes is presented by Table 19 in appendix.

The second database (INSEA_MNG) stores information, which is organised at the level of an intersection between NUTS2 regions and elevation classes (ID = NUTS2_ELEVCLASS):

0 (for whole NUTS2, usually original information at NUTS2 level),

1 (altitude ≤ 300 m),

2 (altitude > 300 m and ≤ 600 m),

3 (altitude > 600 m).

The INSEA_MNG database contains information on management. If the information was disaggregated to elevation classes, these values are recorded under codes ending with 1, 2, or 3. Otherwise, the information for level 1, 2, and 3 is the same as for codes ending with 0. The attributes are: crop shares, crop yields, crop rotations, crop fertilization, nitrogen atmospheric depositions and land cover acreages. The list is shown in Table 20 in appendix.

7.3 The GIS interface for publishing EPIC output indicators

The GIS interface is the point ESRI geo-database, where each point occurs in the middle of cell in a raster with 1 km cell resolution covering EU25 workspace. Each point in geo-database carries identification code of the simulation unit, to which it belongs. The list of attributes is as follows:

ID1: NUTS2_LandCat_Irrig (not valid)

ID2: NUTS2_LandCat_SoilClass_Irrig

ID3: FADN_LandCat_SoilClass

X: coordinate X

Y: coordinate Y

Simulated EPIC output indicators, such as soil organic carbon in topsoil, aboveground and belowground biomass, crop yields, nitrogen fluxes and so forth, can be joined to the interface by matching the ID2 field, which allows visualisation of outputs as maps. Each indicator can be potentially added as a separate field of the geo-database and stored for further analyses. Also single-parameter rasters of indicators can be built through the interface by using the feature-to-raster function in ArcGIS^{TM} environment and then add the indicator rasters to the GIS archive, where it is prompt to use. GIS interface has also two other advantages: (i) the aggregation of results for NUTS2 regions yields automatically weighted numbers when calculated in this database, and (ii) the results can be reorganised and recalculated for different coverages. The final version enables to recalculate the results into FADN coverage (EC 2004), what ensures the direct link to economical models (e.g. AROPAj). The structure of GIS interface for publishing indicators from biophysical modelling is presented by following figure.

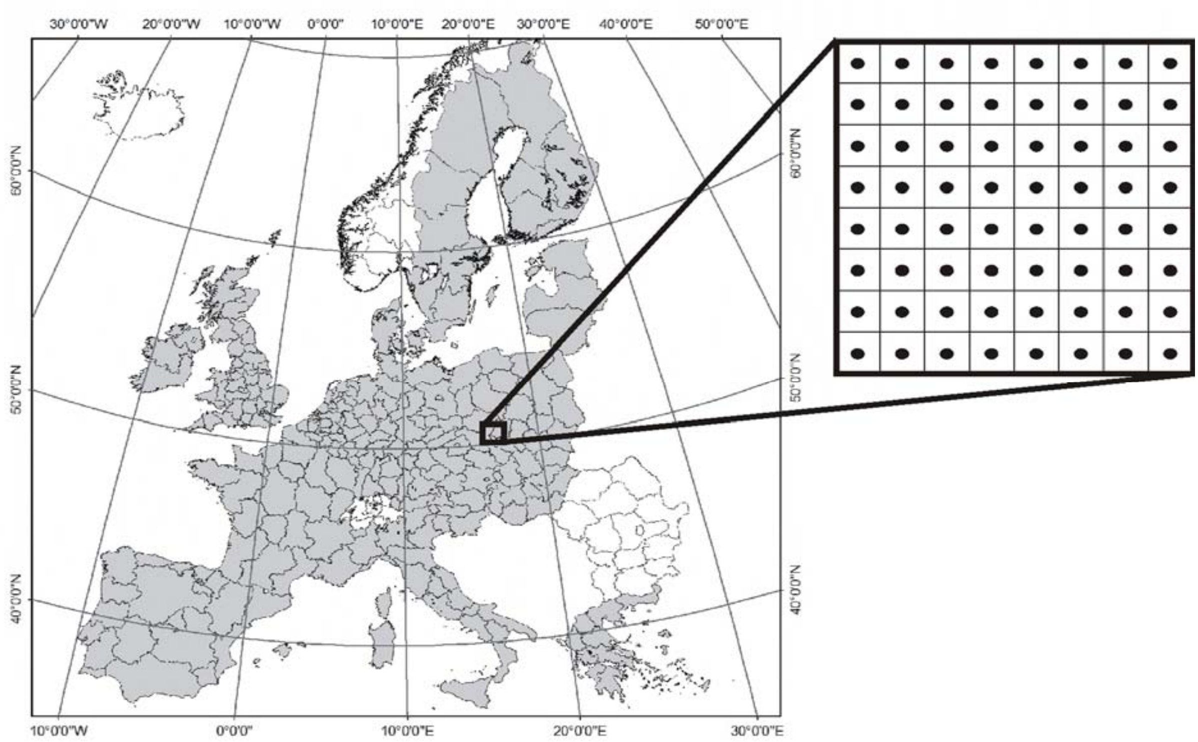


Figure 6. GIS interface for publishing indicators of biophysical modelling – extent and schematic view.

8. Geographical and statistical analyses

Based on data origin, it is possible to generalize the geographical and/or statistical data analyses into a hierarchical structure as outlined below.

Data level	Data integration	Data representation	Data represented	Data operations
LEVEL 1 (Grid based data)	individual cell values	SGDBE and PTRDB 1k DEM 1k CORINE and PELCOM 1k	Soil and topography data land use GIS Archive	data treatment PTF supervised classification integration of data to defined data structure reclassification
LEVEL 2 (spatial units – HRU/simulated units)	raster zone analyses raster masking analyses values related to HRU/SU data disaggregated from LEVEL3	land use categories (Level 1, 2) topographic categories HRU/SU administrative regions MARS mesh EMEP mesh	Average/majority soil data Average/majority topographic data Meteorological statistics Data for simulated units Crop rotations, shares Irrigation Indicators (EPIC results)	Data treatment/PTF GIS analysis Data statistics EPIC runs EPIC interpretation
LEVEL 3 (Administrative spatial units)	Aggregated values statistical values	administrative regions (NUTS2 level)	Fertilization Crop yields Indicators (aggregated EPIC results)	Data statistics Generalization Representation of results

Table 3. Hierarchy of biophysical modelling data.

8.1 Climate

8.1.1 EA-MARS correlation

In order to assess the correspondence between MARS and the EA data (East Anglia), monthly means were evaluated from the MARS data for the cell 54058 and compared with the corresponding data from the EA data (figure 21 in appendix).

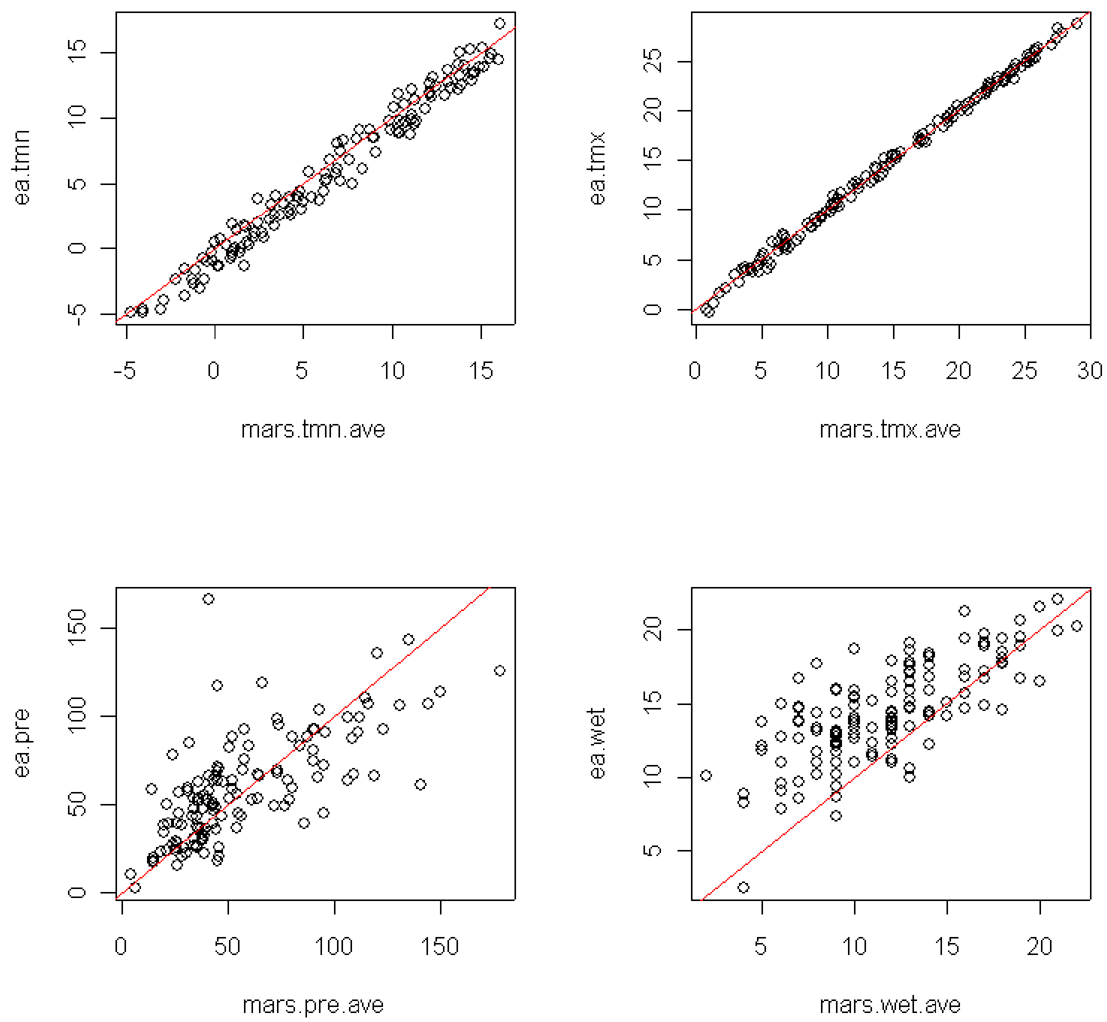


Figure 7. Correlation for the estimated monthly mean Tmin, Tmax, precipitation and N(wet) between MARS (x-axis) and EA(y-axis) data.

Note: The correlations coefficients are 0.9874, 0.9982, 0.7003, and 0.7352 respectively.

8.1.2 Radiation

East Anglia does not provide radiation data, but does provide the information on the monthly average cloud-cover percentage. This together with the latitude and longitude has been used to estimate the radiation (figure 13 in appendix). Average monthly radiation can be estimated using monthly average cloud-cover percentage and geographical location.

8.1.3 Precipitation

In order to generate precipitation a Markov Chain for wet, mid, dry months is employed. The probability of a wet day after a wet day p(W|W), and the probability of a wet day after a dry day p(W|D) are calculated. First analyses show that these probabilities may be dependent on the general ‘wetness’ of the month and the plots made for the MARS data seem to confirm this theory (figure 14 in appendix). Therefore, for each month the annual observations were divided into dry (pre<q25), medium (q25<pre<q75) and wet (x>q75) categories and the transition probabilities were calculated separately for each group (figure 15 in appendix). This distinction might be important with respect to climate change weather seeds where future precipitation patterns might be significantly different from the current ones and division into wet/medium/dry may improve the quality of estimation. If the patterns are “too far“ from the current ones, the probabilities may be interpolated, using linear or other approximations.

Precipitation is assumed to follow the skewed normal distribution. The three parameters (mean, variation, and skewness) for each calendar month may be estimated from the wet days of the observed period.

In addition, EA-data does not predict the number of wet days in the future. Therefore, it must be estimated. One possibility is the quadratic function, passing through the origin, which also appears to fit well with the EA-data.

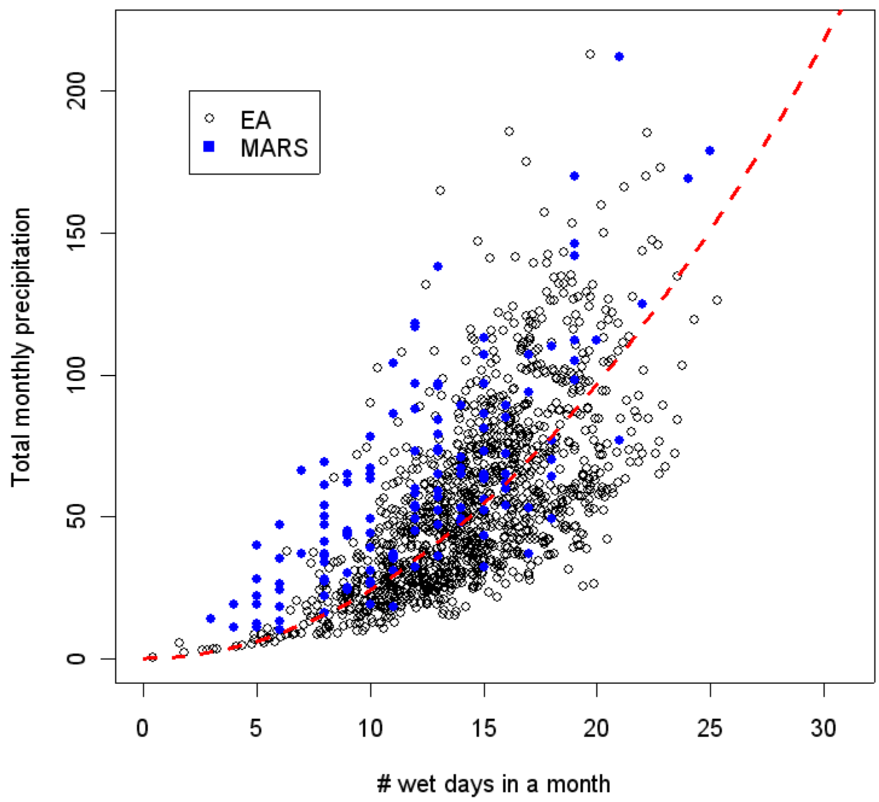


Figure 8: Total monthly precipitation vs. the number of wet days in a month for EA-data and the MARS data, and the fitted quadratic function passing through the origin.

8.1.4 Temperature

For the scenarios EA provides mean monthly temperature and diurnal range, which allow calculating Tmin and Tmax (Figure 8). However, the parameters of the distribution namely, the mean and the standard deviation are not available and should be estimated from the MARS data. Both parameters (mean and variation) exhibit seasonality. Furthermore, the standard deviation of the minimum daily temperature appears to be correlated with the mean. However, the correlation is not very high. The parameters of the normal distribution may be estimated from the minimum and maximum daily temperatures of the observed period.

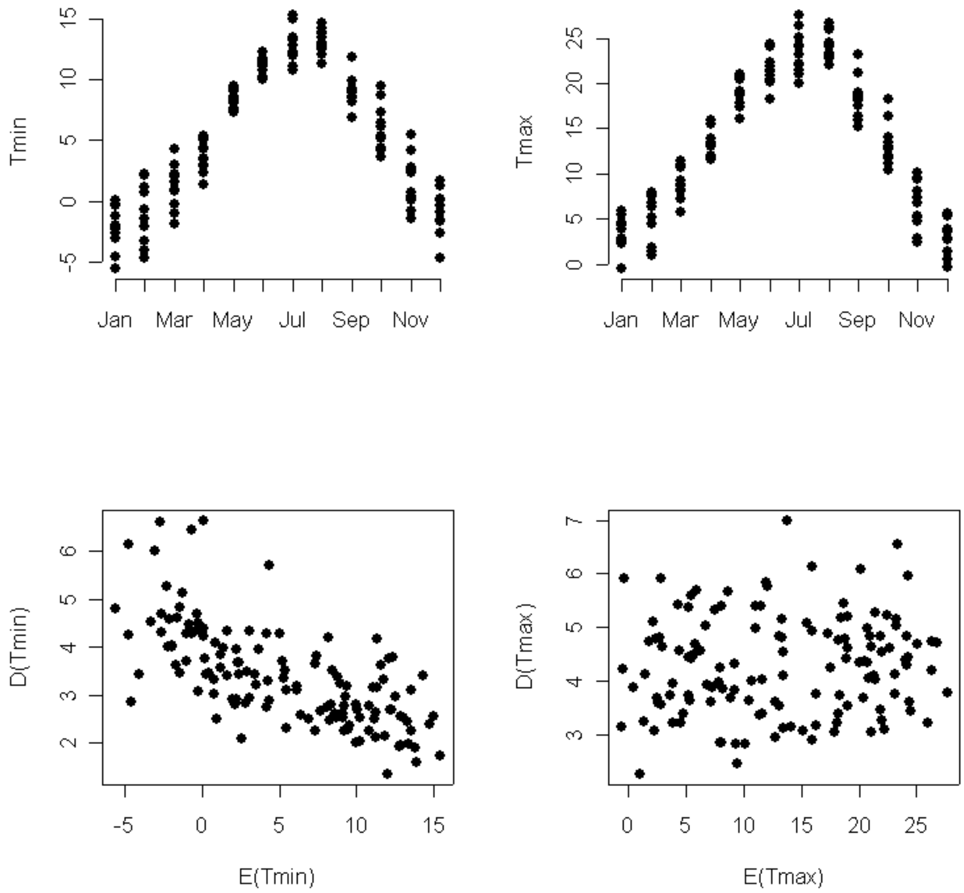


Figure 9. Mean and standard deviation of the minimum and maximum daily temperature. Note: The standard deviation of the minimum daily temperature is correlated with the mean of the minimum daily temperatures (p=-0.69).

8.2 Delineation of Homogenous Response Units

The concept of homogeneous response units was used for several reasons: (i) EPIC does not work directly on a GIS platform, and a transformation of GIS-based information to the model interface was necessary. To avoid multiple simulations with pixels, which may be redundant with respect to contents in many cases, it was decided to aggregate similar cells following some particular rules. It can be considered as kind of supervised reduction of runs to some reasonable number respecting data availability, validity, and scale. (ii) It is not realistic to setup some reliable management scenario for each pixel of the workspace (GIS grid framework with 1km cell resolution) without cumulating redundant runs for management for instance. On the other hand, aggregation of similar cells to "homogeneous" units enables several possibilities how scalar statistical data could be linked to geographical space. It is necessary to realise that delineated units are homogeneous with respect to European information on soils, i.e. to scale 1:1,000,000. (iii) Rules and criteria, which were deployed to the delineation process, follow requirements of economic models (such as EUFASOM, and AROPAj) for data organisation and character. This is the basic principle, which was respected by homogeneous response units when applied to INSEA.

The concept of "homogeneous" response units integrates input data processing, the EPIC simulation framework, and EPIC output data processing for economic modelling or dynamic comparative analyses. It also solves how data of different character, scales and aggregation levels can be consistently merged and linked to the EPIC-GIS workspace. Only those parameters of landscape, which are relatively stable over time and hardly adjustable by farmers were selected to create the raster of HRUs for EU25. The EU25 HRU coverage was obtained by mere intersection of following reclassified and categorized rasters:

- Elevation: 0 (No Data), 1 (< 300m), 2 (300-600m), 3 (600-1100m), 4 (above 1100m),
- Slope: 0 (No Data), 1 (0-3%), 2 (3-6%), 3 (6-10%), 4 (10-15%), 5 (15-30%), 6 (30-50%) and 7(more than 50%) – for arable land only 0-3%, 3-6%, 6-10%, 10-15% and over 15%
- Soil texture: 0 (NoData), 1 (coarse), 2 (medium), 3 (medium fine), 4 (fine), 5 (very fine), 9 (peat)
- Depth of soil: 0 (NoData), 1 (shallow, less than 40 cm), 2 (moderate, 40-80 cm), 3 (deep, 80-120 cm), 4 (very deep, deeper than 120 cm)

- Volume of stones in the subsoil: 1 (less than 5%), 2 (5-25%), 3 (more than 25%)

The elevation and slope rasters originate from the GTOPO30 dataset, soil texture and soil depth are from the PTRDB archive, and volume of stones was derived by reclassifying the raster of volume of stones in the subsoil, which comes from the INSEA GIS archive. The intersection was done in the Spatial analyst for ArcGIS^{TM}, while all combinations of these five input rasters were calculated on the raster base with 1 km cell resolution. Totally 1,084 HRUs for EU25 were delineated as the unique combinations of elevation, slope, soil texture, soil depth and volume-of-stones categories (Figure 10). Each HRU is identified by a SOILCLASS code, and each SOILCLASS code carries the combination of these categorized raster in the ontology table, which is associated to the EPIC input database. The ontology coding enables to follow the information chain from the input table, which is the first contact database, and reorganize data according to texture classes, elevation or slope categories and so on if necessary.

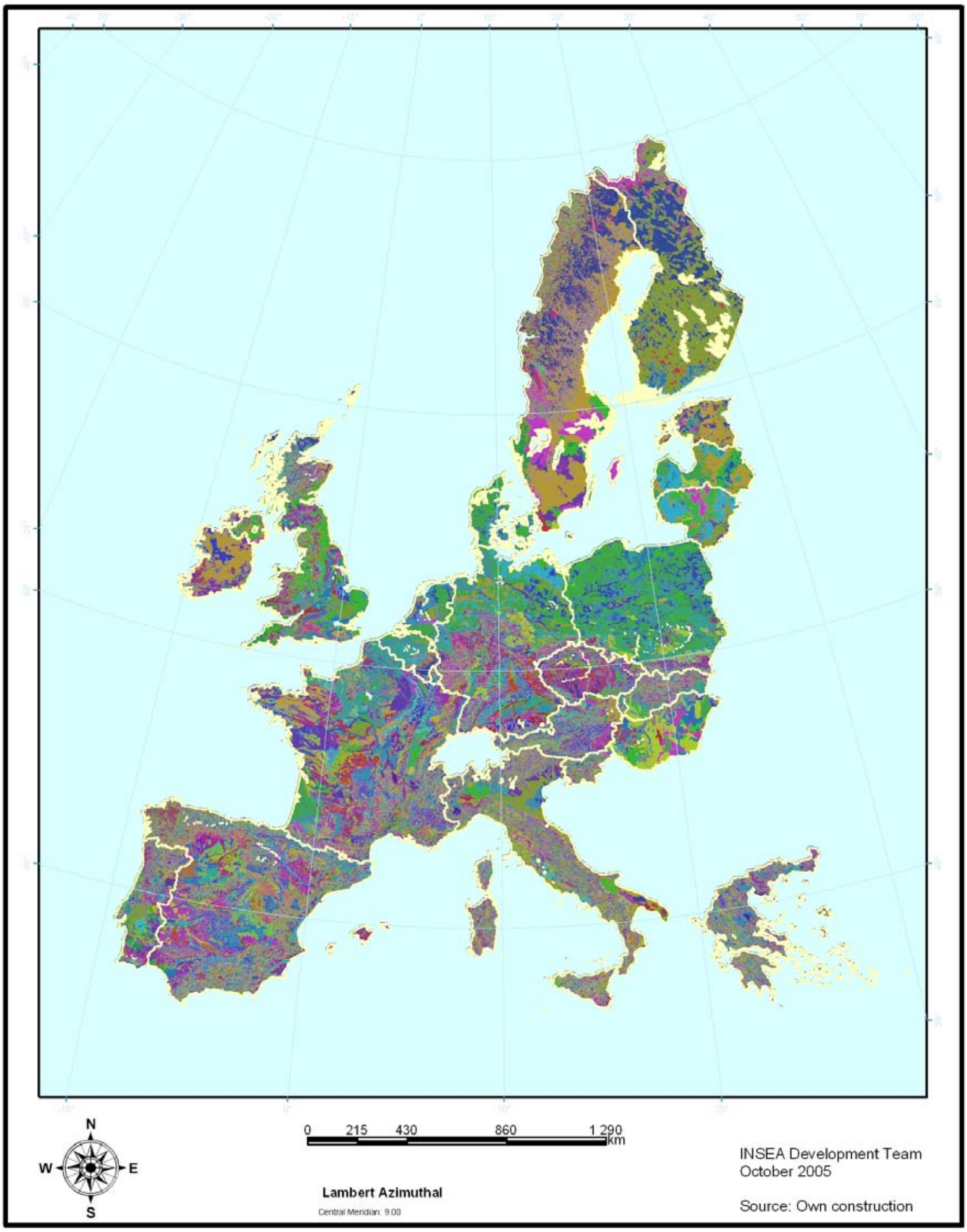


Figure 10. Delineation of Homogeneous Response Units for EU25.

The next step is to mask the layer of HRUs with land cover categories (coding of CORINE and PELCOM level 1), irrigation coverage, and NUT2 regions (AGISCO coding) – by which the individual simulated units (ISU) were obtained. For each ISU (identified by ID2 = NUTS2_LandCat_SoilClass_Irrigation), initial values of soil and topography parameters from GIS archive were calculated in GIS environment. This combination is assumed to be homogeneous enough to be characterised by one management, and small enough to be characterised by one climate, one MARS meteorological file/cell respectively. This HRU process is abstractly described in Figure 11.

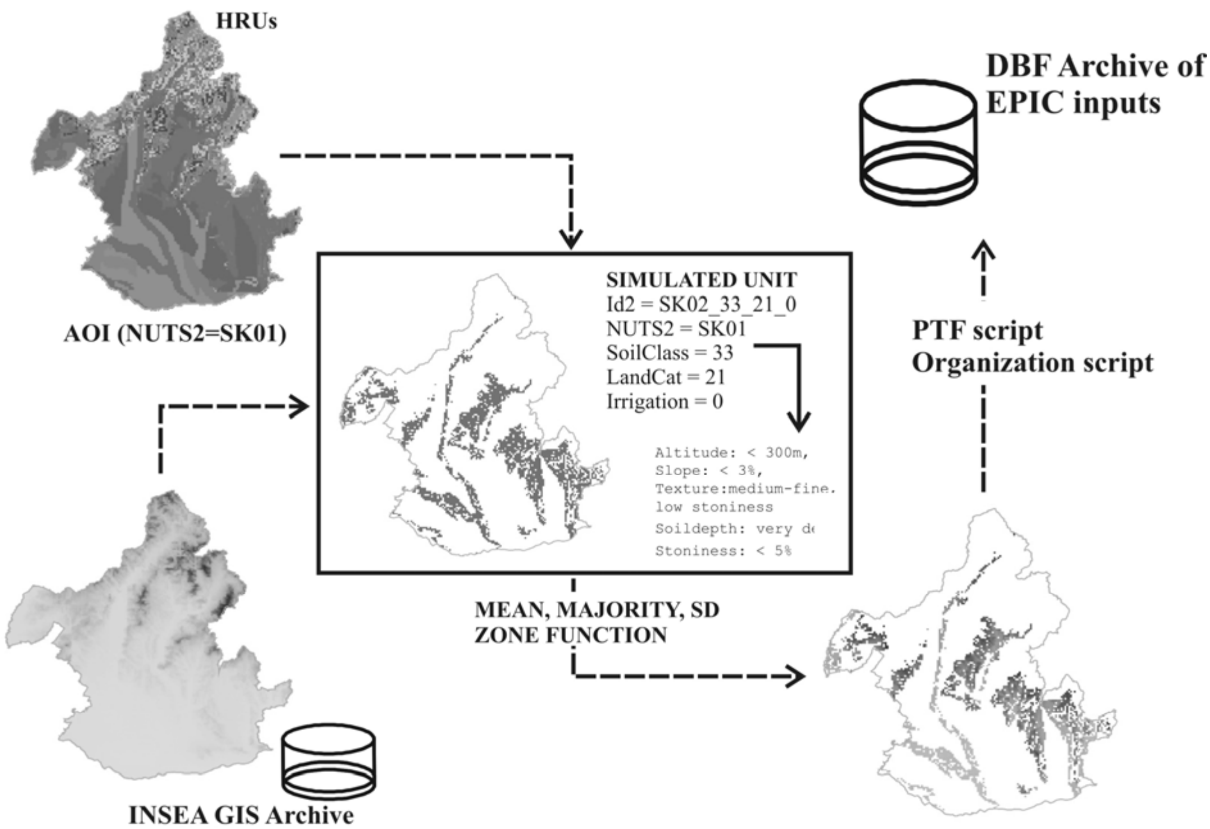


Figure 11. The method of creating input data for EPIC simulations.

