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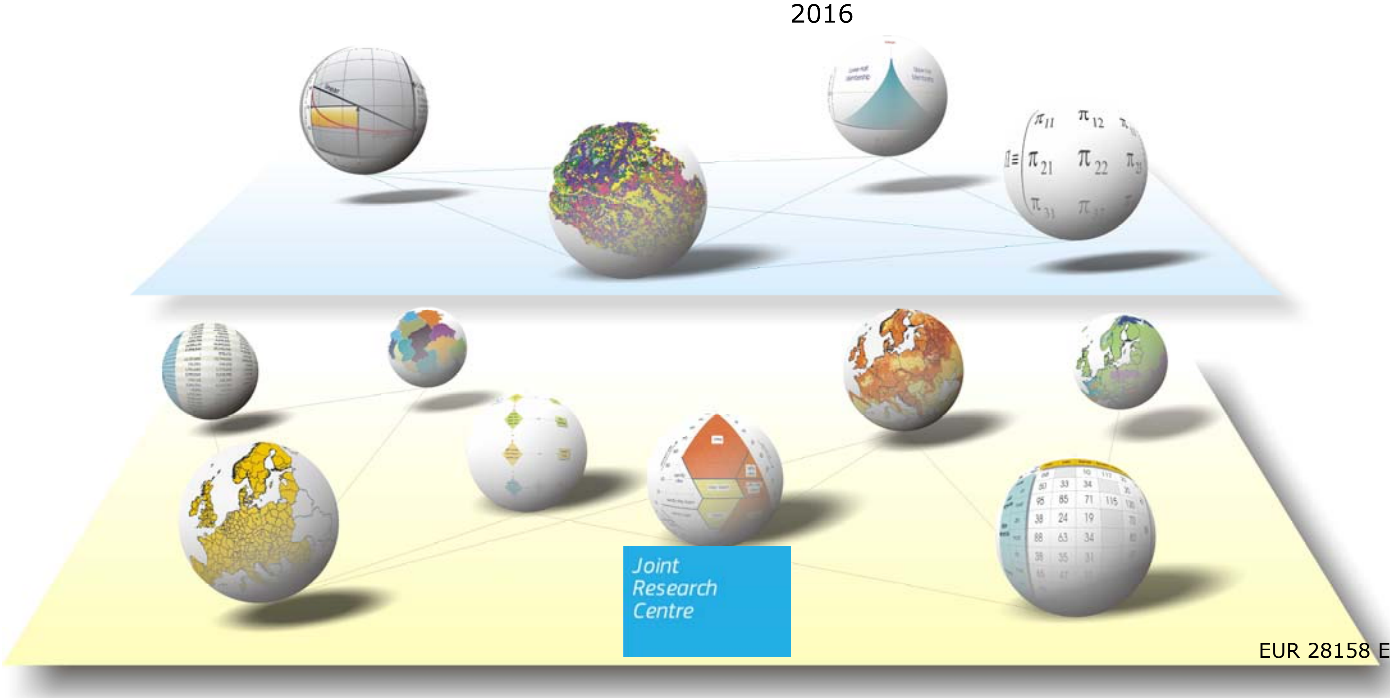
Processing a Soil Organic Carbon C-Stock Baseline under Cropland and Grazing Land Management

Data and Processing CO_2 emissions and removals for IPCC Tier 1 Method

Roland Hiederer

2016



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Abstract

For the years 2013-2020 Decision 529/2013 extended for the Member States of the European Union mandatory accounting for Greenhouse Gas (GHG) emissions and removals to the activities Cropland Management (CM) and Grazing Land Management (GM). For the purpose of accounting GHG emissions and removals from anthropogenic activities and changes in land use the International Panel on Climate Change has specified guidelines which should be applied. The guidelines distinguish three tiers of methods, of which Tier 1 is the most generic. The method uses general default values and national data. For the purpose of accounting land use conversions between categories should be spatially explicit (Approach 3). Spatially explicit data on land use changes should cover a whole country and include all categories, not just areas of CM and GM.

In this document the data needed and the processing implemented to compute a baseline for 2010 for estimating CO_2 emissions and removals from changes in the soil organic C-stocks according to the Tier 1 method for CM and GM are described. Under Tier 1 a baseline for soil organic C-stocks has to cover at least 20 years of changes in land use, management practice and input level. Data processing therefore covers the period 1990 to 2010 and comprises all Member Starts of the European Union.

The method for estimating annual changes in soil organic C-stocks combines statistical data from the Eurostat database with spatial layers from various outer sources. All conditions affecting soil organic C-stocks under Tier 1 are processed as spatial layers in a Geographic Information System. The condition layers are generated using a suitability overlays and a spatial allocation method. The layers are then combined according to the Tier 1 classification schema to provide changes in soil organic C-stocks and thus changes in CO_2 emissions and removals from CM and GM.

The main challenge in estimating changes in soil organic C-stocks was the availability of data suitable to be included, in particular on management practice and input level. The statistical data were prepared by completing instances of missing data in a time-series, identifying outliers and providing consistency with other data. Where thematic data were missing proxies were used and processed in the spatial domain. The outcome of the statistical and spatial processing activity is a set of spatial data on land use, management practices and input levels for each year of the period 1990 to 2010 to estimate a soil organic C-stock baseline for 2010 for CM and GM.