The concept of HRU/ISU in EPIC biophysical process modelling for EU25 deploys to find an image of a likely field, which we could consider as typical for an ISU. We are aware that data availability, quality, and scales, do not allow making nothing more than a “scenario” of a likely field. The real country is much more variable than our generalization, however, we assume that available information on soil, topography and meteorology describes general conditions, which reflect expert opinions for likely site conditions (maps of soil properties and soil mapping units, DEM, MARS meteo-coverage and so on). We construct an image of a representative field, which reflects available data at scale 1:1,000,000, with likely site conditions and management, and we extrapolate the field impacts uniformly to the entire ISU (Figure 12). The effects and impacts of site and management practices for an ISU are therefore expected as field-size effects.

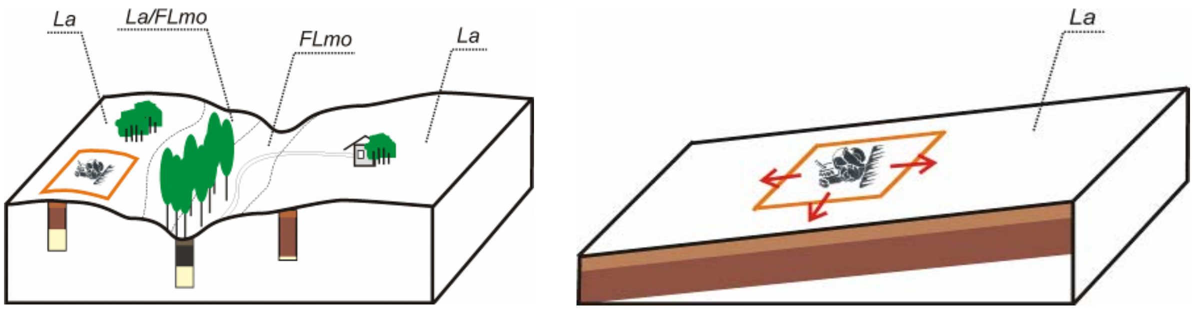


Figure 12. A schematic view of a representative field per ISU. An image of 'real' cropland with variable soil characteristics (La – Albic Luvisols, FLmo – Mollic Fluvisols), different land-cover patches and different land uses (left), and an image of a representative field, which reflects available data at scale 1:1,000,000, with likely site conditions and management, and we extrapolate the field impacts uniformly to the entire ISU (right).

The core of individual sub-procedures for creating the DBF for EPIC input parameters consists of source codes written in ERDAS IMAGINE™ environment, and Microsoft Visual Basic™. The routines are running with GIS raster layers in 1 km resolution. All the process can be divided into 4 individual steps as listed below:

- Subset the GIS raster archive for the Area Of Interest (AOI),
- Zone statistics for soil and topography data (masking for land cover categories)
- Joining individual tables form GIS sub-procedures, and
- EPIC input database.

8.3 Subset of GIS raster archive for Area of Interest (AOI)

AOI coverage (NUTS2 level) acts as information, which allocates particular NUTS2 regions, for which the routine would operate. AOI itself determines the batch process, i.e. the set of NUTS2 regions, which are executed by one run. The subset procedure will cut, encode, and store only that part of GIS raster archive, which is deployed to the analyses per NUTS2 region.

8.4 Zone statistics for soil and topography data

This procedure in ERDAS™ is designed for automatic feeding the output files by soil and topographical data. Each combination of NUTS2 + LandCat + SoilClass + Irrigation is fed by data using zonal statistics. Zone statistics calculate mean values, standard deviations, or majority values in some cases, from all input rasters that belong to the particular zone. Selective querying is done by a procedure described below (for AOI 105 /AT11/ and Land category 21 /arable land/). Mean values from all input parameters of soil and topography are stored in ASCII files named originally by combination of NUTS region and Land Category (e.g. AT11_21.txt).

```
cec_top = ZONAL MEAN ($iso_105_21, $cec_top_1k, IGNORE 0)
cec_sub = ZONAL MEAN ($iso_105_21, $cec_sub_1k, IGNORE 0)
oc_top = ZONAL MEAN ($iso_105_21, $oc_top_1k, IGNORE 0)
sand_top = ZONAL MEAN ($iso_105_21, $sand_top_1k, IGNORE 0)
sand_sub = ZONAL MEAN ($iso_105_21, $sand_sub_1k, IGNORE 0)
silt_top = ZONAL MEAN ($iso_105_21, $silt_top_1k, IGNORE 0)
silt_sub = ZONAL MEAN ($iso_105_21, $silt_sub_1k, IGNORE 0)
sob_top = ZONAL MEAN ($iso_105_21, $sob_top_1k, IGNORE 0)
sob_sub = ZONAL MEAN ($iso_105_21, $sob_sub_1k, IGNORE 0)
vs_top = ZONAL MEAN ($iso_105_21, $vs_top_1k)
vs_sub = ZONAL MEAN ($iso_105_21, $vs_sub_1k)
subl = ZONAL MEAN ($iso_105_21, $subl_1k, IGNORE 0)
elevation = ZONAL MEAN ($iso_105_21, $elevation_1k, IGNORE 0)
slope = ZONAL MEAN ($iso_105_21, $slope_1k, IGNORE 0)
…
```

8.5 Joining individual tables from GIS sub-procedures

Individual input files are joined together and appended to predefined records in MS Access environment. All data, which are NUTS2 and LandCat specific, are stored in Database Archive. A set of scripts written in Visual Basic Application for MS Access were prepared to organise data properly, generate codes and identifications, and to complete missing values, etc. Other scripts were prepared to run particular PTF procedures with new data, to generate additional properties, which are not in GIS raster archive, such as bulk density, hydraulic properties, hydrological groups etc.

8.6 Management practices

An important input for EPIC simulations are land use management practices. Basically it includes crop rotations, fertilization and irrigation schedules, as well as planting, harvesting, and tillage operations. The optimal situation would be one, where for each ISU sufficient information is available to setup base-run management practices. Unfortunately, there exist gaps in data availability for detailed management practices. Most of data are available only in aggregated forms like by regions, by country, by types of farms, or not at all. In INSEA we do not disaggregate management information to very fine resolutions, because it has appeared as problematic and uncertain, and because the regional scope is NUTS2. Nevertheless, we disaggregate NUTS2 statistics of New Cronos to elevation classes, so that we could follow, for example, crop distribution along elevation gradients. The following subchapters describe partial utilities, which were used to specify management practices for the biophysical process simulations.

8.6.1 Crop shares and crop rotations

Crop shares vary a lot within NUTS2 regions and New Cronos statistics at NUTS2 level can be incomplete and inconsistent for crop shares. In INSEA, New Cronos statistics were made geographically explicit by using LUCAS site observation data to better allocate crop shares within NUTS2 regions, and to more appropriately design typical crop rotation systems. No information exists for EU25 for crop rotations, but the numerous crops usually listed in statistics reveal that plenty of crop rotation systems must exist.

The first step involves making crops and the aggregated groups respectively, consistent between New Cronos statistics and LUCAS. Aggregated crop groups are almost consistent, except of total maize (MAIZETOT), and temporary pastures (TEMP_PAST). Temporary pastures by LUCAS could be, but only partially, linked to green fodder by New Cronos. In further step, New Cronos statistics were downscaled to elevation classes. Due to LUCAS data coverage and some minimum requirements for significant amount of LUCAS points, LUCAS data broker does not work for all NUTS2 regions of EU15. Therefore, the distribution of crops along elevation was studies at NUTS1 level, and then the same function was applied to all NUTS2 regions within NUTS1. Lucas observation points, which carry information on observed crops in two years totally, create the maps of individual crops, of which frequencies for a particular elevation class and NUTS1 region (NUTS_ElevClass) can be calculated. The next figure shows where maize was mostly planted in EU15 as gathered by LUCAS, and a crop distribution pattern along elevation classes in Baden-Württemberg.

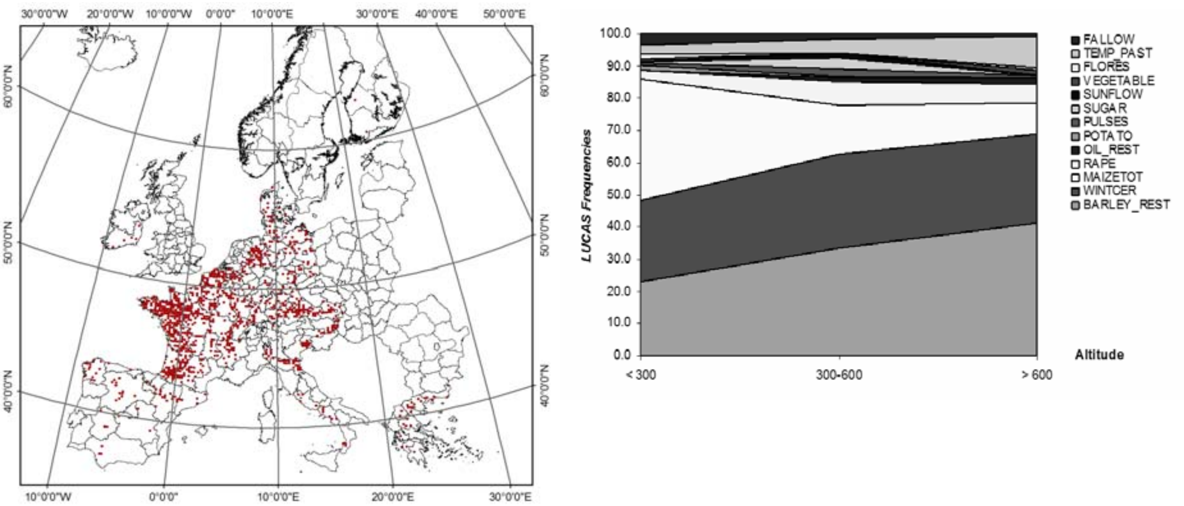


Figure 13. The distribution of maize from LUCAS database (left), and crop distribution pattern along elevation classes for Baden-Württemberg region (right).

The assumptions for the Lucas data broker are that the frequency of '*j*-th' crop (F*j*) in NUTS1 region can be expressed as weighted sum of crop frequencies 'F*ij*' obtained in '*i*-th' elevation class, while the weight coefficient 'w*i*' determines the area fraction of '*i*-th' elevation class in arable land (1). If LUCAS is a good predictor of crop shares, this frequency should be close to crop share of '*j*-th' crop in New Cronos statistics (P*j*), i.e. LUCAS observation system would have the same crop statistics as New Cronos does.

$$F_j = \sum_{i=1}^{3} w_i F_{ji} \qquad (1)$$

In Table 4, LUCAS crop frequencies (Fj) are compared with New Cronos crop shares (Pj) for the NUTS2 region DE11 (Stuttgart). There, soft wheat is slightly overestimated and barley underestimated by the LUCAS database. However, the statistics are relatively close and LUCAS is expected to work properly in downscaling New Cronos statistics to elevation classes.

	$F_{j1} \times W_1$	$F_{j2} \times W_2$	$F_{j3} \times W_3$	F_j	P_j
WHEAT_CER	14.7	16.3	4.9	35.9	27.3
BARLEY	10.7	14.4	4.0	29.0	34.5
MAIZE	5.1	3.5	4.9	13.5	10.9
SUGAR BEET	2.3	1.6	1.0	4.8	5
RAPE	2.8	4.7	1.0	8.5	8
SUNFL	0.0	0.4	0.0	0.4	0.8
OIL_REST	0.0	0.4	0.0	0.4	0.1
PULSES	1.1	0.0	0.0	1.1	1
FALLOW	1.7	0.8	0.0	2.5	4.6
TEMP PAST	1.1	1.6	0.0	2.7	4.6
POTATOES	0.5	0.5	0.2	1.2	1.2

Table 4. A comparison of LUCAS crop frequencies (Fj) with New Cronos crop shares (Pj) in Stuttgart (DE11) region of Baden-Württemberg.

The final stage of this procedure is described by equations 2-4. There, we calculate fractions of weighted frequencies (Fr*ji*) for elevation classes (2) and disaggregate New Cronos crop shares (P*j*) to 3 elevation classes by multiplying them with these fractions (3). Hence, New Cronos crop shares are distributed to elevation classes (C*ji*) respecting the variability gathered by the LUCAS plot observation system. Finally, crop shares (C*ji*) are divided by weight coefficients (w*i*) so crop shares per unit area (4) can be calculated.

$$Fr_{j1} = F_{j1} w_1 / F_j \tag{2}$$

$$CS_{j1} = Fr_{j1} P_j \tag{3}$$

$$P_{j1} = CS_{j1} / w_1 \tag{4}$$

LUCAS crop frequencies (F*ij*) and New Cronos crop shares (P*ij*), which are the results of the LUCAS data broker, are shown in Table 5 using the example from the NUTS2 region Stuttgart. The LUCAS broker disaggregates New Cronos statistics to geographically explicit elevation classes that will enable us to catch regional specifications in the process of crop rotation setup.

	F_{j1}	F_{j2}	F_{j3}	P_{j1}	P_{j2}	P_{j3}
WHEAT_CER	37.1	37.5	31.3	27.9	28.2	23.5
BARLEY	27.1	33.0	25.0	31.9	38.8	29.3
MAIZE	12.9	8.0	31.3	10.2	6.4	24.9
SUGAR BEET	5.7	3.6	6.3	5.9	3.7	6.4
RAPE	7.1	10.7	6.3	6.7	10.0	5.8
SUNFL	0.0	0.9	0.0	0.0	1.8	0.0
OIL_REST	0.0	0.9	0.0	0.0	0.2	0.0
PULSES	2.9	0.0	0.0	2.5	0.0	0.0
FALLOW	4.3	1.8	0.0	7.9	3.3	0.0
TEMP PAST	2.9	3.6	0.0	4.8	6.1	0.0
POTATOES	X	X	X	1.2	1.2	1.2

Table 5. A comparison of LUCAS crop frequencies (Fji) and New Cronos crop shares (Pji) broken down to 3 evelation classes by LUCAS Data in Stuttgart (DE11) in Baden-Württemberg.

The figure below shows an example of the spatial distribution of barley and maize crop shares from New Cronos using the LUCAS data broker.

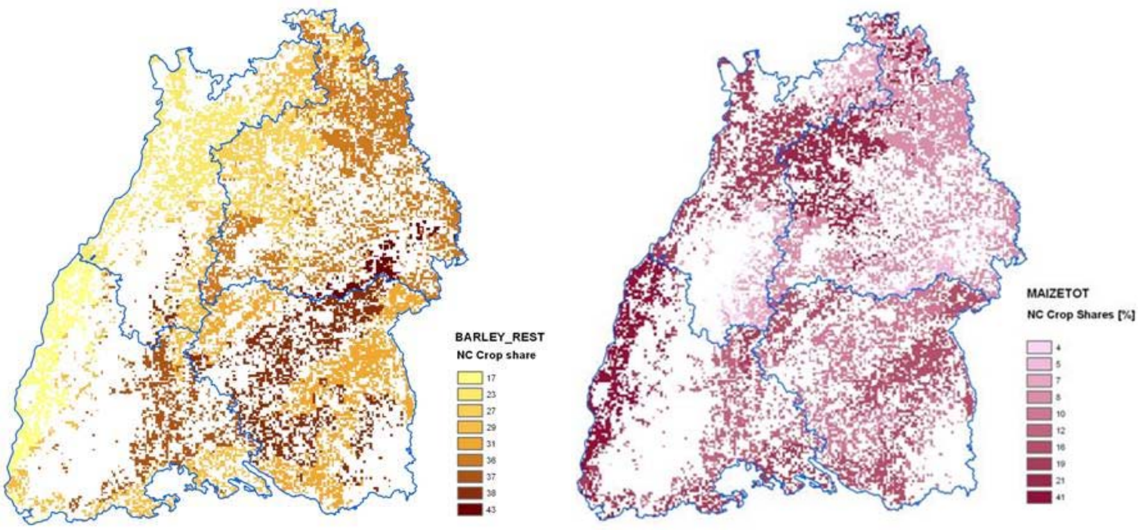


Figure 14. Crop shares of barley (left) and maize (right) for elevation classes of Baden-Wurttemberg Source: New Cronos, disaggregating agent: LUCAS.

Crop rotation has an integral part in the crop production system of a farm. Crop rotation is a common practice for increased yields, soil fertility, fertilizer needs, plant diseases control, erosion reduction, etc. Proper crop rotation systems may reduce partially or at all mineral fertilizer needs, because alfalfa and other legumes provide an nitrogen input for following crops through nitrogen fixation. Based on numerous field experiments, it has been proved that good crop rotation systems will provide more consistent crop yields, build soil structure, and increase profits. Defining crop rotation seems to be one of the most significant information with respect to the INSEA research objectives. Crop rotation systems (CRS) usually play an important role in particular management practices. It strongly determines tillage schedule, irrigation, fertilisation and all alternative management scenarios on arable land. The major challenge is to set basic rules and principles for building crop rotation systems for base-run management practices in EU25.

All CRS are being regarded as scenarios that might be or not be used in reality. Crop rotations are being defined with respect to economical and agronomical production rules. Therefore, CRS scenarios are based on (i) New Cronos statistics on crop shares, and (ii) CRS rules. New Cronos is the only statistical source of crop share information for the extent of EU25. For base-run management simulations, CRS should closely replicate New Cronos crop share statistics. According to agronomic CRS rules, crops are aggregated into three classes as follows:

CLASS 1- Crops can be cultivated after anyone including itself.
CLASS 2- Crops that can follow anyone except of winter and spring cereals.
CLASS 3- Crops can follow anyone except itself;

In summary, the New Cronos crops and crop groups and the agronomic rules for setting up CRS is shown in Table 6. Agronomic rules also respect some sanitation lapses in crop cultivation, which is especially true for rape, sunflower, flax, sugar beet, potatoes, pulses etc.

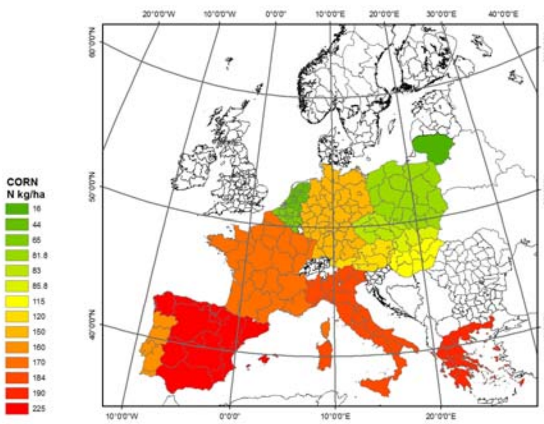
Crop		WINCER	BARL	MAIZ	POTA	SUGR	SUNF	RAPE	SOYA	COTT	OILR	TOBA	PULS	GRNR	FALW	REST
Class		2	3	1	3	3	3	3	3	1	3	3	3	1	1	1
Follow-crop	Class															
WINCER	2	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+
BARL	3	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+
MAIZ	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
POTA	3	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+
SUGR	3	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+
SUNF	3	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
RAPE	3	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+
SOYA	3	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
COTT	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
OILR	3	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+
TOBA	3	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+
PULS	3	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+
GRNG	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
FALW	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
REST	1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

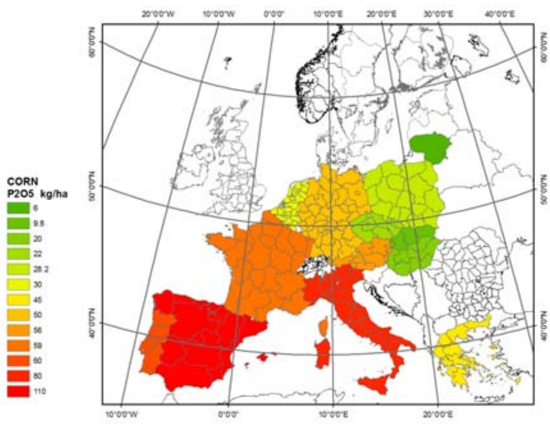
Table 6. Possible combinations of crops respecting basic agronomic CR rules

To approximate CRS, a rule-based optimisation models was developed. Rules include the prohibition of infeasible or highly deficient crop sequences, the matching of observed total crop shares at NUTS2 level, and the preference of sequences with high agronomic values as specified in the German *Fruchtfolgekreuz* (rotation table) and the previous table. The solution of the decision model consists of a set of rotations and their relative share within each NUTS2 region.

8.6.2 Fertilization

Fertilization by mineral fertilizers (N, P and K) is implemented as the information per crops is provided by FAO (IFA-IFDC-IPI-PPI-FAO, 2002). That publication presents data for 88 countries on fertilizer use by crop types expressed in plant nutrients for nitrogen (N), phosphate (P2O5) and potash (K2O). The comparison between crop list in INSEA and FAO source was made first, and country data of crop-specific fertilizer rates were linked to NUTS2 regions, while we assume the same rates for each NUTS2 of a country by default. Average crop yields by NUTS2 region, nutrient removal coefficients for harvested crops, and a multiplier that accounts for surplus fertilization (through the assumption of imperfect knowledge by farmers) are used to re-calibrate the crop and crop rotation specific fertilization schedules by NUTS2 region. Figure 15 presents the distribution of mineral N, P and K fertilizers applied for corn based on FAO (IFA-IFDC-IPI-PPI-FAO, 2002).





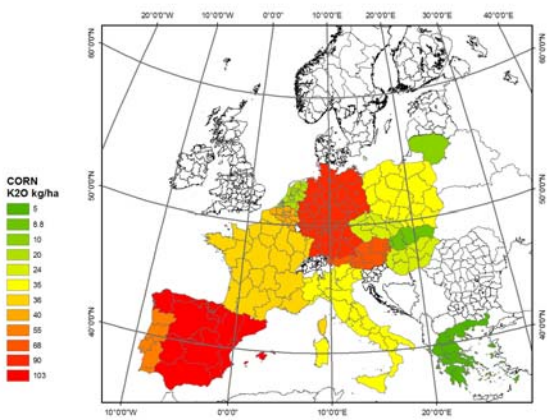


Figure 15. Distribution of mineral N, P and K fertilization rate for corn (source IFA-IFDC-IPI-PPI-FAO, 2002).

8.6.3 Irrigation

Stating the irrigation baseline includes two separate steps: (i) spatial allocation of irrigation devices, and (ii) crop specific information on irrigation rates. It is not possible directly allocate where irrigation is actually applied. Therefore, we use an approximation that the existence of an irrigation system allocates irrigation in the landscape. This kind of information is implemented in the CORINE and PELCOM dataset as well as in LUCAS. By combining these two sources, i.e. the category of permanently irrigated arable land in CORINE and PELCOM database and irrigated plots of LUCAS, the irrigation raster with 1km cell resolution over EU25 was constructed (Figure 16). This information inputs the process of delineating the simulated units in the biophysical process modelling (irrigation code = 1 for these pixels), so that the irrigation schedule can be switched on or off for individual simulations.

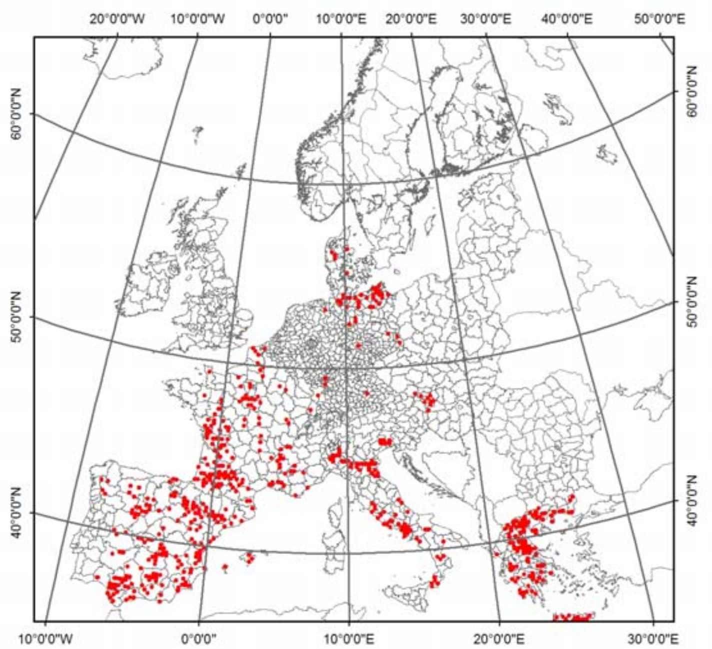


Figure 16. Spatial allocation of irrigation by CORINE and PELCOM (permanently irrigated arable land) and LUCAS (observation plots with positive irrigation).

The identification of irrigation water rates (in mm) is similarly approached as for mineral fertilizer rates. An alternative option is provided by EPIC, which one can set an acceptable drought stress level for automatic irrigation. Therefore, irrigation water rates could be determined endogenously or/and exogenously (e.g. by calculating an irrigation index). In the project we used LUCAS observation system to estimate crop specific irrigation, i.e. which crops are mostly irrigated and which not. We prepared a database for EU15, where the order of crops for irrigation was constructed (weights denoting an importance of irrigation) for individual INSEA crops at NUTS1 region (a shift from NUTS2 to NUTS1 was done because more points from LUCAS would provide statistically more robust analyses). Aggregated results of frequencies for crops that are likely irrigated at EU15 are shown in Figure 17.

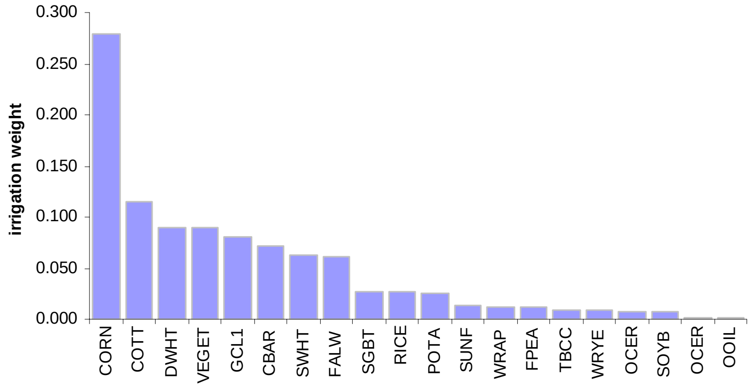


Figure 17. An order of crops according to importance of irrigation for its growth (based on LUCAS dataset for EU15).

8.6.4 Crop calendar

Crop calendar, which provides information on where and when crops are grown, was adopted from the MARS project. It is relevant for 50 km MARS mesh, the same as was used for weather parameters. For some crops (1 – winter wheat, 2 – grain maize, 3 – spring barley, 5 – rice, 6 – sugar beet, 7 – potatoes, 8 – field beans, 9 – soy beans, 10 – oil rapeseeds, 11 – sunflower, 12 – green maize, 13 – winter barley, 14 – spring wheat, 15 – spring rape seed), it contains modelled parameters as listed in Table 7. The information on day of starting growth and duration of vegetation period was also used to calibrate the potential heat units for crops in EPIC model for various conditions across Europe. Figure 18 shows an example of the earliest day in month when maize grain is starting to grow. That information was converted to the level of ISUs for those crops, which information is available.

CROP_CALENDAR (description of where and when crops are grown)	
GRID_NO (grid number)	NOT NULL
CROP_NO (crop number)	NOT NULL
VARIETY_NO (variety number)	NOT NULL
YEAR (calendar year)	NOT NULL
START_TYPE (the way crop starts)	NOT NULL
START_MONTHDAY1 (earliest day in month crop starts)	NOT NULL
START_MONTHDAY2 (latest day in month crop starts -optional)	
START_MONTH1 (earliest month crop starts)	NOT NULL
START_MONTH2 (latest month crop starts - optional)	

END_TYPE (the way a crop ends)	NOT NULL
END_MONTHDAY (day in month crop ends)	NOT NULL
END_MONTH (month crop ends)	NOT NULL
MAX_DURATION (maximum duration for crop on field)	NOT NULL

Source: MARS

Table 7: The metadata structure of crop calendar in MARS project .

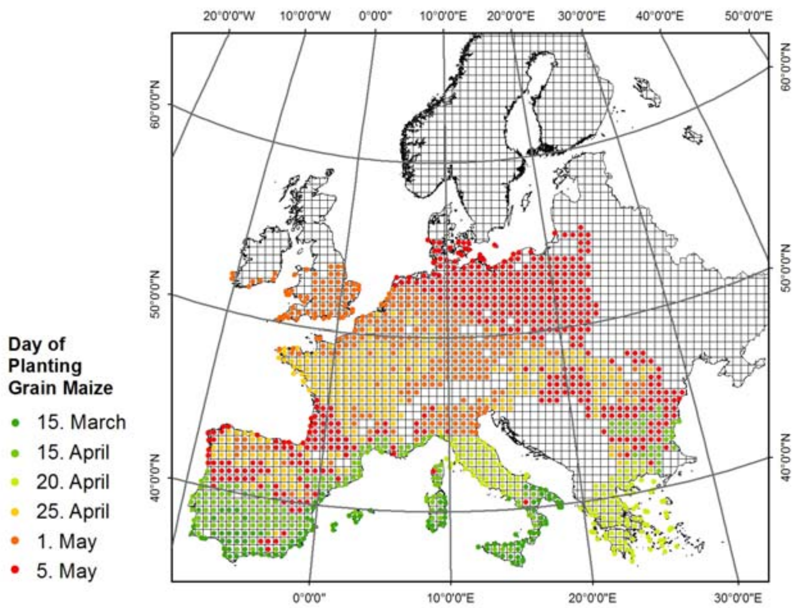


Figure 18. Earliest date of growth for grain maize as generated from MARS crop calendar (source: MARS)

8.6.5 Tillage operations

The list of tillage and management practices examined in the present study includes (i) conventional tillage i.e., moldboard ploughing, (ii) reduced tillage i.e., disk and chisel ploughing, and (iii) minimum tillage i.e., shallow disk and chisel ploughing with direct seeding. These tillage systems differ in their costs and in their effectiveness of mixing crop residues into the soil. Thus, different tillage systems imply different crop residue management (CRM). The Conservation Technology Information Center (CTIC, 2005) defines CRM as a year-round system beginning with the selection of crops that produce sufficient quantities of residue and may include the use of cover crops after low residue producing crops. CRM includes all field operations that affect residue amounts, orientation and distribution throughout the period requiring protection. The residue level after planting determines the tillage category (mulch-till, reduced-till, or intensive-till). Particularly, conservation tillage types are those tillage and planting systems which at planting cover 30 percent or more of the soil surface with crop residue. To employ the CRM definitions, crop specific tillage operations are assembled by subtracting the mixing efficiency coefficients of individual tillage operations from the approximated fractions of residues left on the surface after each tillage operation. The higher a mixing efficiency of a tillage operation (e.g. moldboard plough is 0.95) the lesser crop residues will remain on the surface. All residue fractions are multiplied to obtain the average amount of crop residues left on surface. The calculations were repeated for all combinations of the three investigated tillage systems and all relevant crops. The average percentages of crop residues on surface after planting operations amounted to:

- about 5 % for conventional tillage (moldboard plough),
- about 15 % for reduced tillage (disk and chisel ploughs), and
- about 45 % for minimum tillage (shallow disk and chisel ploughs with direct seeding).

9. Conclusions

The EU has sufficient data to model complex relationships between policy measures and various economic and environmental indicators. However, the data is available in different quality, and from different authorities. To meet the model requirements, the data should be processed in a certain way, including filling the gaps by using the scientific estimations and transfer functions, adjusting and scaling data to common and consistent platforms, processing the data in a way to satisfy model cluster requirements, etc. Consequently, complex landscapes with heterogeneous land management, and individual or collective decision making, have to be stratified into homogeneous unit, i.e. Homogenous Response Units and Decision Making Units. A spatially and temporally indexed common activity based unit (e.g. hectares, animal heads) assures the linkage between homogeneous response and decision making units. The delineation of homogeneous response units and an appropriate data stratification involves statistical or/and GIS based methods by merging weather, soil, topographic, land use, and management information. As a result of described processing, nearly 287,000 of data-intensive simulation units were prepared for EU25, which are ready to use for many biophysically-based model, such as EPIC for example. Soil, topography and climate data were aggregated for different land-cover categories and NUTS levels. In addition, the management scenarios for cropland were proposed. The data is indexed in a way to allow hierarchical re-arranging for different interpretation levels.

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Appendix. Input parameters for the biophysical and economic models

Table 8. Physical and chemical soil parameters needed by EPIC essential soil information.

General soil and hydrologic data	**Useful soil data**
Soil albedo (moist)	initial soil water content (fraction of field capacity)
Hydrologic soil group (A, B, C, or D)	minimum depth to water table in m maximum depth to water table in m initial depth to water table in m initial ground water storage in mm maximum ground water storage in mm ground water residence time in days return flow fraction of water percolating through root zone soil weathering ($CaCO_3$ soils; non-$CaCO_3$ soils that are slightly, moderately or highly weathered) number of years of cultivation soil group (kaolinitic, mixed, or smetitic) fraction of org C in biomass pool fraction of humus in passive pool soil weathering code
Soil layer	
depth from surface to bottom of soil layer in m bulk density of the soil layer (moist) in t/m3 sand content in % silt content in % soil pH organic carbon in % calcium carbonate content in %	bulk density of the soil layer (oven dry) in t/m3 wilting point (1500 kPa for many soils) in m/m field capacity (33 kPA for many soils) in m/m Initial organic N concentration in g/t sum of bases in cmol/kg cation exchange capacity in cmol/kg coarse fragment content in %vol. initial soluble N concentration in g/t initial soluble P concentration in g/t initial organic P concentration in g/t exchangeable K concentration in g/t crop residue in t/ha saturated conductivity in mm/h fraction of storage interacting with NO_3 leaching phosphorous sorption ratio lateral hydraulic conductivity in mm/h electrical conductivity in mm/cm structural litter kg/ha metabolic litter kg/ha lignin content of structural litter in kg/ha carbon content of structural litter in kg/ha C content of metabolic litter in kg/ha C content of lignin of structural litter in kg/ha

	N content of lignin of structural litter in kg/ha C content of biomass in kg/ha C content of slow humus in kg/ha C content of passive humus kg/ha N content of structural litter in kg/ha N content of metabolic litter in kg/ha N content of biomass in kg/ha N content of slow humus in kg/ha N content of passive humus in kg/ha observed C content at the end of simulation

Table 9. List of GIS layers.

1. Vector GIS Archive
SWU_10k.shp (origin in 10kgridSWU.shp) EU_25_NUT2.shp (origin in Nuec1mv7 ArcINFO Coverage) LUCAS_SSU1.shp
Projected coordinate system: Lambert Azimuthal Equal Area Geographic coordinate system: GCS_Sphere_ARC_INFO Longitude of Projection Centre: 9.000000 Latitude of Projection Centre: 48.000000 False Easting: 0.000000 False Northing: 0.000000 Planar Distance Unit: meters Coordinate Encoding Method: coordinate pair Abscissa Resolution: 0.008192 Ordinate Resolution: 0.008192 Geodetic model: D_Sphere_ARC_INFO Ellipsoid Name: Sphere_ARC_INFO Semi-major Axis: 6370997.000000 Denominator and Flattening Ratio: infinity
2. ESRI Grid GIS Archive
soil_class_1k.grd topo_class_1k.grd (origin in GTOPO30) lc_level_2.grd (origin in l_clc_pelc.grd) lc_level_3.grd (origin in l_clc_pelc.grd) nuts2_1k.grd (origin in Nuec1mv7 ArcINFO Coverage) slope1k_perc.grd (origin in GTOPO30) elevation_1k.grd (origin in GTOPO30)
Projected coordinate system: Lambert Azimuthal Equal Area Geographic coordinate system: GCS_Sphere_ARC_INFO Longitude of Projection Centre: 9.000000 Latitude of Projection Centre: 48.000000 False Easting: 0.000000 False Northing: 0.000000 Planar Distance Unit: meters Coordinate Encoding Method: row and column Abscissa Resolution: 1000.000000 Ordinate Resolution: 1000.000000 Geodetic model: D_Sphere_ARC_INFO Ellipsoid Name: Sphere_ARC_INFO Semi-major Axis: 6370997.000000 Denominator and Flattening Ratio: infinity 1.2. Reclassification of Land Categories (LC) for EPIC modelling targets

LUCAS CROP GROUP CODE	DESCRIPTION	NEW CRONOS CROP GROUP CODE	DESCRIPTION
WINTCER	Winter cereals: common wheat (B11), durum wheat (B12), rye (B14)	WINTCER	Soft and durum wheat, rye
SPRINGCER	Spring cereals: barley (B13), oats (B15), other cereals (B18)	BARLEY OATS_REST	Barley Oats and other cereals
MAIZETOT	Grain and fodder maize: maize (B16)	MAIZEGR MAIZEFOD	Grain Maize Green Maize
RICE	Rice (B17)	RICE	Rice
POTATO	Potato (B21)	POTATO	Potato
SUGGAR_REST	Sugar beet (B22) and other root crops (B23)	SUGAR	Sugar beet
SUNFLOW	Sunflower (B31)	SUNFLOWER	Sunflower seeds
RAPE	Rape seeds (B32)	RAPE	Rape seeds
SOYA	Soya (B33)	SOYA	Soya beans
COTTON	Cotton (B34)	COTTON	Cotton
FIBR_OLE	Other fibred and oleaginous crops (B35)	FLAX	Other oilseeds and textile crops
TOBACCO	Tobacco (B36)	TOBACCO	Tobacco
IND_CROP	Other non-permanent industrial crops (B37)	-	-
PULSES	Dry pulses (B41)	PULSE	Dry pulses (total)
VEGETABLE	Tomato (B42), other fresh vegetable (B43)	-	-
TEMP_PAST	Temporary and artificial pastures (B50)	GREEN_REST	Derived from LANDUSE and CROP statistics numbers as difference GREEN FODDER tot – MAIZEFOD
FALLOW	Fallow (B60)	FALLOW	Fallow

Table 10. The aggregation of LUCAS crops with respect to NC Statistics.

1. CEREREAL TOT (total cereals)	1.1. CEREAL	1.1.1. DURWHEAT (durum wheat)
		1.1.2. SOFTWHEAT
		1.1.3. RYE
		1.1.4. BARLEY
		1.1.5. MAIZEGR (grain maize)
	1.2. RICE	
2. MAIZEFOD (green/fodder maize)		
3. POTATO		
4. PULSE (dried pulses total)		
5. SUGAR (sugar beat)		
6. OILSEED (oilseeds)	6.1. RAPE (rape and turnip rape)	
	6.2.SUNFLOWER	
	6.3. SOYA	
7. FLAX (oilseeds and textile)		
8. COTTON(oilseed and textile)		
9. TOBACCO		

Source: EUROSTAT

Table 11. List of crops in New Cronos statistics and its structure.

1. CATTLE (bovines total)	1.1. CALF (bovines less than 1 year)
	1.2. BULL1_2Y (male bovines, 1-2 years)
	1.3. HEIF1_2Y_SL (female bovines for slaughter, 1-2 years)
	1.4. HEIF1_2Y_BR (other female bovines, 1-2 years)
	1.5. BULL2Y (male bovines , 2 years and above)
	1.6. HEIF2Y_SL (slaughter heifers, 2 years and above)
	1.7. HEIF2Y_BR (others heifers, 2 years and above)
	1.8. COW (cows total)
	1.9. BUFFALO (total buffalos)
2. PIG (total pigs)	2.1. PIGLET20KG (piglets with less than 20 kg)
	2.2. PIG20_50KG (pigs of 20 kg or more but less than 50 kg)
	2.3. PIG50KG (fattening pigs of 50 kg and over)
	2.4. BOARS (breeding boars)
	2.5. SOW_BR (total breeding sows)
3. SHEEP (sheep total)	
4. GOAT (goats total)	
5. EQUID (Equidae total)	
6. POULTRY (poultry total)	

Source: EUROSTAT

Table 12. List of livestock categories in New Cronos statistics and its structure.

GISCO Code	New Cronos Code	Administrative region
AT11	AT11	BURGENLAND
AT12	AT12	NIEDEROESTERREICH
AT13	AT13	WIEN
AT21	AT21	KAERNTEN
AT22	AT22	STEIERMARK
AT31	AT31	OBEROESTERREICH
AT32	AT32	SALZBURG
AT33	AT33	TIROL
AT34	AT34	VORARLBERG
BE1	BE1	REG.BRUXELLES-CAP./BRUSSELS HFDST. GEW.
BE21	BE21	ANTWERPEN
BE22	BE22	LIMBURG (B)
BE23	BE23	OOST-VLAANDEREN
BE24	BE24	VLAAMS BRABANT
BE25	BE25	WEST-VLAANDEREN
BE31	BE31	BRABANT WALLON
BE32	BE32	HAINAUT
BE33	BE33	LIEGE
BE34	BE34	LUXEMBOURG (B)
BE35	BE35	NAMUR
CZ01	CZ01	PRAHA
CZ02	CZ02	STREDNI CECHY
CZ03	CZ03	JIHOZAPAD
CZ04	CZ04	SEVEROZAPAD
CZ05	CZ05	SEVEROVYCHOD
CZ06	CZ06	JIHOVYCHOD
CZ07	CZ07	STREDNI MORAVA
CZ08	CZ08	MORAVSKOSLEZSKO
DE11	DE11	STUTTGART
DE12	DE12	KARLSRUHE
DE13	DE13	FREIBURG
DE14	DE14	TUEBINGEN
DE21	DE21	OBERBAYERN
DE22	DE22	NIEDERBAYERN
DE23	DE23	OBERPFALZ
DE24	DE24	OBERFRANKEN
DE25	DE25	MITTELFRANKEN
DE26	DE26	UNTERFRANKEN
DE27	DE27	SCHWABEN
DE3	DE3	BERLIN
DE4	DE4	BRANDENBURG
DE5	DE5	BREMEN
DE6	DE6	HAMBURG
DE71	DE71	DARMSTADT
DE72	DE72	GIESSEN
DE73	DE73	KASSEL
DE8	DE8	MECKLENBURG-VORPOMMERN

Table 13. (Continued)

GISCO Code	New Cronos Code	Administrative region
DE91	DE91	BRAUNSCHWEIG
DE92	DE92	HANNOVER
DE93	DE93	LUENEBURG
DE94	DE94	WESER-EMS
DEA1	DEA1	DUESSELDORF
DEA2	DEA2	KOELN
DEA3	DEA3	MUENSTER
DEA4	DEA4	DETMOLD
DEA5	DEA5	ARNSBERG
DEB1	DEB1	KOBLENZ
DEB2	DEB2	TRIER
DEB3	DEB3	RHEINHESSEN-PFALZ
DEC	DEC	SAARLAND
DED1	DED1	CHEMNITZ
DED2	DED2	DRESDEN
DED3	DED3	LEIPZIG
DEE1	DEE1	DESSAU
DEE2	DEE2	HALLE
DEE3	DEE3	MAGDEBURG
DEF	DEF	SCHLESWIG-HOLSTEIN
DEG	DEG	THUERINGEN
DK	DK	DANMARK
EE	EE	EESTI
ES11	ES11	GALICIA
ES12	ES12	ASTURIAS
ES13	ES13	CANTABRIA
ES21	ES21	PAIS VASCO
ES22	ES22	NAVARRA
ES23	ES23	LA RIOJA
ES24	ES24	ARAGON
ES3	ES3	COMUNIDAD DE MADRID
ES41	ES41	CASTILLA Y LEON
ES42	ES42	CASTILLA-LA MANCHA
ES43	ES43	EXTREMADURA
ES51	ES51	CATALUNA
ES52	ES52	COMUNIDAD VALENCIANA
ES53	ES53	ILLES BALEARS
ES61	ES61	ANDALUCIA
ES62	ES62	REGION DE MURCIA
ES63	ES63	CEUTA Y MELILLA
FI13	FI13	ITA-SUOMI
FI14	NO LINK	VALI-SUOMI
FI15	FI1A	POHJOIS-SUOMI
FI16	NO LINK	UUSIMAA
FI17	FI18	ETELA-SUOMI
FI2	FI2	AALAND
FR1	FR1	ILE DE FRANCE

Table 13. (Continued)

GISCO Code	New Cronos Code	Administrative region
FR21	FR21	CHAMPAGNE-ARDENNE
FR22	FR22	PICARDIE
FR23	FR23	HAUTE-NORMANDIE
FR24	FR24	CENTRE
FR25	FR25	BASSE-NORMANDIE
FR26	FR26	BOURGOGNE
FR3	FR3	NORD-PAS-DE-CALAIS
FR41	FR41	LORRAINE
FR42	FR42	ALSACE
FR43	FR43	FRANCHE-COMTE
FR51	FR51	PAYS DE LA LOIRE
FR52	FR52	BRETAGNE
FR53	FR53	POITOU-CHARENTES
FR61	FR61	AQUITAINE
FR62	FR62	MIDI-PYRENEES
FR63	FR63	LIMOUSIN
FR71	FR71	RHONE-ALPES
FR72	FR72	AUVERGNE
FR81	FR81	LANGUEDOC-ROUSSILLON
FR82	FR82	PROVENCE-ALPES-COTE D'AZUR
FR83	FR83	CORSE
GR	GR	ELLADA
GR11	GR11	ANATOLIKI MAKEDONIA, THRAKI
GR12	GR12	KENTRIKI MAKEDONIA
GR13	GR13	DYTIKI MAKEDONIA
GR14	GR14	THESSALIA
GR21	GR21	IPEIROS
GR22	GR22	IONIA NISIA
GR23	GR23	DYTIKI ELLADA
GR24	GR24	STEREA ELLADA
GR25	GR25	PELOPONNISOS
GR3	GR3	ATTIKI
GR41	GR41	VOREIO AIGAIO
GR42	GR42	NOTIO AIGAIO
HU	HU	MAGYARORSZAG
HU01	HU10	KOZEP-MAGYARORSZAG
HU02	HU21	KOZEP-DUNANTUL
HU03	HU22	NYUGAT-DUNANTUL
HU04	HU23	DEL-DUNANTUL
HU05	HU31	ESZAK-MAGYARORSZAG
HU06	HU32	ESZAK-ALFOLD
HU07	HU33	DEL-ALFOLD
IE01	IE01	BORDER, MIDLANDS AND WESTERN
IE02	IE02	SOUTHERN AND EASTERN
IT11	ITC1	PIEMONTE
IT12	ITC2	VALLE D'AOSTA
IT13	ITC3	LIGURIA

Table 13. (Continued)

GISCO Code	New Cronos Code	Administrative region
IT2	ITC4	LOMBARDIA
IT31	NO LINK	TRENTINO-ALTO ADIGE
IT32	ITD3	VENETO
IT33	ITD4	FRIULI-VENEZIA GIULIA
IT4	ITD5	EMILIA-ROMAGNA
IT51	ITE1	TOSCANA
IT52	ITE2	UMBRIA
IT53	ITE3	MARCHE
IT6	ITE4	LAZIO
IT71	ITF1	ABRUZZO
IT72	ITF2	MOLISE
IT8	ITF3	CAMPANIA
IT91	ITF4	PUGLIA
IT92	ITF5	BASILICATA
IT93	ITF6	CALABRIA
ITA	ITG1	SICILIA
ITB	ITG2	SARDEGNA
LT	LT	LIETUVA
LU	LU	LUXEMBOURG (GRAND-DUCHE)
LV	LV	LATVIJA
NL	NL	NEDERLAND
NL11	NL11	GRONINGEN
NL12	NL12	FRIESLAND
NL13	NL13	DRENTHE
NL21	NL21	OVERIJSSEL
NL22	NL22	GELDERLAND
NL23	NL23	FLEVOLAND
NL31	NL31	UTRECHT
NL32	NL32	NOORD-HOLLAND
NL33	NL33	ZUID-HOLLAND
NL34	NL34	ZEELAND
NL41	NL41	NOORD-BRABANT
NL42	NL42	LIMBURG (NL)
PL01	PL51	DOLNOSLASKIE
PL02	PL61	KUJAWSKO-POMORSKIE
PL03	PL31	LUBELSKIE
PL04	PL43	LUBUSKIE
PL05	PL11	LODZKIE
PL06	PL21	MALOPOLSKIE
PL07	PL12	MAZOWIECKIE
PL08	PL52	OPOLSKIE
PL09	PL32	PODKARPACKIE
PL0A	PL34	PODLASKIE
PL0B	PL63	POMORSKIE
PL0C	PL22	SLASKIE
PL0D	PL33	SWIETOKRZYSKIE
PL0E	PL62	WARMINSKO-MAZURSKIE

Table 13. (Continued)

GISCO Code	New Cronos Code	Administrative region
PL0F	PL41	WIELKOPOLSKIE
PL0G	PL42	ZACHODNIOPOMORSKIE
PT11	PT11	NORTE
PT12	PT16	CENTRO (P)
PT13	PT17	LISBOA E VALE DO TEJO
PT14	PT18	ALENTEJO
PT15	PT15	ALGARVE
SE01	SE01	STOCKHOLM
SE02	SE02	OESTRA MELLANSVERIGE
SE04	SE04	SYDSVERIGE
SE06	SE06	NORRA MELLANSVERIGE
SE07	SE07	MELLERSTA NORRLAND
SE08	SE08	OEVRE NORRLAND
SE09	SE09	SMAALAND MED OEARNA
SE0A	SE0A	VAESTSVERIGE
SI	SI	SLOVENIJA
SK01	SK01	BRATISLAVSKY
SK02	SK02	ZAPADNE SLOVENSKO
SK03	SK03	STREDNE SLOVENSKO
SK04	SK04	VYCHODNE SLOVENSKO
UKC1	UKC1	TEES VALLEY & DURHAM
UKC2	UKC2	NORTHUMBERLAND AND TYNE & WEAR
UKD1	UKD1	CUMBRIA
UKD2	UKD2	CHESHIRE
UKD3	UKD3	GREATER MANCHESTER
UKD4	UKD4	LANCASHIRE
UKD5	UKD5	MERSEYSIDE
UKE1	UKE1	EAST RIDING & NORTH LINCOLNSHIRE
UKE2	UKE2	NORTH YORKSHIRE
UKE3	UKE3	SOUTH YORKSHIRE
UKE4	UKE4	WEST YORKSHIRE
UKF1	UKF1	DERBYSHIRE & NOTTINGHAMSHIRE
UKF2	UKF2	LEICESTERSHIRE, RUTLAND & NORTHANTS
UKF3	UKF3	LINCOLNSHIRE
UKG1	UKG1	HEREFORDSHIRE, WORCESTERSHIRE & WARKS
UKG2	UKG2	SHROPSHIRE & STAFFORDSHIRE
UKG3	UKG3	WEST MIDLANDS
UKH1	UKH1	EAST ANGLIA
UKH2	UKH2	BEDFORDSHIRE & HERTFORDSHIRE
UKH3	UKH3	ESSEX
UKI1	UKI1	INNER LONDON
UKI2	UKI2	OUTER LONDON
UKJ1	UKJ1	BERKSHIRE, BUCKS & OXFORDSHIRE
UKJ2	UKJ2	SURREY, EAST & WEST SUSSEX
UKJ3	UKJ3	HAMPSHIRE & ISLE OF WIGHT
UKJ4	UKJ4	KENT

Table 13. (Continued)

GISCO Code	New Cronos Code	Administrative region
UKK1	UKK1	GLOUCESTERSHIRE, WILTSHIRE & NORTH SOMERSET
UKK2	UKK2	DORSET & SOMERSET
UKK3	UKK3	CORNWALL & ISLES OF SCILLY
UKK4	UKK4	DEVON
UKL1	UKL1	WEST WALES & THE VALLEYS
UKL2	UKL2	EAST WALES
UKM1	UKM1	NORTH EAST SCOTLAND
UKM2	UKM2	EASTERN SCOTLAND
UKM3	UKM3	SOUTH WESTERN SCOTLAND
UKM4	UKM4	HIGHLANDS AND ISLANDS
UKN	UKN	NORTHERN IRELAND

Table 13. The comparison of GISCO and New Cronos coding for NUTS2 regions**.**

1. AGRIAREA (total agricultural area)	1.1. GARDEN (kitchen garden)	
	1.2. GRASSLAND (permanent grasslands)	
	1.3. PERMCROP (permanent crop)	1.3.1. VINEYARD
		1.3.2. OLIVEPL (olive plantations)
	1.4. ARABLAND (arable land)	1.4.1. GREENFOD (green fodder)
		1.4.2. FALLOW
2. FOREST		

Source: EUROSTAT

Table 14. List of land use categories in New Cronos statistics and its structure.

Aggregated group of crops	Process
WINTCER (winter cereals)	= (SOFTWHEAT + DURWHEAT + RYE)
MAIZEGR	
RICE	
BARLEY_REST	= (CERELTOT – WINTCER – MAIZEGR – RICE)
PULSES	
RAPE	
SUNFLOW	
SOYA	
OILS_REST	= (OILSEEDS – RAPE – SUNFLOW – SOYA)
FLAX	
POTATO	
SUGAR	
COTTON	
MAIZEFOD	
GREENF_REST	= (GREENFOD – MAIZEFOD)
FALLOW	
SUM (control)	= SUM(all aggregated groups)

Table 15. Reduction of crops in New Cronos statistics to aggregated groups of crops for biophysical modelling.

Field name	Type	Length	Description
CNTRYCODE	Varchar2	2	Code of the country
PSUCOL	Number	3	Number of the PSU column (country specific)
PSUROW	Number	3	Number of the PSU row (country specific)
SSUCOL	Number	3	Number of the SSU column (1 … 5)
SSUROW	Number	3	Number of the SSU row (1 or 2)
LONGITUDE	Number	11.8	Longitude
LATITUDE	Number	11.8	Latitude
XCOORD	Number	13.5	X-Coordinate in the UTM projection UTM29: IRL, P UTM30: UK UTM31: F UTM32: D, B, DK, L, NL UTM33: A, I, S UTM34: EL UTM35: FIN
YCOORD	Number	13.5	Y-Coordinate in the UTM projection UTM29: IRL, P UTM30: UK UTM31: F UTM32: D, B, DK, L, NL UTM33: A, I, S UTM34: EL UTM35: FIN

Source: EUROSTAT

Table 16. Lucas geographical coordinates.

Abbreviation	Description
Crop categories:	
SWHT	Harvested area of soft wheat
DWHT	Harvested area of durum wheat
WRYE	Harvested area of rye
CBAR	Harvested area of barley (both spring and winter)
CORN	Harvested area of grain maize
OCER	Harvested area of other cereals (CEREAL - (SWHT+DWHT+WREY+CBAR+CORN)), where CEREAL is the attribute in New Cronos statistics for sum of cereals
RICE	Harvested area of rice
CSIL	Harvested area of green maize
POTA	Harvested area of potatoes
FPEA	Harvested area of dried pulses (total)
SGBT	Harvested area of sugar beet
WRAP	Harvested area of rape and turnip rape
SUNF	Harvested area of sunflower seeds
SOYB	Harvested area of soybeans
OOIL	Harvested area of other oilseeds (OILSEED-(WRAP+SUNF+SOYB)), where OILSEED is the attribute in New Cronos statistics for sum of oil seeds
FLAX	Harvested area of flax (oilseed and textile)
COTT	Harvested area of cotton (oilseeds and textile)
TBCC	Harvested area of tobacco
FALW	Harvested area of fallow
GRCL	Harvested area of green fodder rest without closer specification (GREENFOD – CSIL), where GREENFOD is the attribute in New Cronos statistics for green fodders
OCRP	Harvested area of other crops on arable land (the rest to 100 %) - no closer specification, it does not belong to any group mentioned above.
SUM	Sum of crops above
Land cover:	
ARABLELAND	Acreage of arable land
FALLOW	Acreage of fellow, FALLOW belongs to ARABLELAND category
GREENFOD	Acreage of green fodders, GREENFOD belongs to ARABLELAND category

Table 17. The coding of crops and aggregation rules applied to New Cronos datasets to input biophysical modelling of arable land.

DATA GROUP	DATA LAYER	DESCRIPTION
Soil	ESDB soil grid layers	Soil single-parameter maps in 1 km cell resolution, for both topsoil and subsoil
Topography	SLSRTM_PERC.grd	Dominant slope (in percentages) calculated from STRM90 to the raster with 1 km cell resolution
	SLGTOP_PERC.grd	Slope (in percentages) calculated from GTOPO30 to raster with 1 km cell resolution
	ELEVSRTM.grd	Mean elevation calculated from SRTM90 to the raster with 1 km cell resolution
	ELEVGTOP.grd	Elevation map of GTOPO30 (1 km cell resolution)
	TOPOCLASS.grd	Elevation classes (lowlands, uplands, mountains, high mountains) in raster with 1 km cell resolution.
Homogeneous response units	HRU.grd	Homogeneous response units in a raster with 1 km cell resolution
Climate	MARS50.shp	The mesh 50 × 50 km to allocate MARS climatic files and crop calendar.
	EMEP50.shp	The mesh 50 × 50 km to allocate EMEP file with atmospheric depositions of nitrogen.
Land cover	LCLEVEL1.GRD	Land cover (categories of Level 1) from CORINE and PELCOM; raster with 1 km cell resolution.
	LCLEVEL2.GRD	Land cover (categories of Level 2) from CORINE and PELCOM; raster with 1 km cell resolution.
Agricultural statistics	LUCAS.shp	The point data layer with extent of EU15 derived from original LUCAS ASCII files.
Administrative regions	EU25NUTS2.shp	Subset of NUEC1MV7 coverage with NUTS2 level for the extent of EU25.
	FADN.shp	The shapefile of FADN regions for the extent of EU15
	NUTS2.grd	The raster of administrative NUTS2 regions with 1 km cell resolution, which was obtained from EU25NUTS2.shp by feature-to-raster function in the Spatial Analyst for ArcGIS™

Table 18. GIS archive – List of geo-referenced vector and grid layers.

Field	Data type	Character	Description	Unit
ID	Text		NUTS2_LandCat_SoilClass	
ID2	Text		NUTS2_Landcat_SoilClass_Irrig	
NUTS2	Text		Code of NUTS2 region (AGISCO)	
LandCat	Text		Code for land cover category (CORINE and PELCOM) (21 arable land, 22 – permanent crops, 23 – pastures, 24 – heterogeneous agricultural area, 311 – broadleaved forest, 312 – coniferous forest, 313 – mixed forest, 41 – inner wetlands, 42 – maritime wetlands)	
SoilClass	Text		Code of HRU	
Irrig	Integer		0 – non irrigated, 1 – irrigated	
km2	Integer	SUM	Area of ID2 (in km2)	km^2
VS_TOP	Double	Mean	Volume of stones in topsoil	vol. %
VS_SUB	Double	Mean	Volume of stones in subsoil	vol. %
OC_TOP	Double	Mean	Organic carbon content in topsoil	%
SAND_TOP	Double	Mean	Sand content in topsoil	%
SAND_SUB	Double	Mean	Sand content in subsoil	%
SILT_TOP	Double	Mean	Silt content in topsoil	%
SILT_SUB	Double	Mean	Silt content in subsoil	%
CLAY_TOP	Double	Mean	Clay content in topsoil	%
CLAY_SUB	Double	Mean	Clay content in subsoil	%
BD_TOP	Double	Mean	Bulk density in topsoil	g/cm^3
BD_SUB	Double	Mean	Bulk density in subsoil	g/cm^3
CEC_TOP	Double	Mean	Cation exchange capacity in topsoil	cmolc/kg
CEC_SUB	Double	Mean	Cation exchange capacity in subsoil	cmolc/kg
SOB_TOP	Double	Mean	Sum of bases in topsoil	cmolc/kg
SOB_SUB	Double	Mean	Sum of bases in subsoil	cmolc/kg
BS_TOP	Double	Mean	Base saturation in topsoil	%
BS_SUB	Double	Mean	Base saturation ion subsoil	%
PH_TOP	Double	Mean	Soil reaction in topsoil	
PH_SUB	Double	Mean	Soil reaction in subsoil	
KS_TOP	Double	Mean	Saturated hydraulic conductivity in topsoil	mm/hour
KS_SUB	Double	Mean	Saturated hydraulic conductivity in subsoil	mm/hour
WP_TOP	Double	Mean	Wilting point at 1500 kPa in topsoil	cm3/cm3
WP_SUB	Double	Mean	Wilting point at 1500 kPa in subsoil	cm3/cm3
FWC_TOP	Double	Mean	Field water capacity at 33 kPa in topsoil	cm3/cm3
FWC_SUB	Double	Mean	Field water capacity at 33 kPa in subsoil	cm3/cm3
HYDR_GR	Integer	Majority	Hydrological group	
SLENGTH	Integer		Average slope length	m
FLDSIZE	Integer		Average field size	ha
ELEVATION	Double	Mean	Average elevation	m
SLOPE	Double	Majority	Most frequent slope	%
TOPL	Integer		Depth of topsoil	m
SUBL	Integer		Depth of subsoil	m
SOILIDFR	Double		Fraction of ID2 per total LandCat area within NUTS2	
MARSCd	Integer		Code of representative MARS meteo-file	

Table 19. Metadata of INSEA_HRUs database.

Field	Description	Unit
ID	NUTS2_ELEVCLASS	
NUTS2	NUTS2 region (AGISCO)	
ELEVCLASS	elevation class (0: without specification, 1: =< 300 m, 2: > 300 and =< 600 m, 3: > 600 m	
SWHT	Crop share	%
DWHT	Crop share	%
WRYE	Crop share	%
CBAR	Crop share	%
CORN	Crop share	%
OCER	Crop share	%
RICE	Crop share	%
CSIL	Crop share	%
POTA	Crop share	%
FPEA	Crop share	%
SGBT	Crop share	%
WRAP	Crop share	%
SUNF	Crop share	%
SOYB	Crop share	%
OOIL	Crop share	%
FLAX	Crop share	%
COTT	Crop share	%
TBCC	Crop share	%
FALW	Crop share	%
GCL1	Crop share	%
OCRP	Crop share	%
SWHTYld	Crop yield	t/ha
DWHTYld	Crop yield	t/ha
WRYEYld	Crop yield	t/ha
CBARYld	Crop yield	t/ha
CORNYld	Crop yield	t/ha
OCERYld	Crop yield	t/ha
RICEYld	Crop yield	t/ha
CSILYld	Crop yield	t/ha
POTAYld	Crop yield	t/ha
FPEAYld	Crop yield	t/ha
SGBTYld	Crop yield	t/ha
WRAPYld	Crop yield	t/ha
SUNFYld	Crop yield	t/ha
SOYBYld	Crop yield	t/ha
FLAXYld	Crop yield	t/ha
COTTYld	Crop yield	t/ha
TBCCYld	Crop yield	t/ha
Year1	Crop in year 1	
Year2	Crop in year 2	
Year3	Crop in year 3	
Year4	Crop in year 4	
Year5	Crop in year 5	
Year6	Crop in year 6	

Table 20. (Continued)

Field	Description	Unit
CBAR_N	N fertilization rate	kg/ha
CORN_N	N fertilization rate	kg/ha
CSIL_N	N fertilization rate	kg/ha
FPEA_N	N fertilization rate	kg/ha
GCL1_N	N fertilization rate	kg/ha
POTA_N	N fertilization rate	kg/ha
SUNF_N	N fertilization rate	kg/ha
SWHT_N	N fertilization rate	kg/ha
WRAP_N	N fertilization rate	kg/ha
WRYE_N	N fertilization rate	kg/ha
CBAR_P2O5	P2O5 fertilization rate	kg/ha
CORN_P2O5	P2O5 fertilization rate	kg/ha
CSIL_P2O5	P2O5 fertilization rate	kg/ha
FPEA_P2O5	P2O5 fertilization rate	kg/ha
GCL1_P2O5	P2O5 fertilization rate	kg/ha
POTA_P2O5	P2O5 fertilization rate	kg/ha
SUNF_P2O5	P2O5 fertilization rate	kg/ha
SWHT_P2O5	P2O5 fertilization rate	kg/ha
WRAP_P2O5	P2O5 fertilization rate	kg/ha
WRYE_P2O5	P2O5 fertilization rate	kg/ha
CBAR_K2O	K2O fertilization rate	kg/ha
CORN_K2O	K2O fertilization rate	kg/ha
CSIL_K2O	K2O fertilization rate	kg/ha
FPEA_K2O	K2O fertilization rate	kg/ha
GCL1_K2O	K2O fertilization rate	kg/ha
POTA_K2O	K2O fertilization rate	kg/ha
SUNF_K2O	K2O fertilization rate	kg/ha
SWHT_K2O	K2O fertilization rate	kg/ha
WRAP_K2O	K2O fertilization rate	kg/ha
WRYE_K2O	K2O fertilization rate	kg/ha
NHXDEPOZ	NHx depositions from atmosphere	kg/km2
NOXDEPOZ	NOx depositions from atmosphere	kg/km2
ARABLELAND	Acreage of arable land, CORINE and PELCOM level 2	km2
PASTURES	Acreage of pastures, CORINE and PELCOM level 2	km2
OLIVEGR	Acreage of olive groves, CORINE and PELCOM level 2	km2
PERMCROPS	Acreage of permanent crops, CORINE and PELCOM level 2	km2
VINEYARD	Acreage of vineyards, CORINE and PELCOM level 2	km2
FOREST	Acreage of forests, CORINE and PELCOM level 2	km2

Table 20. Metadata of INSEA_MNG database.

Field name	Type	Length	Description
CNTRYCODE	Varchar2	2	Code of the country
PSUROW	Number	3	Number of the PSU row (country specific)
PSUCOL	Number	3	Number of the PSU column (country specific)
SURVEYTYPE	Number	1	Type of the survey
SURVEYORID	Number	10	Unique identifier of the surveyor (contractor specific)
SURVEYDATE	Date	10	Date of the survey of the PSU (formatted as *yyyy/mm/dd*)
STARTTIME	Date	5	Start time of the survey of the PSU (formatted as *hh:mm*)
ENDTIME	Date	5	End time of the survey of the PSU (formatted as *hh:mm*)
REMARKS	Varchar2	1000	Remarks written on the field form during the survey

Source: EUROSTAT

Table 21. Lucas PSU items.

DATA ITEM	DATA TYPE	DESCRIPTION
CNTRYCODE	Varchar	Code of the country
PSUCOL	Number	Number of PSU column (country specific)
PSUROW	Number	Number of PSU row (country specific)
SSU	Number	Number of SSU
YEAR	Number	year of observation
LC_1	Varchar	land cover 1
LC_2	Varchar	land cover 2
LU_1	Varchar	land use 1
LU_2	Varchar	land use 2
IRRIG	Number	irrigation

Table 22. LUCAS data structure in INSEA.

Field name	Type	Length	Description
CNTRYCODE	Varchar2	2	Code of the country
PSUROW	Number	3	Number of the PSU row (country specific)
PSUCOL	Number	3	Number of the PSU column (country specific)
SSU	Number	2	Number of the SSU
SURVEYTYPE	Number	1	Type of the survey
YEAR	Number	4	Year of the survey
OBSSTAT	Number	1	Status of the observation
OBSDIST	Number	1	Class of distance of observation
OBSRADIUS	Number	1	Radius of observation
OBSDIREC	Number	1	Direction of observation
LCOVER1	Varchar2	3	Land cover 1
LCOVER2	Varchar2	3	Land cover 2
LUSE1	Varchar2	3	Land use 1
LUSE2	Varchar2	3	Land use 2
PHOTODIST	Number	1	Class of distance of photo from the SSU
PHOTO_N	Number	1	Status of photo taken to the North
PHOTO_S	Number	1	Status of photo taken to the South
PHOTO_W	Number	1	Status of photo taken to the West
PHOTO_E	Number	1	Status of photo taken to the East
IRRIG	Number	1	Irrigation
EROSSTAT	Number	1	Status of erosion
EROSGRILL	Number	1	Number of rills
EROSGULLY	Number	1	Number of gullies
EROSACCUM	Number	1	Presence of accumulation
ISOLATREE	Number	1	Presence of isolated trees
NATHAZARD	Number	1	Damage caused by natural hazards
FARMSTAT	Number	1	Identification of the farmer
NOISESTAT	Number	1	Status of noise
NOISETYPE	Number	1	Type of noise
NOISESOUR	Number	1	Source of noise
NOISELEVEL	Number	1	Level of noise

Source: EUROSTAT

Table 23. Lucas SSU items.

Field name	Type	Length	Description
CNTRYCODE	Varchar2	2	Code of the country
PSUROW	Number	3	Number of the PSU row (country specific)
PSUCOL	Number	3	Number of the PSU column (country specific)
SURVEYTYPE	Number	1	Type of the survey
YEAR	Number	4	Year of the survey
TRANSECT	Number	2	Number of the transect
TRANORDER	Number	2	Order of the linear feature / land cover in the sequence
TRANCODE	Varchar2	6	Code of the linear feature / land cover

Source: EUROSTAT.

Table 24. Lucas transect file items description.

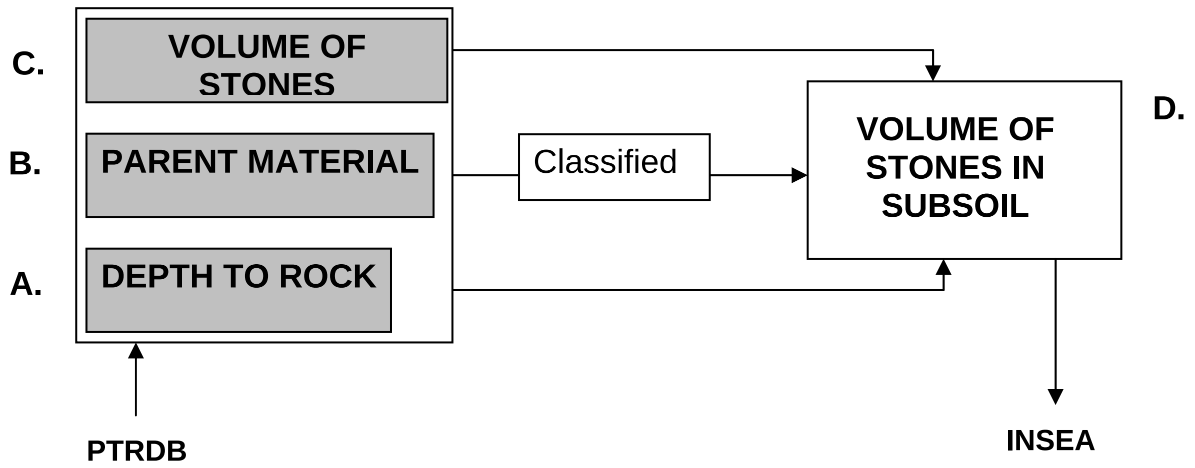


Figure 19. Pedotransfer rules for estimating volume of stones in the subsoil.

A. Classification of depth-to-rock parameter (PTRDB)

DR	Description
1	Deep (80-120 cm)
2	No Data
3	Moderate (40-80 cm)
4	Shallow (< 40 cm)
5	Very deep (› 120 cm)

B. Classification of parent material paramdo2 (PTRDB) into classes 1 (coarse, rock), 2 (mixed), 3 (fine) and 999 (no data)

Orig. Value	Description	Value
0	No information	999
10	consolidated-clastic-sedimentary rocks	1
11	psephite or rudite	1
12	psammite or arenite	1
13	pelite, lutite or argillite	1
14	facies bound rock	1
20	sedimentary rocks (chemically precipitated, evaporated, or organogenic or biogenic in origin)	1
21	calcareous rocks	1
22	evaporates	1
23	siliceous rocks	1
30	igneous rocks	1
31	acid to intermediate plutonic rocks	1
32	basic plutonic rocks	1
33	ultrabasic plutonic rocks	1
34	acid to intermediate volcanic rocks	1
35	basic to ultrabasic volcanic rocks	1
36	dike rocks	1
37	pyroclastic rocks (tephra)	1
40	metamorphic rocks	1

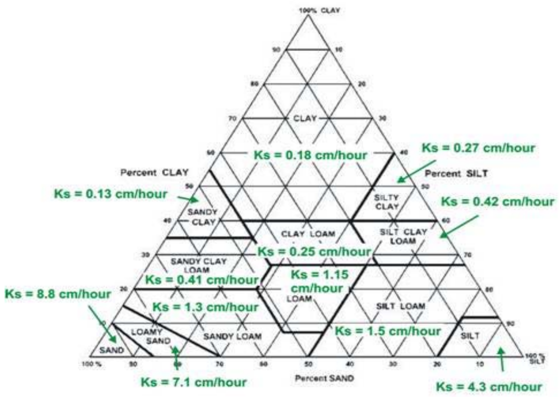
41	weakly metamorphic rocks	1
42	acid regional metamorphic rocks	1
43	basic regional metamorphic rocks	1
44	ultrabasic regional metamorphic rocks	1
45	calcareous regional metamorphic rocks	1
46	rocks formed by contact metamorphism	1
47	tectogenetic metamorphism rocks or cataclasmic metamorphism	1
50	unconsolidated deposits (alluvium, weathering residuum and slope deposits)	2
51	marine and estuarine sands	3
52	marine and estuarine clays and silts	3
53	fluvial sands and gravels	2
54	fluvial clays, silts and loams	3
55	lake deposits	2
56	residual and redeposited loams from silicate rocks	3
57	residual and redeposited clays from calcareous rocks	3
58	slope deposits	2
60	unconsolidated glacial deposits/glacial drift	2
61	morainic deposits	2
62	glaciofluvial deposits	2
63	glaciolacustrine deposits	2
70	eolian deposits	3
71	loess	3
72	eolian sands	3
80	organic materials	3
81	peat (mires)	3
82	slime and ooze deposits	3
83	carbonaceaous rocks (caustobiolite)	2
90	anthropogenic deposits	2
91	redeposited natural materials	2
92	dump deposits	2
93	anthropogenic organic materials	2

C. Classes of volume of stones (PTRDB)

VS_TOP	Description
0	0 % stones
15	15 % stones
999	No Data
20	20 % stones
10	10 % stones

D. The matrix evaluating combinatorial occurrences of A, B, and C, and with estimation of volume of stones in subsoil (VS_SUB, vol. %) as used in INSEA

Dr	Reclassified parent material / VALUE	VS_TOP (%)	VS_SUB (%)
5	2	15	25
5	3	15	20
5	1	15	30
5	3	0	0
5	2	0	0
5	1	0	10
4	1	15	40
4	3	15	25
4	2	15	30
4	1	10	30
4	1	0	20
4	3	0	0
4	2	0	10
3	3	20	25
3	1	20	40
3	2	20	30
3	3	15	20
3	2	15	25
3	1	15	35
3	1	10	25
3	2	10	20
3	3	10	15
3	3	0	0
3	2	0	5
3	1	0	15
2	1	999	999
2	3	15	20
2	3	0	0
2	1	0	15
2	2	0	5
1	2	20	40
1	1	20	50
1	3	20	30
1	1	15	30
1	3	15	20
1	2	15	25
1	1	10	25
1	2	10	20
1	3	10	15
1	1	0	10
1	2	0	5
1	3	0	0



Categories:
A: sand, loamy sand, silt
B: sandy loam, loam, silt loam
C: sandy clay loam, clay loam, silt clay loam, silt clay
D: clay, sandy clay

Evaluation matrix Step 1:

Subsoil \ Topsoil	A	B	C	D
A	A	A	B	C
B	B	B	B	C
C	C	C	C	D
D	D	D	D	D

Evaluation matrix Step 2:

Texture \ DTG	Shallow	Moderate	Deep
A	D	B	A
B	D	C	B
C	D	D	C
D	D	D	D

DTG = depth to gley horizon (PTRDB)

Figure 20. Rules of pedotransfer function used for estimation of hydrological soil group.

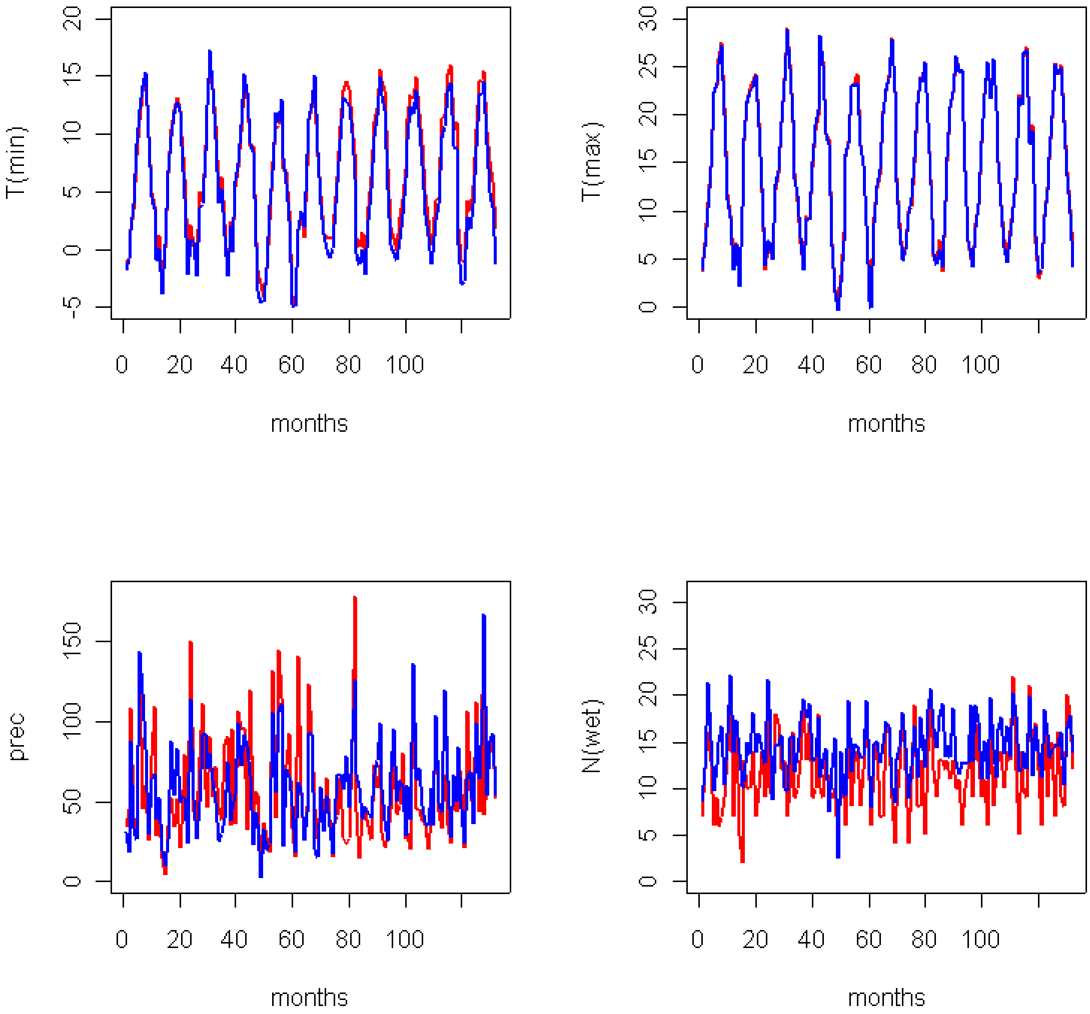


Figure 21. Time – series jan 1992 – dec 2002 for MARS (red) and EA (blue) data.

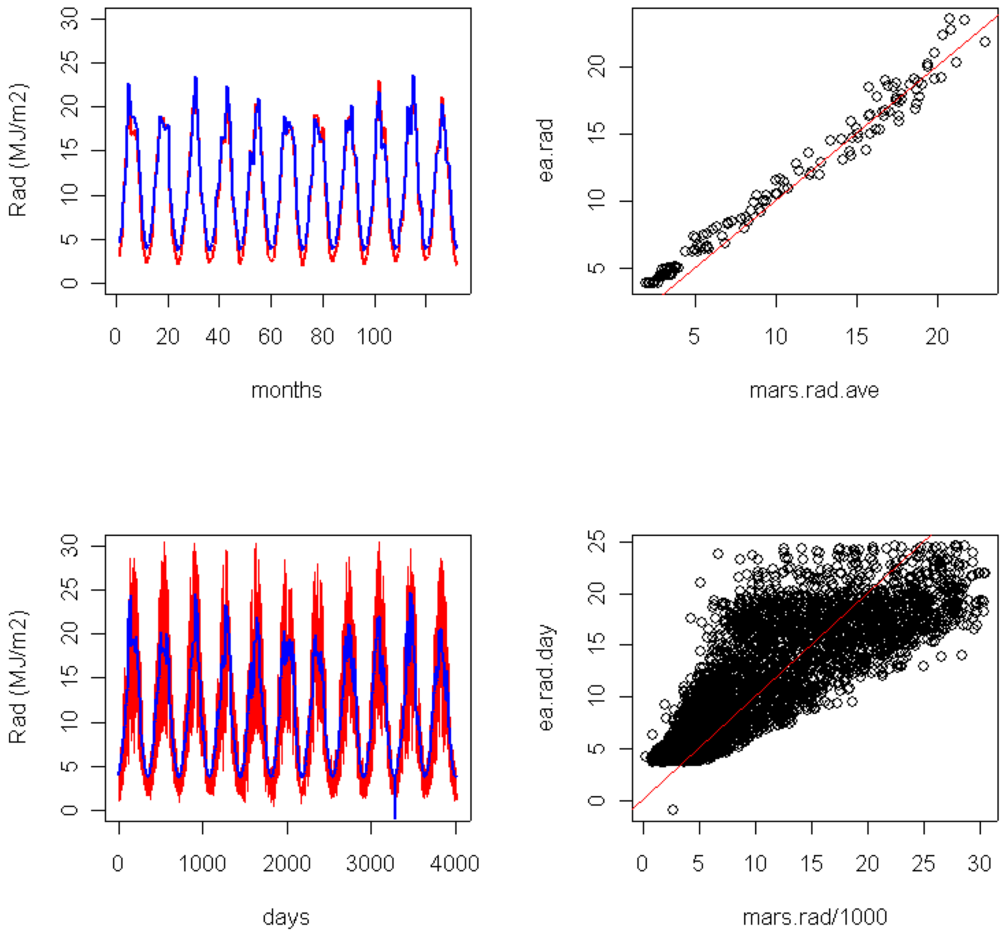
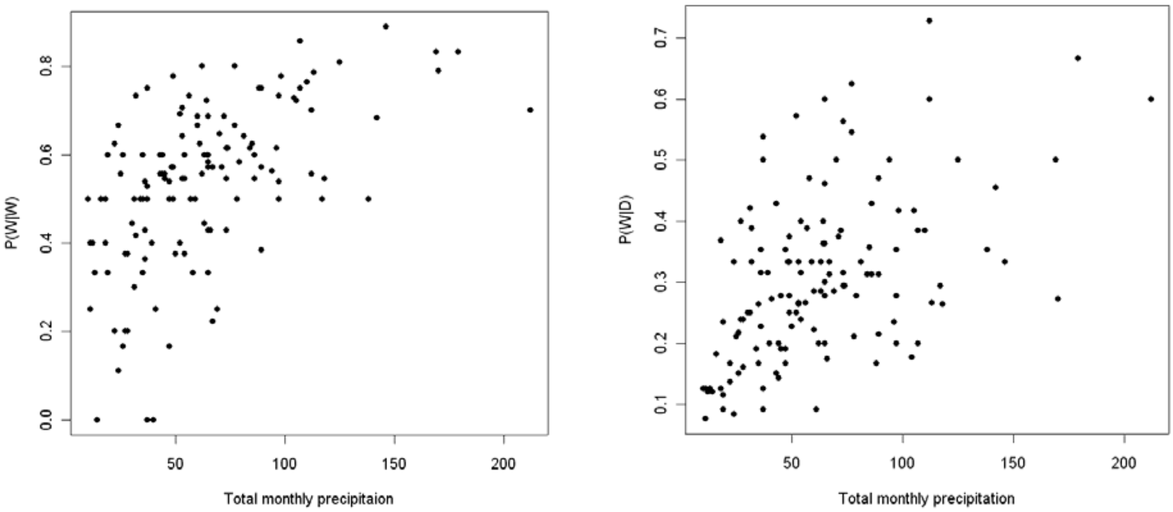


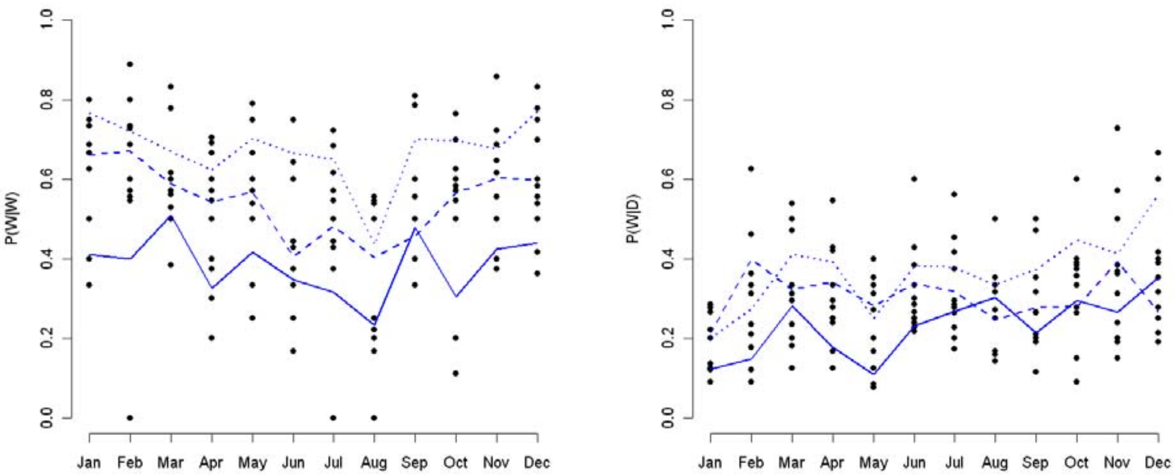
Figure 22. Monthly average and daily radiation data estimated from EA cloud cover (blue) and compared to the MARS data (red).

Note: Correlation for monthly averages is 0.9895.



a) b)

Figure 23. Correlation between the probability of: a) a wet day after wet day and the total monthly precipitation, b). a wet day after dry day and the total monthly precipitation.



a) b)

Figure 24. Transition probability of : a) a wet day after wet day for a dry (solid line), medium (no-solid line) and wet (dotted line) month, b) a wet day after a dry day for a dry (solid line), medium (non-solid line) and wet (dotted line) month.

Validation of the Soil organic carbon for bio-physical modeling: Slovakia case study

J. Balkovič, E. Schmid, R. Skalský, R. Bujnovský

1. Introduction

Soil organic carbon (SOC) is a major driver in determining soil quality and fertility. It significantly affects chemical, physical and microbiological properties such as sorption capacity, soil reaction, soil structure, water infiltration, water storage capacity, microbial activity and many others. SOC affects soil productivity and functions, which give reasons to mitigate the negative effects of SOC depletion and degradation, as implemented in the communication 'Towards a Thematic Strategy for Soil Protection' (EC 2002). Improving the SOC stocks through land-use management is considered as a measure to mitigate the effects of Greenhouse Gas emissions (GHG) in the atmosphere (UNFCCC 1998, IPCC 2000), because SOC can be effectively sequestered in vegetations and soil resources. Consequently, SOC sequestration potentials under different LULUCF activities (Land Use, Land-Use Change, and Forestry, IPCC 2000) have become an important policy option.

Nowadays, computer models are commonly used to quantify environmental impacts of alternative policies in agricultural and forest land management. Different studies have been performed with RothC (e.g. PARSHOTAM et al. 1995, KING et al. 1997), CENTURY (e.g. DONIGAN et al., 1994), or EPIC (e.g. LEE et al., 1993, IZAURRALDE et al., 2006). The Integrated Sink Enhancement Assessment – INSEA (http://www.insea-eu.info) applies the bio-physical process model EPIC (SHARPLEY and WILLIAMS 1990, WILLIAMS 1990, 1995) to predict SOC dynamics, and to simulate scenarios of SOC stocks in soils. EPIC was originally developed to simulate the economic and environmental impacts of erosion (e.g. PUTNAM et al. 1988), and later it was extended to analyse and evaluate integrated environmental problems (WILLIAMS et al. 1996). A major carbon cycling routine for EPIC was performed by IZAURRALDE et al. (2006) based on the approach used in CENTURY (PARTON et al. 1994).

Bio-physical process modelling requires data with sufficient quality, which can be derived from available data sources using adequate data processing tools and a consistently designed modelling concept. Addressing the quality and validity of initial SOC values is the major objective of this analysis. A core objective of INSEA is to model SOC stocks for EU25 in a temporal and spatial frame. Consequently, a geographically explicit coverage of SOC contents in soils is a prerequisite for policy analysis and evaluation. The INSEA bio-physical process modelling approach integrates the continuous spatial map of organic carbon in topsoil elaborated at European level (JONES et al. 2004, 2005), which improves a previous study of SOC in the topsoil being based on European Soil Database (RUSCO et al. 2001). This study has used an approach based on pedotransfer rules and limited data from national observations due to their insufficiency over Europe. The developed SOC map was verified by comparing the modelled data with measured values gathered in United Kingdom (England and Wales) and Italy (JONES et al. 2005).

This paper aims to validate SOC values from European sources using the Soil Information System of Slovakia (AISOP). Slovakia was chosen to validate European soil data for Central European conditions, i.e. a region for which the model of SOC distribution (JONES et al. 2004, 2005) was not originally validated. Special attention is given to (i) SOC contents that respect specific processing routines related to delineation of homogeneous response units (HRU), and (ii) methods that adjust SOC contents to sufficiently meet quality standards.

2. Materials and methods

Both GIS and statistical data were processed, harmonised and consistently designed to create a geo-database for EPIC modelling for EU25 (SCHMID et al. 2006). Because EPIC is not fully operating in GIS framework (except some attempts with GEPIC, LIU et al. 2007), a concept of delineating homogeneous response units (HRU) was developed to cope with the EU25 modelling approach. This HRU concept respects homogeneity in parameters that are generally hardly adjustable by farm management (i.e. elevation, slope, soil texture, soil depth, and stoniness). The delineated coverage of HRUs is representative for the scale 1:1,000,000 as soil parameters were derived from the European Soil Database and Soil Geographical Database of Europe respectively (JAMAGNE et al. 2001). The HRU layer for Slovakia is presented in Figure 4. HRUs within a considered administrative region (NUTS2 level) are seen as small enough, which are also characterised by homogeneous weather seeds (respecting altitude classes), and land management systems (land cover and use). Individual simulation units (ISU) were obtained by intersecting HRU information with land cover information, for which initial SOC values were derived from the *Map of organic carbon in topsoil in Europe*. The validation database (AISOP) was provided by Soil Science and Conservation Research Institute (SSCRI) in Bratislava (Slovakia). In particular, following data sources are used for this validation analysis:

⇒ *Soil Information System of Slovakia (AISOP):* 17,741 soil profiles from the so-called KPP DB of the 'Complex soil survey of agricultural soils of Slovakia' of the 1960s (BIELEK et al., 2005) – Figure 1,

⇒ *The map of organic carbon in topsoil in Europe (OC Top v. 1.2)*: thematic continuous map of the soil organic carbon content for Europe with 1 km resolution (JONES et al. 2004) – Figure 2.

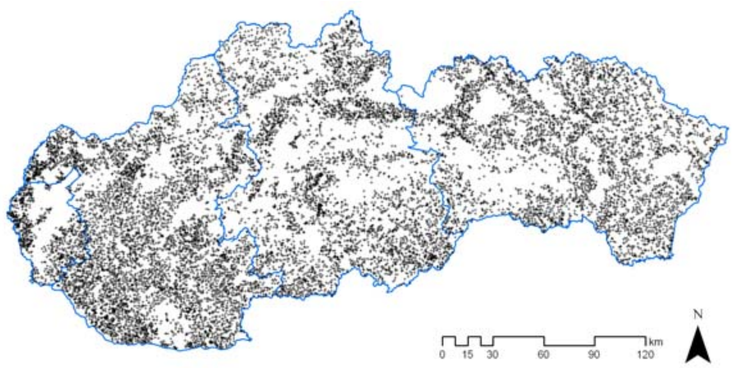


Figure 1. Point profiles of Soil Information System of Slovakia (Source: KPP of AISOP).

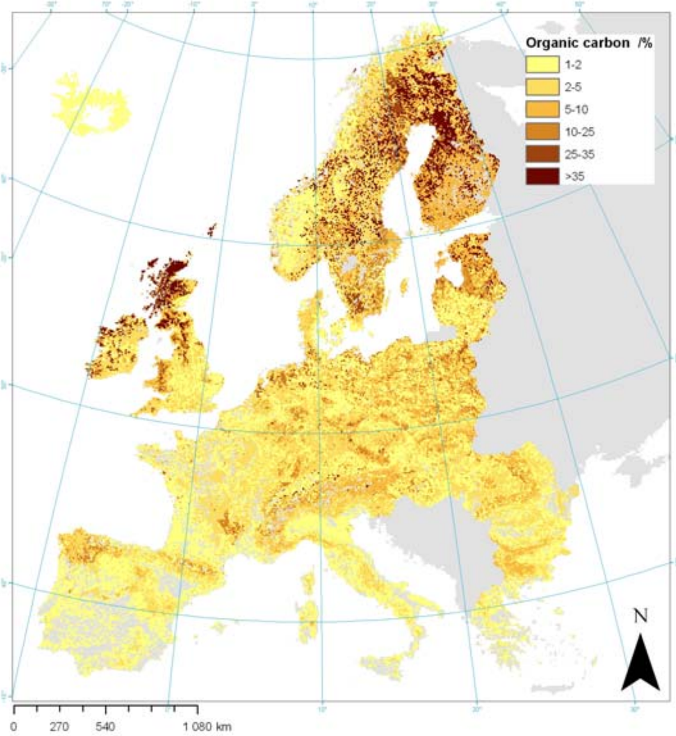


Figure 2. The map of organic carbon in topsoil in Europe (OC Top v. 1.2)(Source: Jones et al., 2004).

Three qualitatively different approaches were used to test initial SOC values and stocks for EPIC modelling: (i) a raster-based comparison of SOC layers, (ii) a comparison of initial SOC values using the HRU concept, and (iii) by using HRU information and EPIC to adjust SOC stocks in topsoil (0-30 cm) through simulation exercises. Each approach uses a specific set of tools and methods to address data quality issues and provides validity information for the INSEA modelling approach. Only arable land is considered in this analysis, because the AISOP database does not cover forest ecosystems.

3. Raster-based comparison of SOC layers

Soil profile SOC data from AISOP were interpolated by ordinary kriging to obtain a continuous raster of organic carbon content in the topsoil (0–30 cm) for arable land (BALKOVIČ and SKALSKÝ, 2005). The results were adjusted to meet the resolution being used in the *Map of organic carbon in topsoil in Europe*, and to arable land according to the CORINE and PELCOM land cover map. Raster based analysis was found to be more appropriate than raster-by-point testing. An interpolated distribution function of SOC, which is derived from measured data, smoothes extreme contents, land-cover discrepancies, scale and topological inconsistencies, and it follows regional distribution patterns. A spatial distribution of SOC contents as presented by OC Top v. 1.2 (JONES et al. 2004) and Slovakian national soil database is given in Figure 3.

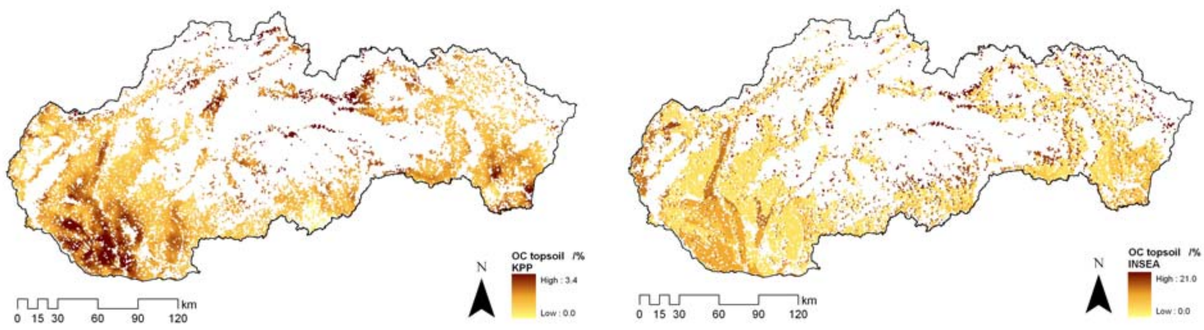


Figure 3. Spatial distribution of topsoil organic carbon in arable land of Slovakia: AISOP (left) and OC Top v. 1.2 (right).

4. Comparison of initial SOC values using the HRU concept

This approach tests the HRU concept, where initial SOC contents are obtained by masking HRUs with land cover information. Initial SOC values were calculated from OC Top v. 1.2 (OC-INSEA) and AISOP raster layers (OC-KPP). Both datasets are then statistically compared. The uncertainty within HRU is addressed by calculating the Mean Square Estimation Error (MSEE) using Eq. 1.

Eq.1 $$MSEE = \frac{1}{n}\sum_{i=1}^{n}\left(SOC_E - SOC_M\right)^2 ,$$

where $\boldsymbol{SOC_E}$ is estimated SOC content, $\boldsymbol{SOC_M}$ is measured SOC content, and $\boldsymbol{n}$ is the number of 1 km cells within an HRU. In this case, SOC_M denotes SOC content of the AISOP raster, and SOC_E is derived from OC Top v. 1.2 raster.

Figure 4 shows the distribution of HRUs in Slovakia, which consists of four NUTS2 regions, which are listed from West to East: SK01 (Bratislava), SK02 (Západné Slovensko), SK03 (Stredné Slovensko), and SK04 (Východné Slovensko).

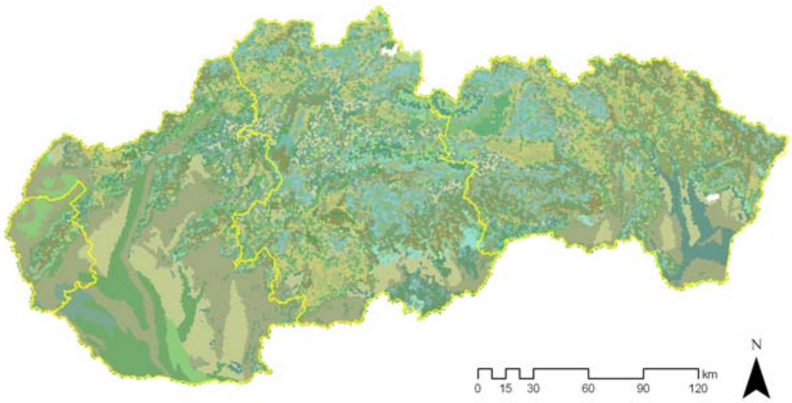


Figure 4. Homogeneous Response Units (HRU's) in Slovakia derived from European data sources.

5. EPIC pre-run simulation for initial SOC values

Pre-run simulations are commonly used to adjust initial values of soil components that are relatively sensitive to soil cultivation, such as SOC. The approach was also suggested and tested to quantify carbon sequestration potentials in EU25 by SCHMID et al. (2004).

Such pre-run simulations are also performed with the European data to compare simulated SOC stocks with Slovakian national database. Initial SOC contents for all ISUs were derived from the OC Top. v. 1.2, and re-calculated to SOC stocks in topsoil (0-30 cm). Typical land management systems were constructed using European agricultural statistics (New Cronos, LUCAS) as developed in INSEA (SCHMID et al. 2006). Soil and topographical data for INSEA dataset were adopted from (i) the European Soil Database v.2 (SGDBE and PTRDB), (ii) the HYPRESE Database and (iii) the SRTM90 Digital Elevation Model. The MARS Project climatic data were used for stochastic weather simulation in EPIC. Land cover was delineated by the CORINE and PELCOM combined map, where only arable land is used in this analysis.

We use a 100-year simulation period to adjust SOC stocks to some equilibrium state using pre-defined crop rotations (derived from NewCronos Statistics) and conventional crop management practices. Initial SOC values from the European datasets are referred to 5, 10 or 15 cm soil depth, respectively. By using statistical methods and EPIC, we try to verify the potential of improving biased initial values of SOC from the European data sources.

We are also statistically testing the impacts of management practices between the simulations from the two datasets. We used AISOP soil and topography database, which is considered more reliable and accurate than European datasets for Slovakia, to supply ISUs for parallel simulations of SOC stocks under conventional and conservative tillage systems. Weather parameters were the same for both simulation sets, i.e. the MARS database. Since management schedules, land cover delineation and ISUs were also the same, simulations would yield differences that result only from different quality of soil and topography data. The total content of soil organic carbon (in $t.ha^{-1}$) in topsoil layers (0–30 cm) are chosen as indicator of comparison between:

- conventional tillage systems; mold board plough, chisel plough (10 cm), regular seeding and two times spike harrow,
- reduced tillage systems; chisel plough (15 cm), regular seeding and spike harrow, and
- minimum tillage systems; chisel plough (10 cm) with direct seeding.

6. Results and discussion

6.1 Raster-based comparison of OC layers

We compared the spatial distributions of SOC given by the OC Top v. 1.2 (OC-INSEA) and SOC form the national database AISOP (OC-KPP), both constructed in 1 km raster presentation and corrected for arable land using the CORINE and PELCOM information. The grid-by-grid samples show only weak correlation (GLM, R^2=7.7%, $p < 0.01$, N=16 070). To provide more readable results, we compared medians of both OC-KPP and OC-INSEA data through box-whisker graph (Fig 6). The graph plots data using medians, 75th and 25th percentiles, outliers [75th percentile + 1.5 × (75th percentile – 25th percentile)], and extremes [75th percentile + 2.0 × (75th percentile – 25th percentile)] grouped by the OC-KPP variable. Relatively good accordance occurs between medians of estimated and measured SOC values. However, a relatively large overestimation can be observed within the most abundant classes of OC-KPP. Since many pixels are highly overestimated compared to measured data, we can expect that real organic carbon contents in arable land do not depend on climatic parameters in such intensive way as they are derived with PTF as proposed by JONES et al. (2005). Figure 5 shows that PTF modelled values are more then 2 times overestimated to measured data at higher altitude levels (above 800 m).

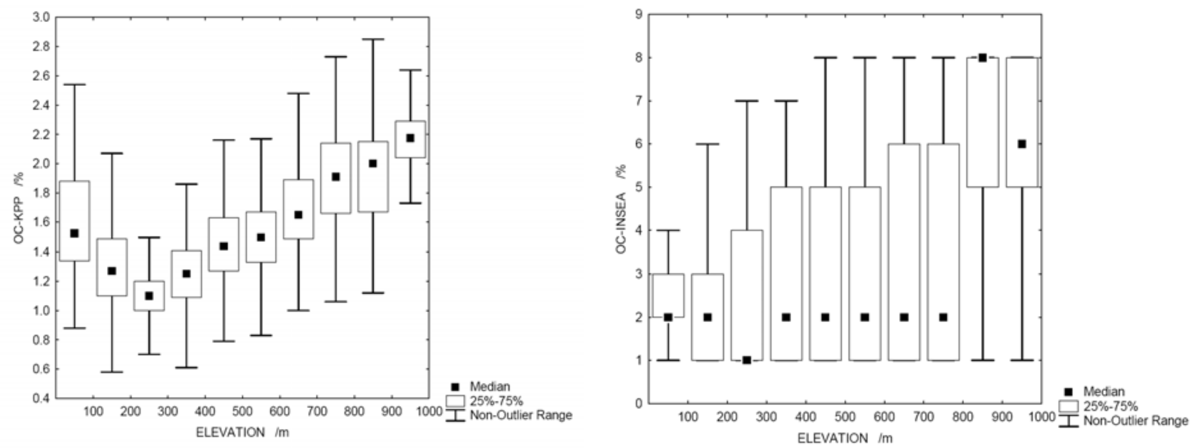


Figure 5. The response of SOC content in topsoil of arable land on elevation gradient estimated for measured data (left) and PTF (right).

Despite medians of both datasets show some level of accordance for Slovakia, high variability within grouped categories of OC-INSEA indicate that high errors can be expected in some regions, where SOC is nearly 20 times overestimated for instance.

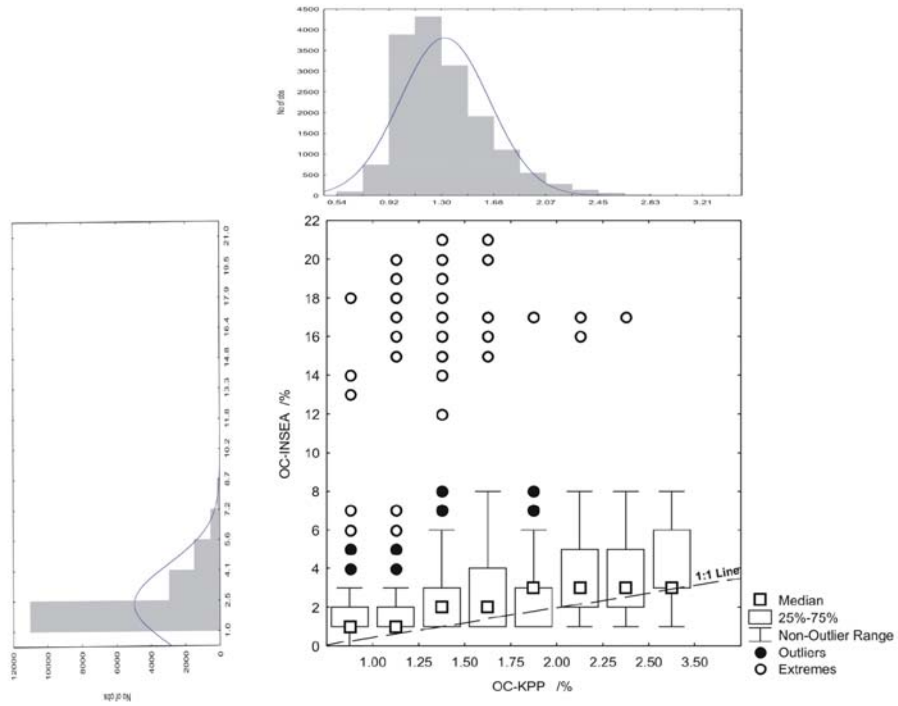


Figure 6. Raster-based comparison between topsoil organic carbon content from AISOP (OC-KPP) and OC Top v. 1.2 (OC-INSEA); GLM: Adj. R2=7.7%, N=16 070, p<0.01.

6.2 Comparison of initial OC values using the HRU concept

EPIC requires initial organic carbon contents, which are currently derived in the HRU delineation process. This methodology was used to generate a finite number of ISU's in Slovakia. Initial organic carbon contents are calculated as arithmetic average from OC Top v. 1.2. We compared these HRU derived values with measured profile *KPP* data. As a result, OC-INSEA data are also generally overestimated with respect to measured data, but to a lesser extent. The geometric mean is more than two times greater for OC-INSEA then OC-KPP. Both variables show slightly left-centred distribution.

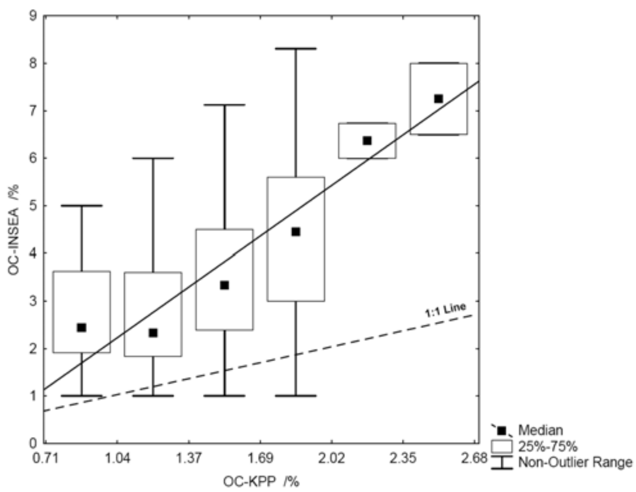


Figure 7. Correlation between SOC from KPP (AISOP) and SOC from INSEA database when calculated through HRU (dashed line is 1:1 Line, solid line is the line of linear regression).

The box-whisker plot with linear trend-line (solid line) is presented in Figure 7, where dashed line denotes the equality diagonal. Statistical test (linear regression: R = 0.44, P < 0.0001) show significant relationships between OC-KPP and OC-INSEA. The aggregation approach of SOC data to areas with relatively homogeneous parameters (HRU) provides a dataset that is relatively consistent with measured data. The aggregation improves the relation between PTF-derived distribution pattern and measured data. Nevertheless, SOC values being generated from European data (OC Top v. 1.2) are still overestimated with respect to measured data. This overestimation is substantial in many localities, and therefore model simulations might be highly influenced by these deviations. This evaluation, similarly to previous ones, also shows that initial SOC data for HRUs have serious shortcomings in validity though the trend in SOC distribution is doubtlessly ascertained by OC Top v. 1.2 data.

Spatial uncertainty of OC Top v. 1.2 for individual HRUs on arable land is estimated through MSEE and presented by Figure 8. It is evident that SOC contents in upland and low-mountain regions are still overestimated when processed through HRUs. On the other hand, loess hilly-countries in lowlands and lower uplands are matched quite well as MSEE is less than 1%. Information within HRU is obtained through pixel-by-pixel square estimation error. Despite that organic carbon contents vary within HRU regions, the HRU concept developed in INSEA seems to be an appropriate aggregation method for NUTS2-level analysis.

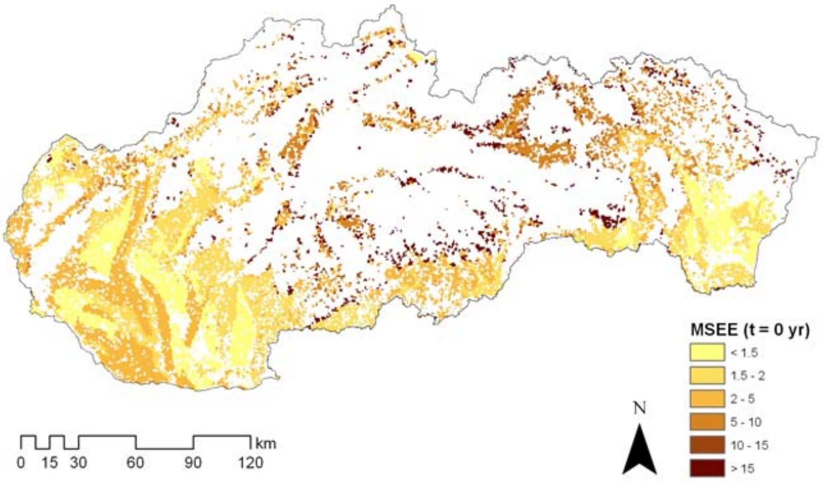


Figure 8. Mean Square Estimation Error (MSEE) between Slovakian and European sources of OC content in topsoil – expressed for simulated units.

6.3 EPIC pre-run simulation for initial OC values

Because SOC contents form OC Top v. 1.2 are generally overestimated, EPIC pre-runs could adjust these values according to some 'homogenized' information processed in INSEA (e.g. HRU, crop rotations, crop management, weather) and by making some more appropriate assumptions. Therefore, we simulated the evolution of soil organic carbon stocks in topsoil by assuming that the initial SOC values refer to soil layer depths of 5, 10, or 15 cm, respectively. In general, a decline of simulated SOC stocks in topsoil (0-30 cm) was observed during a 100-year simulation period (Figure 9). There exists a shift in simulated stocks, which depends on initial organic carbon values and soil layer depths. It appears that if the initial SOC values refer to 5 cm soil depth, it would approximate the reference SOC stock (from national sources) faster and closer. Therefore, all further analyses were done by assuming that all initial SOC values refer to 5 cm soil depth.

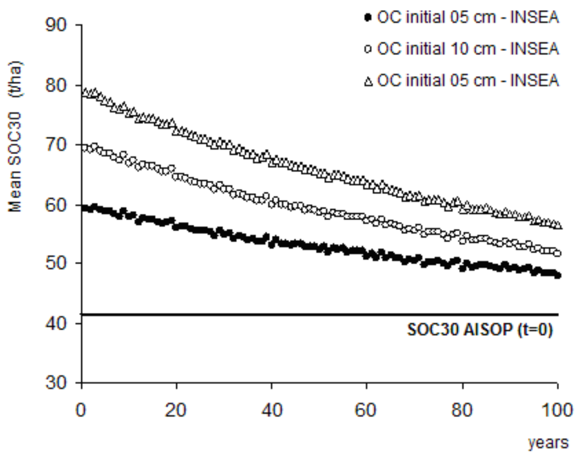


Figure 9. Trends in simulated mean SOC stocks in Slovakia for 100 years, given that initial SOC refer to 5, 10 and 15 cm soil depth (SOC30 AISOP is the mean stock of SOC in topsoil (0-30 cm) as obtained from national AISOP database).

Preparatory simulations improve the estimation error (MSEE) in all NUTS2 regions of Slovakia – Figure 10. The value of MSEE does not vary strongly after 50 years of simulation and therefore this time horizon can be considered as an appropriate period for pre-run simulations.

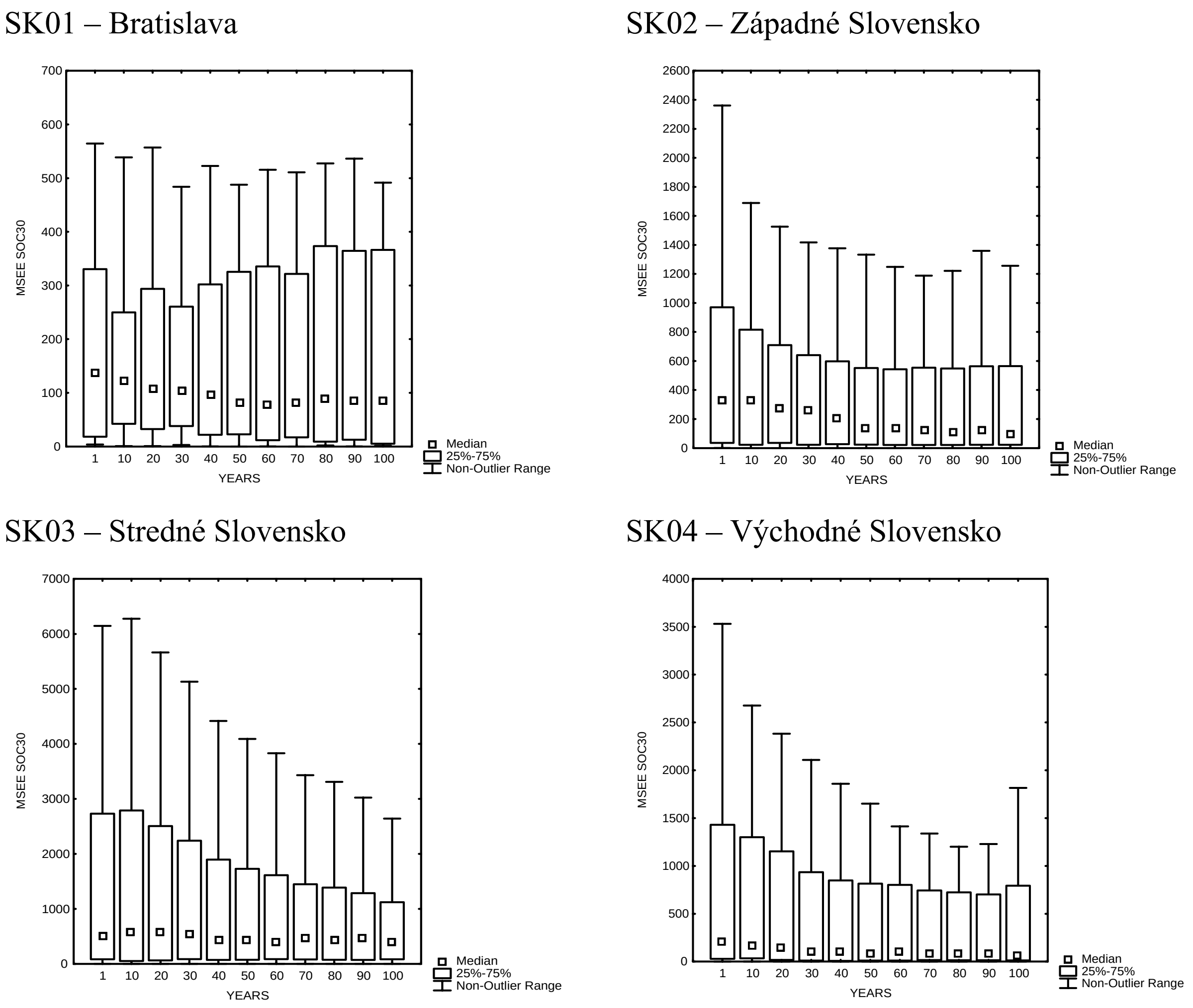


Figure 10. Trends in MSEE in SOC stocks in topsoil (0-30 cm) aggregated for NUTS2 regions in Slovakia (100 years).

Figure 11 shows a scatter plotting of organic carbon stocks in topsoil being calculated from national sources of AISOP (SOC30 KPP) and INSEA European data sources (SOC30 INSEA). They refer to the first year of simulation; hence, the initial state for simulations. The left part of Figure 10 illustrates a correlation, where initial SOC were input at 10 cm soil depth, while in the right part of the Figure shows the correlation of initial SOC at 5 cm soil depth. Both correlations are statistically significant despite the unexplained variation is still relatively high. Nevertheless, assuming initial SOC values are referring at 5 cm soil depth, it improves the estimation of SOC stocks at aggregated levels (Figure 11 right part).

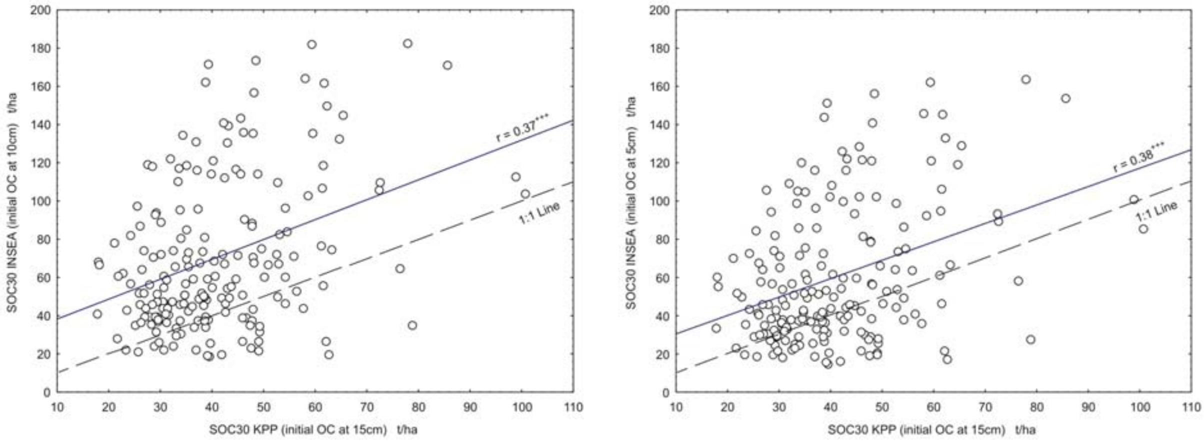


Figure 11. Scatter graph of SOC stocks of KPP and INSEA for Slovakia, where SOC initial values refer to 10 cm (left) and 5 cm (right) soil depth

Pre-run simulations using conventional management practices and assuming SOC values referring at 5 cm soil depth yield SOC stocks that are in equilibrium or close to it. We also compared SOC stocks after 100 years of simulation (mean value of SOC30 from years 80-100), which is shown in Figure 12. Many simulated units are located along the 1:1 line; but there still exists a large number of units that are over- or underestimated. High variability seems logical when perceiving the differences in data quality and scale. Consequently, the INSEA bio-physical process modelling approach is able to gather mean trend in distribution and behaviour of SOC stocks at aggregate levels (e.g. NUTS2 level), but it is not sufficiently appropriate to simulate every ISU accurately due to biases in input data.

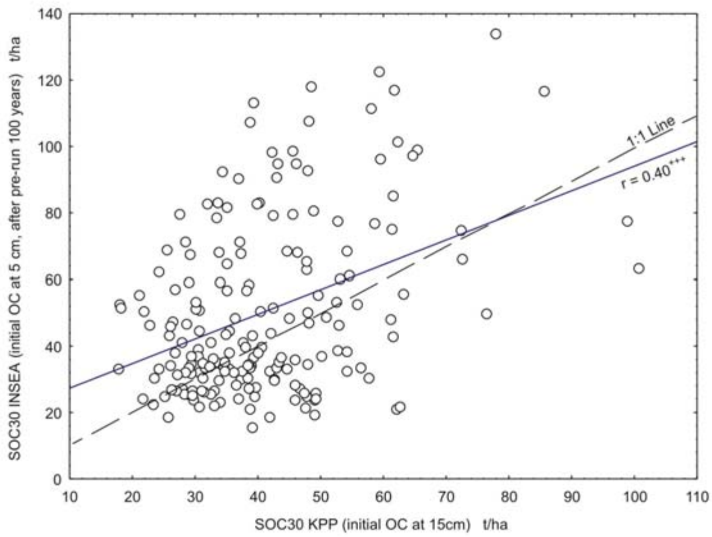


Figure 12. Scatter plot of SOC stocks of KPP (AISOP) and INSEA for Slovakia, where SOC of INSEA was optimised by 100 year pre-run (mean value of years 80-100)

Spatial evaluation of errors in SOC stocks are obtained using the final values of 100-year preparatory simulation runs, which are presented in Figure 13. The highest uncertainty level is located in upland basins and low mountain areas of Slovakia, and also in some areas of lowlands.

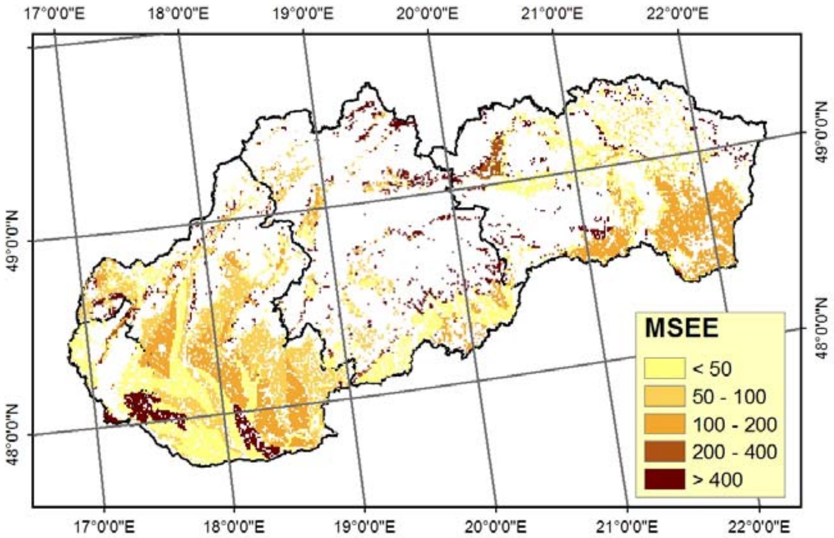


Figure 13. Mean Square Estimation Error (MSEE) of SOC stocks in topsoil (0-30 cm) between KPP (AISOP) reference data and SOC stocks after 100 years of pre-run simulations (initial OC refers to 5 cm depth)

6.4 Impacts of alternative tillage systems on SOC stocks

We also compare the effects from converting conventional tillage systems to reduced or minimum tillage systems using soil and topography data from different sources, i.e. the national database of soils of Slovakia (AISOP) and the European data collected in INSEA. The results are summarised in Figure 14, where simulated changes in SOC stocks are plotted for NUTS2 regions, and both datasets. The impacts on SOC from alternative tillage systems are quite similar between the two datasets. Higher differences are observed in the Bratislava region (SK01), which, however, represents a relatively small area.

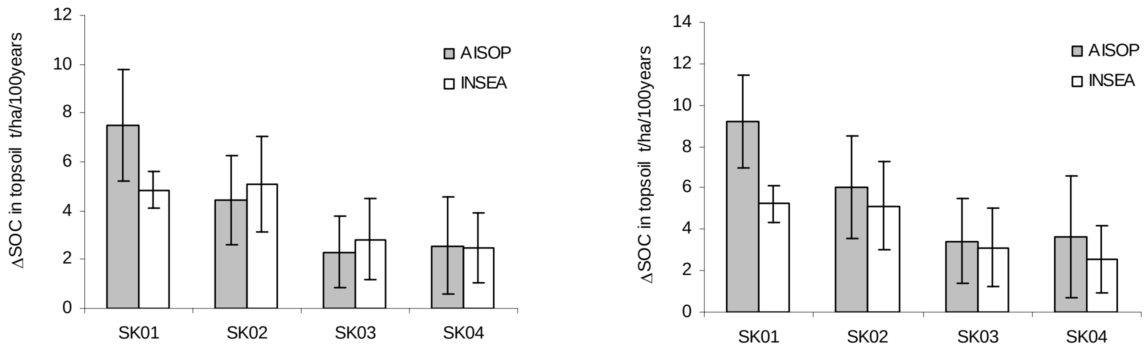


Figure 14. Changes in SOC stocks at NUTS2 levels, when converting from conventional to reduced tillage (left), or minimum tillage (right) systems. Simulation results are presented for soil and topography data from Slovakian AISOP database (grey), and INSEA database (white).

7. Conclusions

This study focuses on the validation of the *Map of organic carbon in topsoils in Europe*, because it is not validated for Central-European conditions, yet. OC Top v. 1.2 was originally verified by Italian and United Kingdom soil data, for which it was found relatively representative (JONES et al. 2005). However, we can expect that the PTF approach has different validity in different naturally distinct areas. Therefore, we use soil profile data (AISOP) from Slovakia to validate the OC Top v. 1.2 for Central-European conditions.

This analysis shows that the PTF-derived data significantly overestimates carbon resources of arable land in Slovakia. The PTF data generally accords with distribution rules respecting natural differences; however a significant number of highly overestimated pixels bias SOC values, which is problematic when using them as initials for bio-physical process modelling. This lack can be partially eliminated when SOC values are averaged and aggregated to a finite number of homogeneous response units (HRU). In such a case, a relatively good fit between measured values (AISOP) and PTF-derived data can be obtained, indicating that European data sources succeed in describing the general gradient. However, SOC stocks calculated through HRU processing are still overestimated.

Preparatory bio-physical process simulations using EPIC (Environmental Policy Integrated Climate) may help to equilibrating SOC stocks at NUTS2 levels. Site and management information are also adopted using NewCronos and other statistical sources at EU level, which respect the scale 1:1,000,000. Consequently, results should be aggregated and presented with respect to these assumptions. Figure 15 shows the development of soil organic carbon stocks (in tonnes) in the topsoil layer (0-30 cm) over a 100-year simulation period, which are estimated[10] for all four NUTS2 regions in Slovakia. Topsoil SOC stocks are calculated from national AISOP data (grey column) and European data sources (white columns). The initial SOC stocks are overestimated in the NUTS2 regions Stredné Slovensko (SK03) and Západné Slovensko (SK04), which are relatively mountainous. In this case, pre-run simulations are able to adjust total SOC stocks more closely to the reference of AISOP data. It is shown that preparatory simulations and by assuming that initial SOC values refer to shallow soil depths (5 cm) can help to sufficiently adjust SOC stocks in cases, where initial values are highly overestimated by the original European input SOC layer. This is especially true if data were aggregated at NUTS2 level. The two other NUTS2 regions (SK01 and SK02), which are mostly lowlands, are underestimated as for total organic carbon stocks. Nevertheless, the evolution of total SOC stocks does not show any dramatic de- or increase in these regions.

Consequently, a combination of preparatory biophysical process simulations and appropriate assumptions (reference of OC values in soil profile) could improve the quality of input data, which are generally available at European scales.

Finally, it was also shown that bio-physical process modelling with INSEA data could provide impacts on SOC under alternative tillage systems, which are relatively consistent with impacts being simulated from national sources (AISOP). The effects on SOC from a change in conventional tillage systems to reduced or minimum tillage systems are, in relative terms, similar between the Slovakian soil databases and the INSEA database for Slovakia.

[10] using bulk densities from AISOP database.

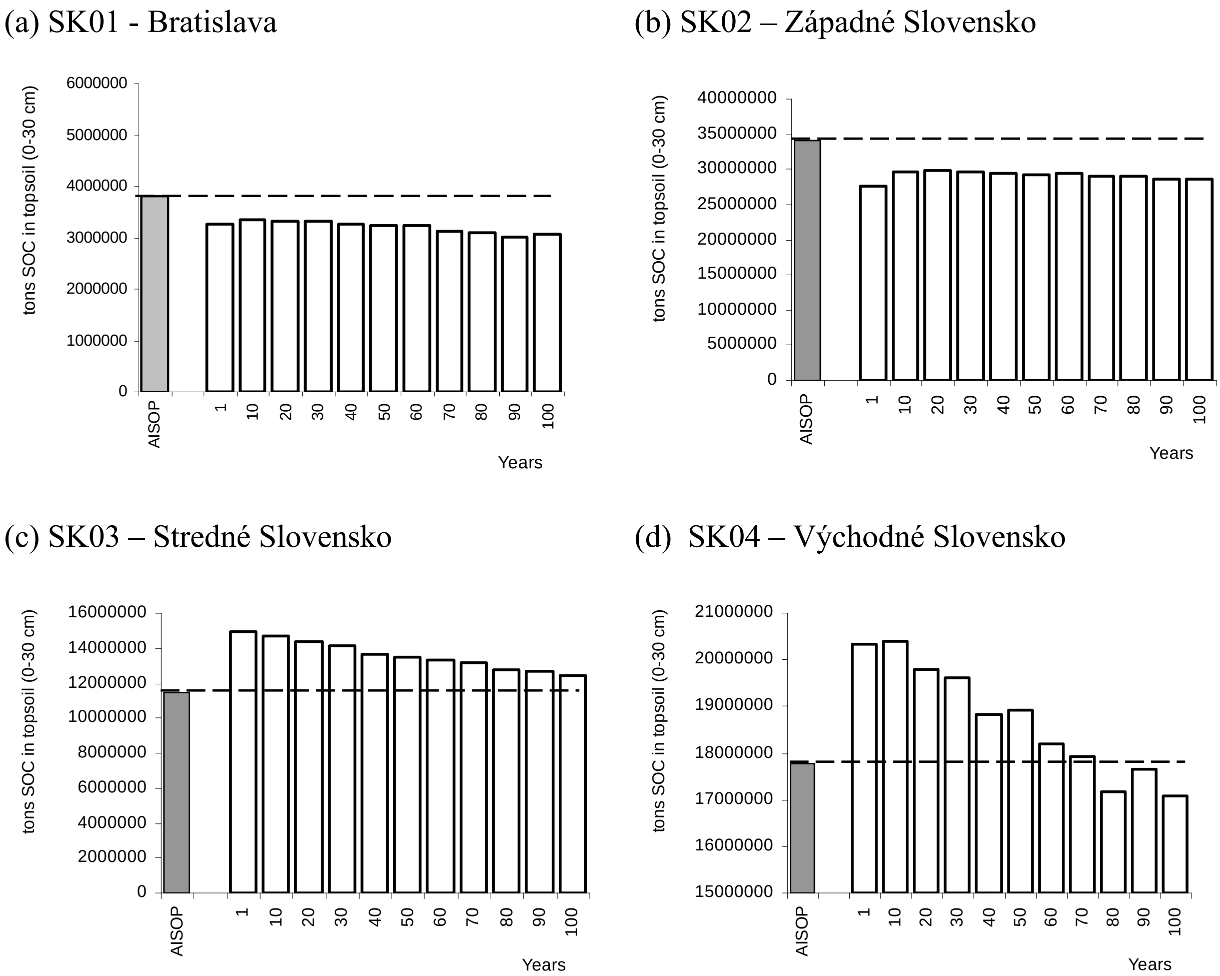


Figure 15. Development of organic carbon stocks in topsoil (in tonnes) by NUTS2 regions in Slovakia from national (grey) and simulated data (white).

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Biophysical impact assessment of crop land management strategies in EU25 using EPIC

E. Schmid, J. Balkovič and R. Skalský

1. Introduction

The diffuse nature of emission loads from crop lands and the randomness of weather events resulting in discontinuous environmental impacts (e.g. soil carbon sequestration, nutrient leaching) are difficult to address and usually include a significant source of uncertainty. Environmental indicators such as nutrient and sediment losses from crop lands are categorized as non-point source and by their very nature are not directly attributable to specific fields and/or management practices. In addition, on-site monitoring of environmental indicators is usually prohibitively expensive and a reliable way to estimate the effect of site-specific land management on the delivery of emission loads is through biophysical process models. Consequently, the utilization of complex biophysical process models have improved our ability to predict the changes of selected production and environmental indicators, which significantly vary across weather events, soil types, topographies, and management practices. The combination of biophysical process models with economic land use optimisation models is a powerful tool to reduce uncertainties in utilizing and managing land resources and it generates sufficient information to comprehensively analyse economic and environmental policy implications.

Adequate delineation and aggregation approaches are essential in biophysical process modelling, because the heterogeneity of natural resources, management practices, and individual decision-making would imply literally millions of model applications (Putman et al., 1987; Rosenberg et al., 1992; Haan et al., 1995; Atwood et al., 2000; Schmid, 2001). Consequently, complex landscapes with heterogeneous land use management and individual decision-making have to be stratified into homogeneous units, i.e. Homogenous Response Units (HRU), and Decision Making Units (DMU). In general, an increasing number of HRUs and DMUs may better reflect the natural and decision-making heterogeneities within a region (e.g. watershed, NUTS2, EU25) and may also improve the model performance at aggregate levels. The natural homogeneity (HRU) usually relates to similar physical conditions including weather, soils, topography, land use and management practices. The economic homogeneity (DMU) usually includes similar attitudes of decision makers (e.g. farmers) with respect to price, cost, and policy expectations, risk preferences and knowledge as well as technical and resource endowments.

The challenge is to delineate a number of representative HRUs and DMUs for a given region (i.e. NUTS2) that sufficiently depicts the heterogeneity in natural processes and decision-making. A spatially and temporally indexed common activity based unit (e.g. hectares, animal heads) assures the linkage between HRU and DMU (Schmid, 2001). The HRU delineation procedure usually involves statistical or/and GIS based methods (e.g. cluster analysis) by merging weather, soil, topographic, land use, and management information. The DMU delineation is usually scale (e.g. farm, region, sector), commodity, resource endowment, and management type based by establishing individual crop and livestock budgets (e.g. Standard Gross Margin Calculations), or estimating a set of production functions. However, the number of HRUs and DMUs should be small enough to be computational feasible for a given time and resource endowment.

This environmental assessment involves biophysical simulations of alternative land management strategies to establish a functional relationship between production and selected environmental indicators for EU25. Each HRU is simulated with the field-scale model EPIC (Environmental Policy Integrated Climate). EPIC delivers production and environmental indicators on a per hectare base (crop yield in t/ha, sediment transport in t/ha, nitrogen leaching in kg/ha, carbon sequestered in kg/ha, etc.) that can be further used to describe production activities (among cost and revenue items) in economic land use optimization models (EUFASOM, AROPAj, EFEM). Ideally, the individual simulations include all potential combinations describing production, carbon sequestration, and emission possibilities that are independently distributed within and among regions. The aggregation (weighting) of all individual simulation outcomes is usually computed by the acreage shares of each individual simulation unit (ISU). Economic land use optimisation models are most suitable for this exercise and additionally include economic and policy relevant information necessary for policy analyses. Such models are usually structured to mimic the decision-making under observed market and policy situations (e.g. prices, costs, and policy payments). These models are usually employed for comparative static/dynamic analysis in which scenarios are described and the economic and environmental effects are compared with some base-run situation. In addition, economic models can be modified to analyse a different set of policy instruments (e.g. tax, subsidies) and policy objectives (e.g. environmental standards, farm welfare).

The remainder of the chapter is structured such that EPIC and input data requirements are described next. It is followed by a very brief description of data and their sources which are used in the biophysical impact analysis for EU25. The biophysical process modeling framework has been applied to analyze the production and environmental impacts of alternative tillage systems (i.e. reduced and minimum tillage systems). In particular, potentials of sequestering soil organic carbon applying reduced and minimum tillage systems have been analysed as well as their impacts on crop yields and nitrous oxide emissions. The effects of alternative tillage systems have been put in relation to the effects of conventional tillage systems, which serves as reference or base-run scenario. The report finishes with a summary and outlines some outlook.

2. The EPIC model

2.1 Model description

The Erosion Productivity Impact Calculator (EPIC) was developed by an USDA modelling team in the early 80s to asses the status of U.S. soil and water resources (Williams et al., 1984; Williams, 1990; Jones et al., 1991). The first major application of EPIC was to evaluate soil erosion impacts for 135 U.S. land resource regions (Putnam et al., 1988). EPIC compounds various components from CREAMS (Knisel, 1980), SWRRB (Williams et al., 1985), GLEAMS (Leonard et al., 1987), and has been continuously expanded and refined to allow simulation of many processes important in land use management (Sharpley and Williams, 1990, 1995; Williams et al., 2000). This development resulted in the model name being changed to *Environmental Policy Integrated Climate* (Williams et al., 1996). A major carbon cycling routine was performed by Izaurralde et al. (2006) based on the approach used in CENTURY (Parton et al., 1994). Current research efforts are focusing on model algorithms that address green house gases emissions (e.g. N_2O, CH_4). The most recent documentation of EPIC's historical development and applications can be found in Gassman et al. (2004).

The drainage area considered by EPIC is generally a field-size area - up to 100 ha - where weather, soil, topography, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, and plant environment control. EPIC operates on a daily time step, and is capable of simulating hundreds of years if necessary. The optional Green and Ampt infiltration equation simulates rainfall excess rates at shorter time intervals (0.1 h). The model offers options for simulating several processes with different algorithm -- five PET equations, six erosion/sediment yield equations, two peak runoff rate equations, etc., which allow reasonable model applications in very distinct natural areas.

EPIC can be used to compare management systems and their effects on water, nitrogen, phosphorus, pesticides, organic carbon, and sediment transport, on organic carbon sequestration, and eventually on green house gas emissions. The management components that can be changed are crop rotations, crop/grass mixes, tillage operations, irrigation scheduling, drainage, furrow disking, liming, grazing, burning operations (e.g., on prairies), tree pruning, thinning and harvest, manure handling (e.g., lagoons), and fertilizer and pesticide application rates and timing.

The need to address whole farm and watershed related problems has led to the development of the Agricultural Policy/Environmental eXtender (APEX) model (Williams, 1995; Williams et al., 2000) in the 90s. EPIC provides the individual field simulation component in APEX and components for routing water, sediment, nutrients, and pesticides across complex landscapes and channel systems to the watershed outlet are added. APEX also has groundwater and reservoir components. A watershed can be subdivided as much as necessary to assure that each sub-area is relatively homogeneous in terms of soil, land use, management, etc. The routing mechanisms provide for evaluation of interactions between sub-areas involving surface run-on/runoff, return flow, sediment deposition and degradation, nutrient, manure, and organic carbon transport, and groundwater flow. Water quality in terms of nitrogen (ammonium, nitrate, and organic), phosphorus (soluble and adsorbed/mineral and organic), and pesticides concentrations may be estimated for each sub-area and at the watershed outlet. Because of routing and subdividing, a spatial rainfall generator, and a hydrograph algorithm, there is no limit on the watershed size.

Both models use the same input files (i.e. crops, fertilizers, pesticides, and tillage operations), which are provided by the model developers. In addition, site specific information (soil, weather, management practices, etc.) that are usually defined by the model users, are stored in files that are readable by both models. This data and model framework provides a comprehensive data and modelling tool to analyse production and environmental problems for various scales (field, farm, watershed, region, EU25).

2.2 EPIC input data requirements

Like for any biophysical process model, the quality and completeness of input data is very important. Information on four major input data components is essential to run EPIC. These are weather, soil, topography, land use and management practices. An homogenous area (HRU and ISU) – see the chapter on data processing – basically reflects a certain combination of these four data components (i.e., combining one weather seed with one soil type with one topographic exposition, and with one land use management system). Consequently, heterogeneous landscapes can be portrayed by identifying a reasonable number of HRU/ISU for a region.

2.2.1 Weather

The weather parameters, necessary for running EPIC, are precipitation (in mm), minimum and maximum air temperature (in degree Celsius), and solar radiation (in MJ/m²). If the Penman methods are used to estimate potential evapo-transpiration, wind speed (in m/sec measured at 10 m height), and relative humidity (in %) are also required. If measured daily weather data is available, it can be directly input into EPIC. In addition, monthly statistics of this daily weather (mean, standard deviation, skew coefficient, probabilities of wet-dry and wet-wet days, etc.) need to be computed and input in the model. EPIC provides a support programme to compute the statistics of relevant weather parameters based on historical daily weather records. Consequently, long historical daily weather records (at least 20-30 years) for all weather parameters are desirable for statistical calculations. Based on the statistics of the weather parameters, EPIC can generate weather patterns for long-run analyses (over 100 years of daily weather), or as indicated above, daily weather records (e.g. from world climate models with downscaling procedures) can be input directly. There is also an option of reading a sequence of actual daily weather and use generated weather afterwards within a simulation run.

2.2.3 Soil

A large number of physical and chemical soil parameters describing soil layers and entire soil profile can be input in EPIC (table 1 in appendix). These soil parameters are separated between general and layer-specific as well as between essential and useful soil information. The essential soil parameters are mandatory inputs, while the remaining ones would help to better describe the specific soil profile properties. In EPIC, a soil profile can be split in up to 15 soil layers, of which each is described by a set of specific chemical and physical soil parameters. If, for instance, the description of only two soil layers is available (top-soil and sub-soil), EPIC still allows (optional) to split the soil profile into fifteen soil layers. It assures that e.g., soil temperature and soil moisture can be appropriately estimated through all soil layers and time scales.

2.2.4 Topography

As EPIC is a field-size model, the topography of a field is described by field size (ha), slope length (m), and slope steepness (%). In addition, elevation, longitude and latitude are needed for each site. Information on elevation is usually obtained from high-resolution digital elevation models as for modelling in GIS workspace. Since biophysical modelling for EU25 is explicit for the coverage of homogeneous response units, the topography parameters are considered as mean (elevation), majority (slope) or default (field size and slope length) parameters for each HRU.

2.2.5 Management Practices

A single model is used in EPIC for simulating more than 100 different crops and trees, of which each is described by a unique set of crop/tree describing parameters (provided by the model developers). EPIC is capable of simulating growth for annual and perennial crops, and trees. The annual crops grow from planting date to harvest date or until the accumulated heat units equal the potential heat units for the crop. The perennial crops maintain their root systems throughout the year, although they may become dormant after frost. They start growing when the average daily air temperature exceeds their base temperature. The phenological development of the crop is based on daily heat unit accumulation. A heat unit index is computed as the fraction of daily heat unit accumulation and potential heat units, which may be input or calculated by the model from normal planting and harvest dates. The heat unit index ranges from zero at planting to one at physiological maturity and affects the date of harvest, leaf area growth and senescence, optimum plant nutrient concentrations, and partition of dry matter among root, shoots, and crop yield. The potential growth in biomass is a function of the biomass energy conversion parameter and the intercepted photosynthetic active radiation parameter. In many crops, the leaf area index decreases after reaching a maximum and approaches zero at physiological maturity. In addition, leaf expansion, final leaf area index, and leaf duration are reduced by water, nutrients, bulk density, and temperature stresses (Acevedo et al., 1971; Eik and Hanway, 1965). The fraction of total biomass portioned to the root system normally decreases from seeding to maturity (Jones, 1985) and the model simulates this portioning by decreasing the fraction linearly from emergence to maturity. The rooting depth normally increases rapidly from the seeding depth to a crop specific maximum. In many crops, the maximum is usually attained well before physiological maturity (Borg and Grimes, 1986) and is simulated in the model as a function of heat units and potential root zone depth. The crop yield of most grain, pulse, and tuber crops is a reproductive organ. In general, crops have a variety of mechanisms which ensure that their production is neither too great to be supported by the vegetative components nor too small to ensure survival of the species. As a result, EPIC uses a harvest index (crop yield/above ground biomass) which is often a relatively stable value across a range of environmental conditions.

The tillage component in EPIC is designed to mix nutrients and crop residue within the plough depth, to simulate the change in bulk density, and to convert standing residue to flat residue. Moreover, there are functions in this component that simulate ridge height and surface roughness. The tillage component is very user oriented in allowing specifying the date and depth of each tillage operation. The tillage operation is carried out on a specified date if the soil is dry enough and if not, the operation occurs on the next suitable day. It is possible to schedule operations by a fraction of the heat unit accumulations. The heat unit schedule may be input by the user or automatically developed by EPIC, or with all possible combinations of both. The harvest index and harvest efficiency provide adequate flexibility to accommodate almost any harvest strategy (e.g. harvesting of grains solely or with straw). The harvest index is specified for each crop and is adjusted during each year of simulation. The adjusted harvest index dictates the fraction of the above ground biomass removed from the crop. The harvest efficiency indicates what portion of the harvested material actually leaves the field.

The plant environment control component provides scheduling options for timing and rate of irrigation water, fertilizer, lime, pesticide, grazing, and drainage systems. This component is also very user oriented and provides many combinations of application modes (e.g. rigid or flexible application).

This wide range of management scheduling in EPIC allows flexibility in modelling different cropping, forestation, and tillage systems (including crop rotations and crop mixes).

However, it requires reliable information of the actual management practice for a given region or site. Generally, information on:

- Date of planting (including potential heat units the crop needs to reach maturity),
- Date, type (commercial; dairy, swine, etc. manure) and amount of fertilizer (elemental N, P, K) in kg/ha; if manure is applied, information on application rate (in case of grazing the stocking rate) and nutrient composition (orgN, minN (NO3-N + NH3-N), orgP, minP, minK, orgC, and fraction of NH3-N on minN) is needed,
- Date and amount of irrigation (including NO_3 and salt concentration in irrigation water) in mm,
- Date and type of tillage operation (plough, harrow spike, field cultivator, thinning, etc.), and
- Date and type of harvesting (combine harvester, hay cutting, grazing, etc.), is needed.

3. Data for bio-physical process modelling in EU25

3.1 Input Data

The biophysical process modelling for EU25 is highly data demanding. Generally, GIS explicit data as well as statistical and auxiliary data have been provided by several authorities, mainly by the Joint Research Centre (JRC), and EUROSTAT and processed as described in chapter – data processing. The data provided are listed and briefly described in table 2.

Data	Source	Description	Contributor
Climate	MARS	Monitoring of agriculture with remote sensing. Geo-referenced database (50 km grid) and related attribute data on climate	JRC
	EAST ANGLIA	The Climatic Research Unit, and Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK data. Geo-referenced database (0.5° grid), monthly average meteorological parameters.	Univ. of East Anglia
	EMEP	Monitoring and evaluation of the long-range transmission of air-pollutants in EUROPE. Geo-referenced database (50 km grid) with atmospheric depositions of nitrogen.	IIASA
Soil	ESDB v.2	The European soil database v. 2. SGDBE and PTRDB databases (grid with cell resolution 1km) and database of estimated and measured soil profiles of Europe.	JRC
	OC Top v. 1.2	The map of organic carbon in topsoil in Europe, Ver. 1.2 (grid with 1 km cell resolution)	JRC
	HYPRES	Hydraulic properties of European soils – pedotransfer functions for hydraulic and retention soil properties	JRC
Topography	GTOPO30	Global digital elevation model (grid with 1 km cell resolution).	JRC
	SRTM90	High resolution digital elevation model (grid with 90 m cell resolution)	JRC
Land cover	CORINE & PELCOM	Combined CORINE & PELCOM data. Land cover grid with 1 km cell resolution.	JRC
Agricultural statistics	NEW CRONOS	New Cronos Regional Statistics and New Cronos agriculture database. Aggregated statistical data at NUTS level.	EUROSTAT
	LUCAS	Land use and land cover area frame statistical survey – Phase I. Geo-referenced point database.	EUROSTAT
	FAO	Fertilizer usage by crops, 5th edition	FAO
	MARS	Monitoring of agriculture with remote sensing. Crop calendar.	JRC
Administrative regions	AGISCO	Geographic information system of European commission. Geo-referenced coverage of administrative units (point and polygon data in scales from 1:M to 1:10M).	JRC

Table 2: List of data provided to INSEA.

The data is processed (see chapter data processing) to delineate an HRU layer for EU25 and to establish an EPIC input database containing information on weather, soil, topography, land use, crop rotations and crop management. This HRU concept assures consistency in integrating the biophysical impact vectors from EPIC in an economic land use optimization model (e.g. EUFASOM).

The aggregation of site-specific biophysical impacts in land use optimization models needs to meet consistency criteria. Suppose two crops (wheat and corn) are grown on two different land units that have different physical and chemical properties (Figure 1). Such crop specific land units are often obtained by a delineation process as described above or in the chapter *data processing*. Consequently, each land unit is described by site-specific attributes (altitude, soil texture, slope, orgC, pH, crop rotation, etc.). The biophysical impacts of these land units are a function of land use and management (i.e. crops and management) and the site-specific characteristics.

Economic land use optimisation models usually simulate land use changes endogenously which will lead to a different weighting of site-specific biophysical impact vectors and therefore to changes in production and emissions. Suppose, corn becomes more profitable then the economic land use model will increase the share of corn and all the associated attributes of site-specific bio-physical impacts. This would result that the share of silty soils and the 6%-slope class in our case increases as well, which would be inconsistent to what one usually observes. Therefore, the key-question is: which physical and chemical properties of land units should be included?

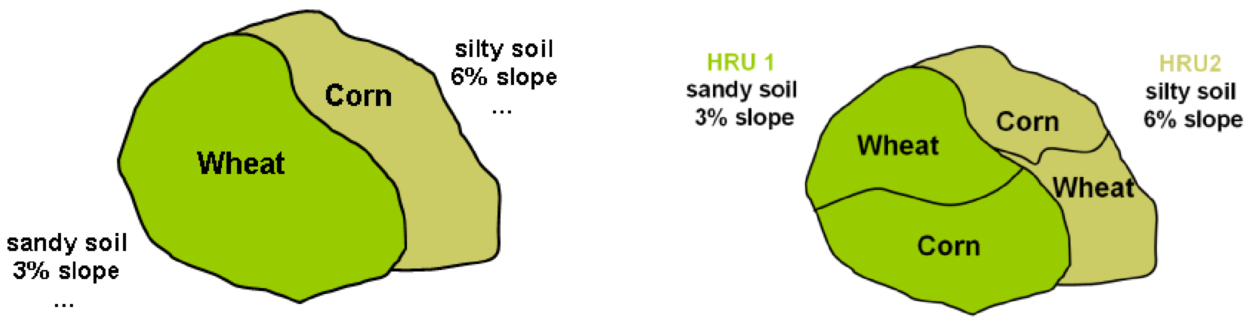


Figure 1. Consistent delineation of homogeneous land use units

A two-step hierarchical process to delineate HRUs is necessary to address this problem (Schmid et al., 2006):

- In the first step, parameters of landscape are merged (e.g. altitude, slope, soil texture, soil depth, and volume-of-stones classes), which are relatively stable over time (even under climate change) and hardly affected by farm management.
- In the second step, the HRU layer obtained in the first step is merged with land cover categories, weather, crop rotation and management, and regional boundary information to derive individual simulation units (ISU) for each region (e.g. NUTS2 or watersheds).

Each ISU represents a certain share in the region, which is simulated with the biophysical process model EPIC to deliver spatially and temporally explicit biophysical impact vectors. These ISUs along with their physical characteristics (crop yields, emissions) and their specific other attributes (size, management) are treated as an activity in economic land use optimization models. If all potential alternative ISUs are simulated with the biophysical process model then one can construct a production and / or emission possibility curve. Economic models are employed in the next step to find the optimal combinations in the scenarios.

4. Biophysical Modelling Results for EU25

Comparative dynamic analyses have been carried out to simulate environmental and production effects of alternative tillage systems. In particular, potentials of sequestering soil organic carbon using either reduced or minimum tillage systems have been analysed as well as their impacts on crop yields and nitrous oxide emissions. The effects of alternative tillage systems have been put in relation to the effects of conventional tillage systems, which serves as reference or base-run scenario. The different tillage systems are simulated with EPIC for ten years of which average effects have been calculated and are presented in the following maps. All other management operations (e.g. fertilization and irrigation rates) are the same for all tillage systems. The corresponding maps also show average effects from this simulation exercise. All analyses focus on arable lands in the EU25, which amount to about 100 million hectares in total. There are 9555 individual simulation units (ISU) that represent the biophysical responses of arable lands in EU25, which are the bases for the following maps.

The spatial distribution of average organic carbon in topsoil (<30 cm) for the base-run scenario (i.e. conventional tillage) on arable lands in EU25 is shown in Figure 2.

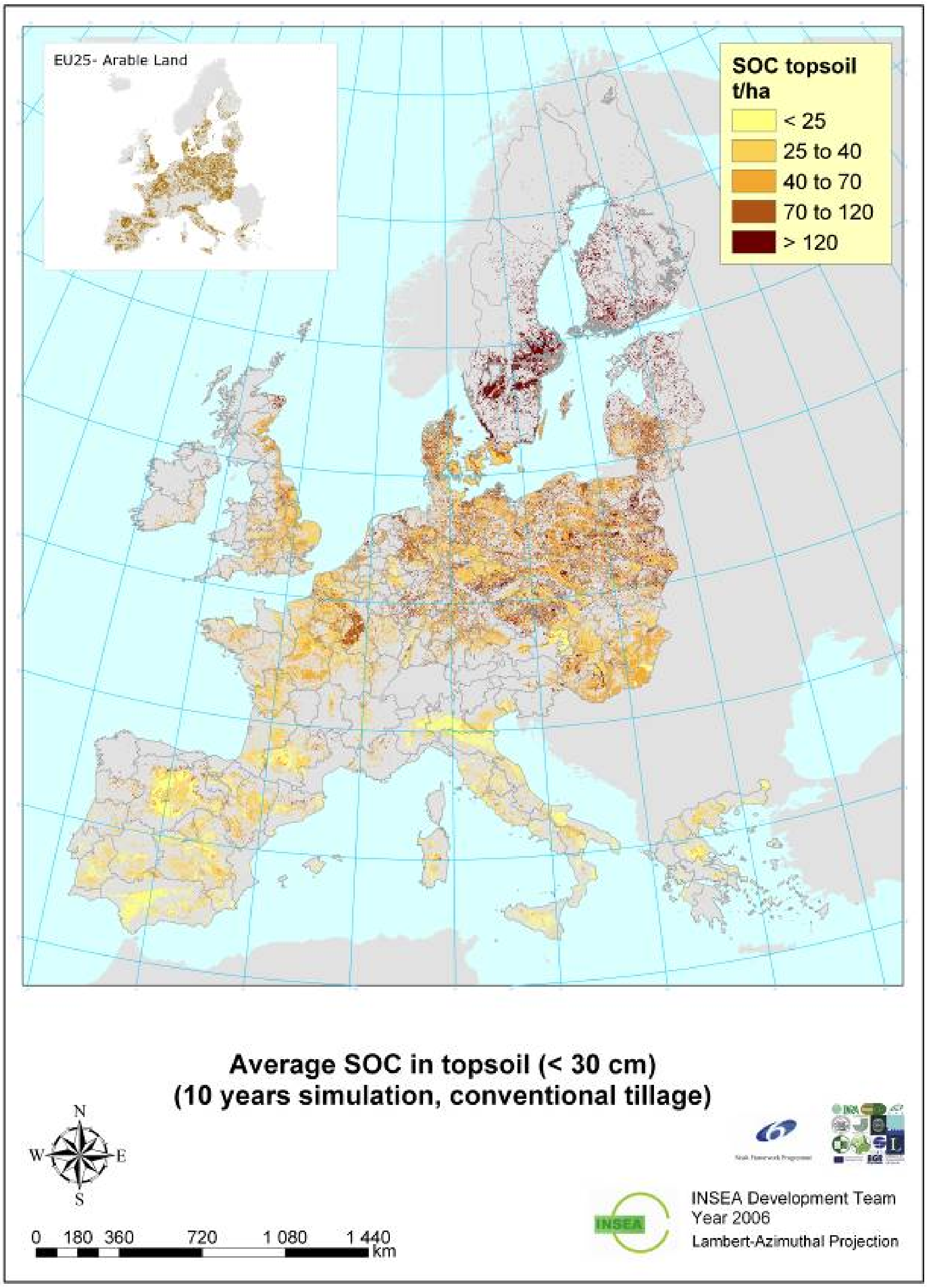


Figure 2. Spatial distribution of organic carbon in topsoil (< 30cm) of arable lands in EU25.

The weighted average of organic carbon in topsoil on arable lands in EU25 is 60 t/ha. The average effects on topsoil organic carbon and dry matter crop yields from a change in tillage systems for ten years are shown in Figure 3 and 4.

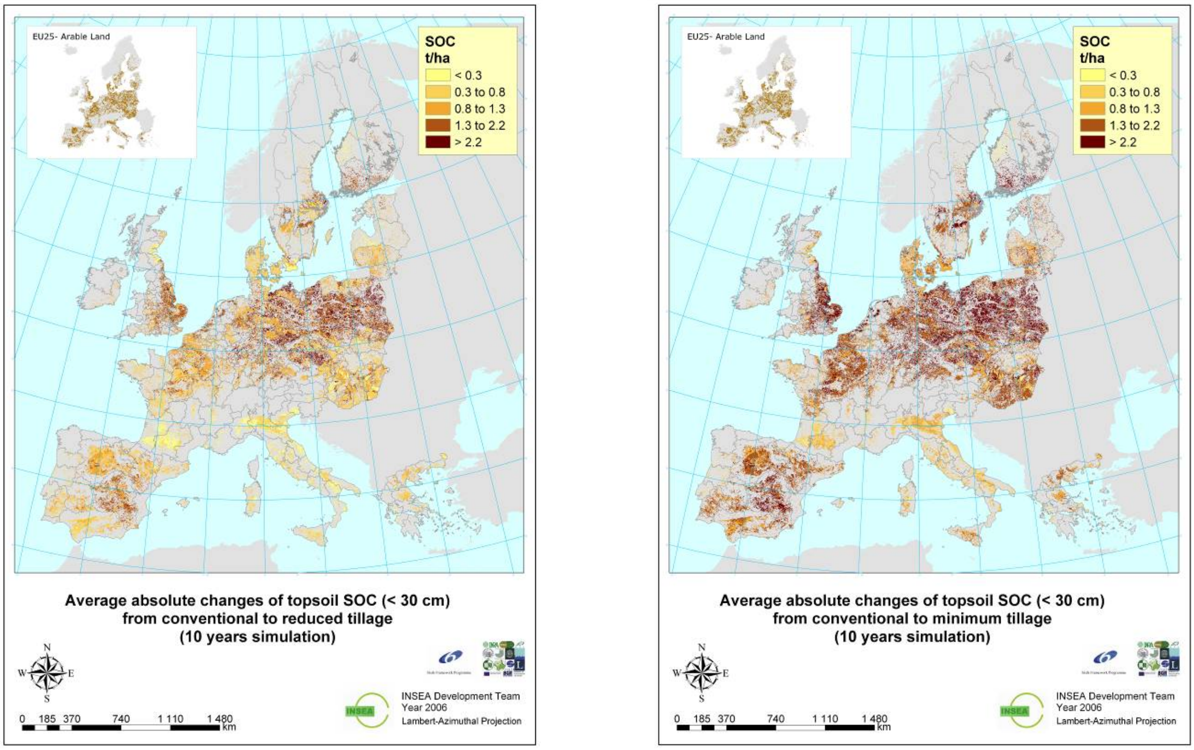


Figure 3. Changes in topsoil organic carbon on arable lands in EU25 when shifting from conventional tillage systems to reduced (left), or minimum tillage systems (right) over ten years of simulations.

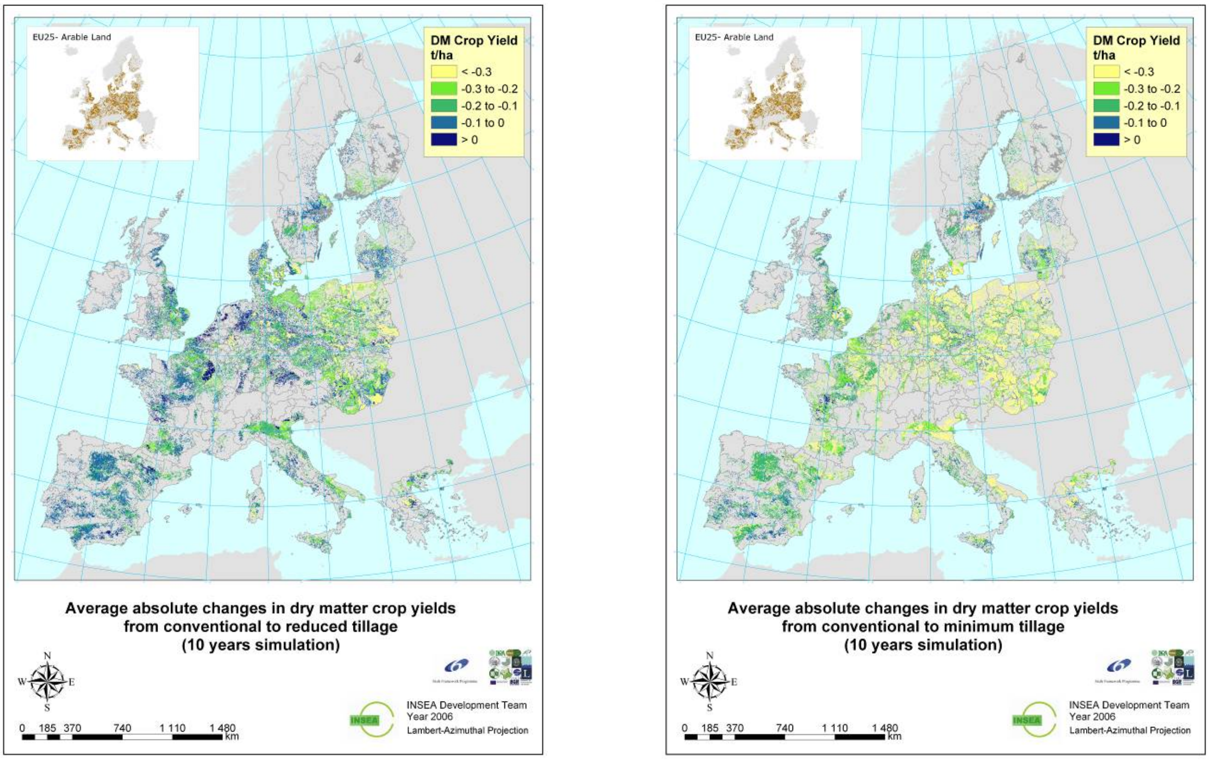


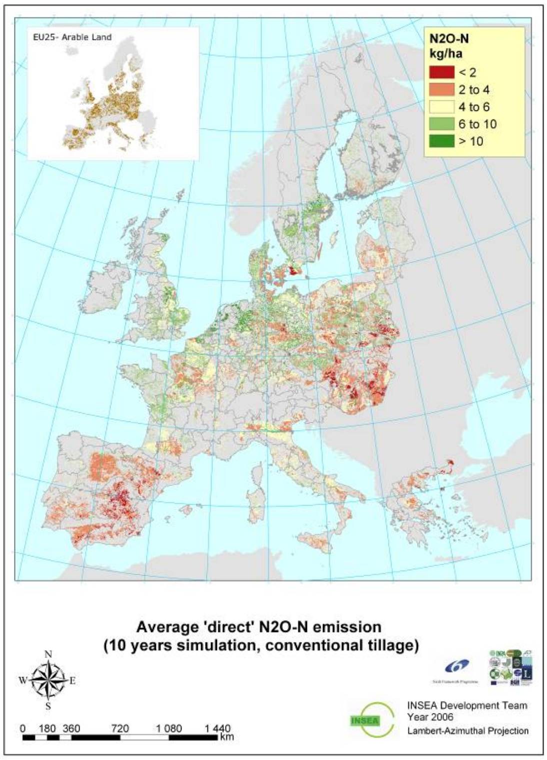
Figure 4. Average changes in dry matter crop yields on arable lands in EU25 when shifting from conventional tillage systems to reduced (left), or minimum tillage systems (right).

The potential to sequester carbon in topsoil by applying reduced tillage systems on arable lands in EU25 is 0.11 t/ha/yr, where the highest potentials are located in the North-Eastern part of EU25 as shown by the map in Figure 3. The weighted average impact on dry matter crop yields from such a tillage change are -0.13 t/ha, or -3.6% compared to crop yields from conventional tillage systems. The range covers positive and negative crop yield impacts as shown in Figure 4. A shift towards minimum tillage systems reveals a potential to sequester carbon in topsoil of 0.18 t/ha/yr, and would impact dry matter crop yields by -0.30 t/ha, or -7.9% on average. The corresponding map in figure 4 indicates that there are less positive crop yield impacts and the areas with major losses in crop yields are located in the North-Eastern part of EU25.

The impacts on N_2O-N emissions are externally calculated, because EPIC does not have a gas diffusion module included yet. The calculation of *direct* and *indirect* N_2O-N emissions follows mainly IPCC guidelines and uses also some of their default values. Nevertheless, there are major differences in this calculation procedure, which are:

- 'direct' N_2O-N emissions are calculated using fractions from nitrification and de-nitrification, processes that are simulated in EPIC. The fractions are based on the field experiments from Khalil, Mary, and Renault (2004) and are assumed to be 0.54% of nitrified nitrogen, and 11% of de-nitrified nitrogen.
- 'indirect' N_2O-N emissions are calculated using EPIC output variables of nitrogen in leaching and run-off waters, and in volatilization, and using IPCC default values. The default values used are 2.5% of N leached and in run-off, and 1% of N that is volatilized.

It is important to notice that our calculation procedure for 'direct' N_2O-N emissions includes background N_2O-N emissions, because it is based on nitrification and de-nitrification processes, while the IPCC method dose not accounting for it.



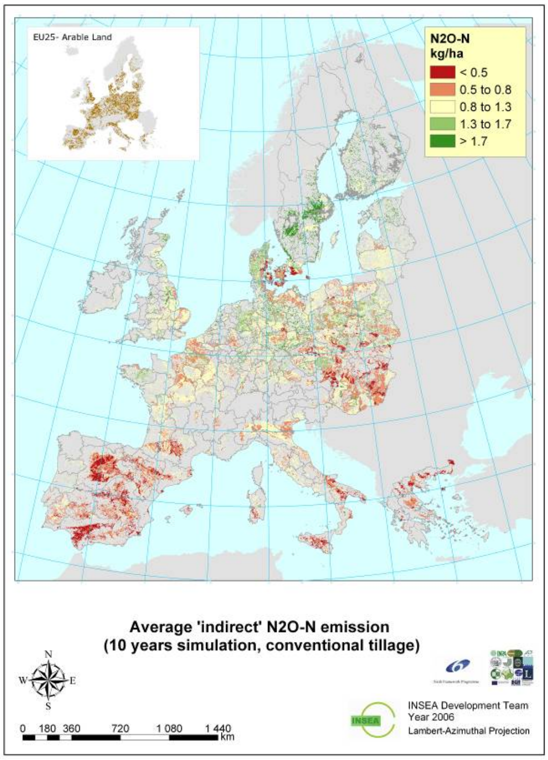


Figure 5. Average 'direct' (left) and 'indirect' (right) N_2O-N emissions from conventional tillage systems on arable lands in EU25.

The spatial distribution of average 'direct' and 'indirect' N_2O-N emissions from conventional tillage systems on arable lands in EU25 are shown in Figure 5. The weighted average of 'direct' N_2O-N emissions is 5.3 kg/ha/yr, or 511.9 Gg/yr in total, and the weighted average of 'indirect' N_2O-N emissions is 0.9 kg/ha/yr, or 91.7 Gg/yr in total.

It is important to notice that so far nitrogen is fertilized only in mineral form (i.e. no organic N application from animal manures) and the application rate is computed by nitrogen removal through crop yield harvests times a fertilization excess coefficient of 1.2. This assumption may be appropriate in regions where crop production is dominant, but highly inappropriate in regions with substantial livestock production. In addition, there are regions where the N surpluses of more than 200 kg/ha, which are also not captured yet. Nevertheless, there is ongoing work to calculate nutrient balances for all NUTS2 regions including mineral and organic nutrient forms.

The average changes in 'direct' N_2O-N emissions when shifting to reduced or minimum tillage systems are shown in Figure 6. Both maps indicate that the N_2O-N responses from a tillage change can be spatially quite different and there are regions where 'direct' N_2O-N emissions can increase and in others decrease. The net-effect on ‘direct’ N_2O-N emission from shifting towards reduced tillage systems on arable lands in EU25 is on average -0.12 kg/ha/yr, or -12.5 Gg/yr in total. A change towards minimum tillage systems would cause a net-effect in ‘direct’ N_2O-N emissions of -0.38 kg/ha/yr, or -37.1 Gg/yr in total.

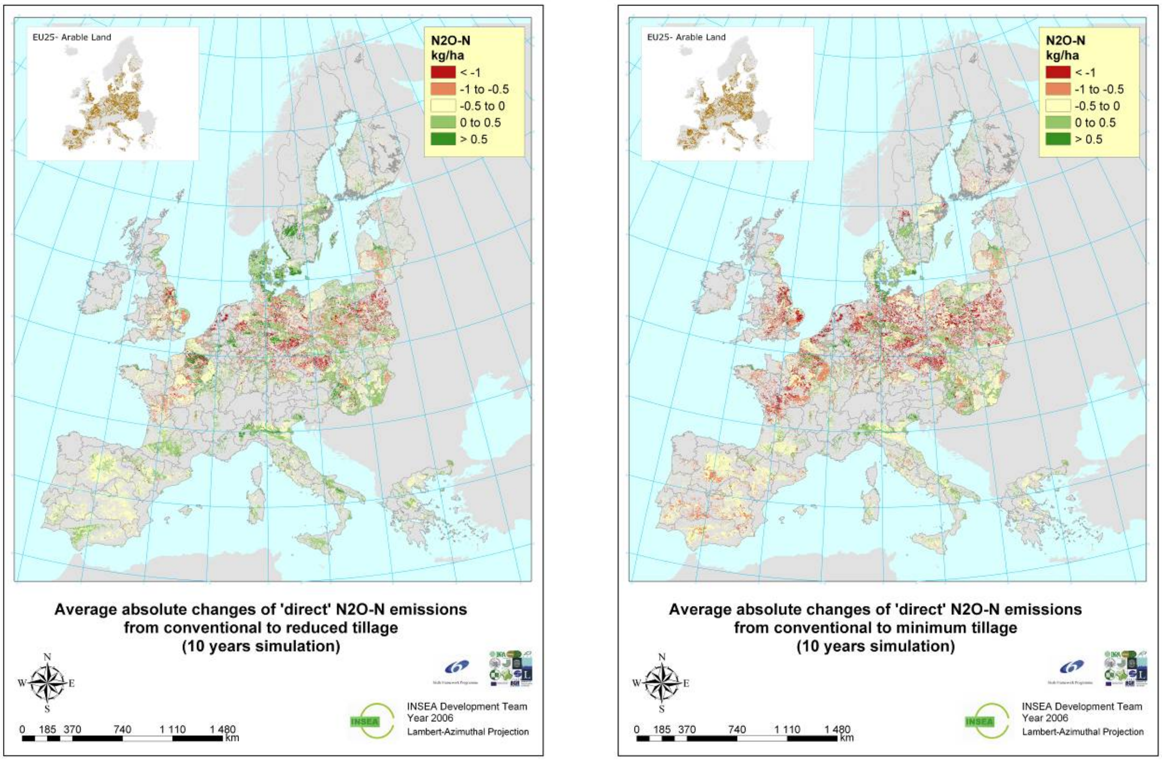


Figure 6. Average changes in ‘direct’ N_2O-N emissions on arable lands in EU25 when shifting from conventional tillage systems to reduced (left), or minimum tillage systems (right).

The general picture of the range in spatial impacts on ‘indirect’ N_2O-N emissions from a tillage system change is similar to the one of ‘direct’ N_2O-N emissions, and is shown in Figure 7.

The net-effect on ‘indirect’ N_2O-N emission from shifting towards reduced tillage systems on arable lands in EU25 is on average -0.06 kg/ha/yr, or -5.9 Gg/yr of N_2O-N in total. A change towards minimum tillage systems would cause a net-effect in ‘indirect’ N_2O-N emissions of -0.08 kg/ha/yr, or -8.0 Gg/yr in total.

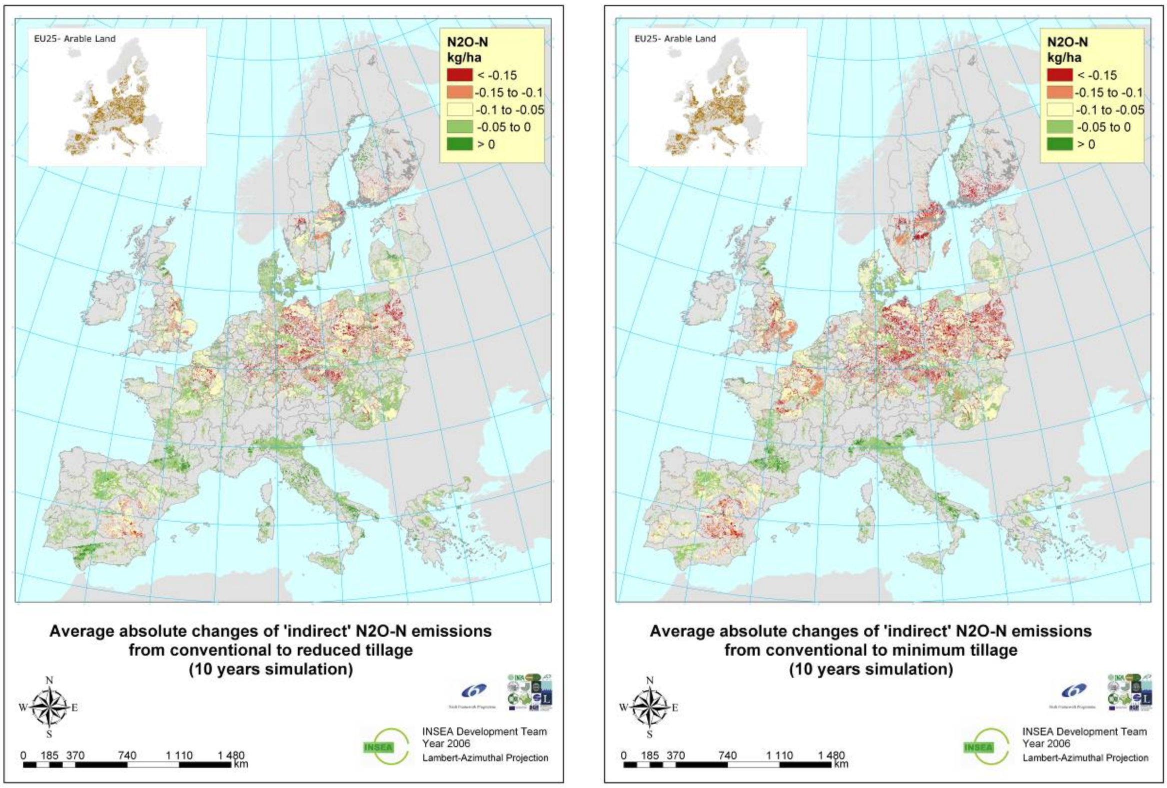


Figure 7. Average changes in ‘indirect’ N_2O-N emissions on arable lands in EU25 when shifting from conventional tillage systems to reduced (left), or minimum tillage systems (right).

The impact analysis of alternative tillage systems shows that there are substantial potentials in sequestering organic carbon through more soil conserving tillage systems (i.e. reduced and minimum tillage systems). In addition, such a tillage change would also lead to reduced ‘direct’ and ‘indirect’ N_2O-N emissions on average, but are not uniformly distributed and exhibit +/- effects locally. Crop yields are also reduced from such tillage change, which range between 3% and 8% on average. Nevertheless, there is strong evidence that a change of tillage systems will also lead to other environmental side-effects such as more pesticide, or fertilizer applications, which should be also accounted for in evaluating the environmental performance of alternative tillage systems.

5. Summary

This paper presents an integrated biophysical process modelling framework at EU25, which is capable to address production and environmental impacts of alternative management practices for alternative crop production systems. Policy analysts are increasingly using computer intensive modelling systems to consistently analyse the complex relationship between policy instruments, the reaction of individual decision makers and the consequences for economic and environmental indicators. An adequate delineation and aggregation approach is essential, because the heterogeneity of natural resources, management practices, and individual decision-making would imply literally millions of model applications.

The biophysical process model EPIC has specific data requirements with respect to weather, soil, topography, and management practices. To fulfil the minimum of requirements, data from various sources, mostly provided by JRC, EUROSTAT, IIASA, and other institutions, are processed in GIS and relational Data Base environment. The concept of "Homogeneous Response Units" integrates input data processing, the EPIC simulation framework, and EPIC output data processing for economic land use modelling and/or dynamic comparative analyses. It also solves how data of different character, scales and aggregation levels can be consistently merged and linked to the EPIC-GIS workspace. Only those parameters of landscape, which are relatively stable over time (even under climate change) and hardly adjustable by farmers, were selected to create the raster of HRUs for EU25 (i.e. elevation, slope, soil texture, soil depth, and stoniness).

This biophysical process modeling framework has been applied to analyze the production and environmental impacts of alternative tillage systems (i.e. reduced and minimum tillage systems). In particular, potentials of sequestering organic carbon in soils through reduced or minimum tillage systems have been analysed as well as their impacts on crop yields and nitrous oxide emissions. The effects of alternative tillage systems have been put in relation to the effects of conventional tillage systems, which serves as reference or base-run scenario. The different tillage systems are simulated with EPIC for ten years of which average effects have been calculated. All other management operations (e.g. fertilization and irrigation rates) are kept the same for all tillage systems.

All analyses focus on arable lands in the EU25, which amount to about 100 million hectares in total. There are 9555 individual simulation units (ISU) that represent the biophysical responses of arable lands in EU25.

The impacts on N_2O-N emissions are externally calculated, because EPIC does not have a gas diffusion module included yet. The calculation of *direct* and *indirect* N_2O-N emissions follows mainly IPCC guidelines and uses also some of their default values. Nevertheless, there are major differences in this calculation procedure, which are:

- 'direct' N_2O-N emissions are calculated using fractions from nitrification and de-nitrification, processes that are simulated in EPIC. The fractions are based on the field experiments from Khalil, Mary, and Renault (2004) and are assumed to be 0.54% of nitrified nitrogen, and 11% of de-nitrified nitrogen.
- 'indirect' N_2O-N emissions are calculated using EPIC output variables of nitrogen in leaching and run-off waters, and in volatilization, and using IPCC default values. The default values used are 2.5% of N leached and in run-off, and 1% of N that is volatilized.

It is important to notice that our calculation procedure for 'direct' N_2O-N emissions includes background N_2O-N emissions, because it is based on nitrification and de-nitrification processes, while the IPCC method dose not accounting for it.

The impact analysis of alternative tillage systems shows that there are substantial potentials in sequestering soil organic carbon through more soil conserving tillage systems (i.e. reduced and minimum tillage systems). In particular, additional soil organic carbon could be sequestered when changing towards reduced tillage systems of 0.11 t/ha/yr, or when changing towards minimum tillage systems of 0.18 t/ha/yr.

The calculation procedure for N_2O-N emissions from food crop production on arable lands in EU25 results in 'direct' N_2O-N emissions of 5.3 kg/ha/yr, or 511.9 Gg/yr in total, and in 'indirect' N2O-N emissions of 0.9 kg/ha/yr, or 91.7 Gg/yr in total. Taking the assumptions on computing fertilization rates then 104 kg/ha of nitrogen are applied for crop production on arable lands on average. Consequently, almost 6% of fertilized nitrogen are 'direct' and 'indirect' N2O-N emissions, which also includes background N_2O-N emissions. In addition, a tillage change would also lead to reduced 'direct' and 'indirect' N_2O-N emissions on average, but, which are not uniformly distributed exhibiting +/- effects locally.

Crop yields are also reduced from such tillage change, which can range between 3% (reduced tillage) and 8% (minimum tillage) on average. Furthermore, there is strong evidence that a change of tillage systems will also lead to other environmental side-effects such as more pesticide, or fertilizer applications, which should be also accounted for in evaluating the environmental performance of alternative tillage systems.

Nevertheless, the validity of the tool needs to be further tested with respect to its data inputs and simulation results. In this respect, Balkovič et al. 2006 (and see chapter validation) have validated initial soil organic contents from the European Soil Map (Map of organic carbon in topsoil in Europe) by using the profile database from Soil Information System of Slovakia (AISOP), which includes soil attributes of 17,741 agricultural soil profiles Slovakia. This analysis shows that the European Soil Map data significantly overestimates carbon resources of arable land in Slovakia. These data generally accords with distribution rules respecting natural differences; however a significant number of highly overestimated pixels bias SOC values, which is problematic when using them as initials for bio-physical process modelling. This lack can be partially eliminated when SOC values are averaged and aggregated to a finite number of homogeneous response units (HRU). In such a case, a relatively good fit between measured values (AISOP) and European Soil Map data can be obtained, indicating that European data sources succeed in describing the general gradient. However, SOC stocks calculated through HRU processing are still overestimated.

We have developed a tool that is capable of analysing biophysical impacts of alternative management practices a at EU25 scale. Such a tool is highly valuable to carry-out comparative dynamic analyses in evaluating alternative natural resource management options with respect to their impacts on production and environment, but also provides a consistent link to economic land use optimisation models, which aim to find the optimal combination of alternative land use and management options.

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Appendix. List of physical and chemical soil parameters needed by EPIC

Essential soil information	Useful soil information
General soil and hydrologic information	
soil albedo (moist)	initial soil water content (fraction of field capacity)
hydrologic soil group (A, B, C, or D)	minimum depth to water table in m
	maximum depth to water table in m
	initial depth to water table in m
	initial ground water storage in mm
	maximum ground water storage in mm
	ground water residence time in days
	return flow fraction of water percolating through root zone
	soil weathering ($CaCO_3$ soils; non-$CaCO_3$ soils that are slightly, moderately or highly weathered)
	number of years of cultivation
	soil group (kaolinitic, mixed, or smetitic)
	fraction of org C in biomass pool
	fraction of humus in passive pool
	soil weathering code
Soil layer	
depth from surface to bottom of soil layer in m	bulk density of the soil layer (oven dry) in t/m3
bulk density of the soil layer (moist) in t/m3	wilting point (1500 kPa for many soils) in m/m
sand content in %	field capacity (33 kPA for many soils) in m/m
silt content in %	Initial organic N concentration in g/t
soil pH	sum of bases in cmol/kg
organic carbon in %	cation exchange capacity in cmol/kg
calcium carbonate content in %	coarse fragment content in %vol.
	initial soluble N concentration in g/t
	initial soluble P concentration in g/t
	initial organic P concentration in g/t
	exchangeable K concentration in g/t
	crop residue in t/ha
	saturated conductivity in mm/h
	fraction of storage interacting with NO_3 leaching
	phosphorous sorption ratio
	lateral hydraulic conductivity in mm/h
	electrical conductivity in mm/cm
	structural litter kg/ha
	metabolic litter kg/ha
	lignin content of structural litter in kg/ha
	carbon content of structural litter in kg/ha
	C content of metabolic litter in kg/ha
	C content of lignin of structural litter in kg/ha
	N content of lignin of structural litter in kg/ha
	C content of biomass in kg/ha

	C content of slow humus in kg/ha
	C content of passive humus kg/ha
	N content of structural litter in kg/ha
	N content of metabolic litter in kg/ha
	N content of biomass in kg/ha
	N content of slow humus in kg/ha
	N content of passive humus in kg/ha
	observed C content at the end of simulation

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Abstract
The results on 'Data and Database Strategy'of the Integrated Sink Enhancement Assessment (INSEA) project of the 6th Framework Programme are presented. The collection of papers include a wide range of studies carried out in the EU: observation of available data sources on soils; the organic carbon content in the top soil and its validation; field verification of the changes in the soil organic carbon; application of the field-scale model EPIC (Environmental Policy Integrated Climate) to predict the changes in soil organic carbon content due to land management.
The book addresses specialists and those who are focused on the research of the soil organic carbon.

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