1 Introduction

In Decision 529/2013/EU the European Commission proposes a legislative package for the inclusion of the *Land use, land use change and forestry* (LULUCF) sector in the EU emissions reduction target. For achieving the reduction target a two-stage approach is foreseen:

a) establish robust common accounting, monitoring and reporting rules on how MS shall account for the various land use activities for the 2nd Commitment Period (2013-2020) of the *Kyoto Protocol* (KP);

b) formal inclusion of the sector in the EU climate commitment when a harmonized and robust accounting is implemented.

For the KP reporting and *accounting* relates to land management *activities*:

- Afforestation/reforestation (AR)
- Deforestation (D)
- Forest Management (FM)
- **Cropland Management (CM)**
- **Grazing land Management (GM)**
- Revegetation (RV)
- Wetland Drainage and Rewetting (WDR).

For the 1st Commitment Period of the KP (2008-2012), accounting was mandatory for AR and D since 1990 and voluntary for other activities. For the 2nd Commitment Period (2013-2020) Decision 529/2013 established mandatory accounting also for CM and GM for the European Union.

Estimates of GHG emissions and removals must follow the guidelines specified by the *International Panel on Climate Change* (IPCC). Guidance for preparing annual greenhouse gas inventories in the *Agriculture, Forestry and Other Land Use* (AFOLU) Sector are given in Chapter 4 of the guidance document.

For estimating *greenhouse gas* (GHG) emissions resulting from anthropogenic activities leading to changes in land use and cover IPCC distinguishes three levels or Tiers with increasing complexity. The most generic method is defined by Tier 1. The method uses general default values and national data. Tier 2 follows the same basic approach as Tier 1, but uses country-specific data in the computations. Tier 3 uses a different approach based on modeling annual variability in carbon fluxes.

In this document the data needs to compute estimates of CO_2 emissions and removals from the soil according to the Tier 1 method for **Cropland Management** (**CM**) and **Grazing Land Management** (**GM**) are described.

2 Concept of C-Stock Accounting

Accounting relates to the rules for comparing emissions and removals as reported with commitments. Accounting for CO_2 emissions and removals for CM and GM covers three aspects:

- Accounting Rule
- Tier for key and non-key categories
- Reporting Method

In the subsequent sections these aspects are detailed only as far as data needs and processing methods are concerned.

2.1 Temporal Cover: Accounting Rule

The method specified for accounting for CM and GM is "Net-Net Accounting". Under Net-Net Accounting the difference of the carbon sink or source in the reporting year and the carbon sink or source in the base year is computed. This implies that data on land use, management and input under CM and GM are available from the base year to the reporting year. With an adjustment period of 20 years to reach a state of equilibrium of SOC levels (mineral soils) after a change in any one of the parameters data should be available for at least this period preceding the reporting year.

2.2 Thematic Detail: IPCC Tier

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories [1] specify three levels of thematic detail for estimating CO_2 emissions or removals from change in soil organic carbon (SOC) stocks. The highest Tier (3) is stipulated when a category represents a "key category"[1]. Tier 3 concerns the use of inventory data or models to estimate CO_2 emissions and removals and is not covered in this document.

When a category is not a "key category" a Tier 1 or 2 method can be used. Under Tier 1 changes in C-stocks are estimated based on default reference values as published in the Guidelines. Tier 2 represents largely an extension of Tier 1 by substituting the default reference values with country-specific data. For data on the areas affected by changes in land use and management practices the Guidelines point to sources of generally available data at national level, such as FAO databases.

Independent of the method the Guidelines distinguish between emissions and removals from mineral and from organic soils:

- for mineral soils CO_2 emissions or removals are derived from changes in C-stocks relative to a reference C-stock;
- for organic soils annual C-emission factors are specified.

While the default factors for changes in C-stocks of mineral soils change comparatively little between publications the C-emission factors for organic soil show great variations depending on the document used.

1 Key Category: a category that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both.

2.3 Spatial Unit of Change: Approach

As part of a consistent representation of lands the IPCC Guidelines distinguish three types for area units where a change in one or more of the factors affecting soil C-stocks is reported. The types are characterised by the detail of the spatial units to which the changes can be attributed:

- **Approach 1**

  Total areas are provided at only two points in time for climate, soil and land use management system. Specific transitions in land use and management cannot be attributed to areas (only aggregate or net change). An example are national statistics on areas.

- **Approach 2**

  Total areas together with specific transitions between each land management system are provided. Specific transitions may have been derived from aggregating data with a spatial dimension to larger units, such as administrative regions. While the source data for the transitions referred at one stage to a spatial unit of change, the transitions are not spatially explicit. Such data can be obtained from farm surveys.

- **Approach 3**

  Land use conversions between categories are spatially explicit.

For accounting purposes Approach 3 should be used. Potential methods for developing datasets for Approach 3 are given in Annex 3A.4 of the 2006 Guidelines. Spatially explicit data on land use changes may cover a whole country (wall-to-wall) and include all categories. One source of spatially explicit transitions are maps of land cover derived from remote sensing data with at least two points in time, such as CORINE Land Cover (CLC). The overview of methods for developing Approach 3 data sets includes the option of using point data, for example from inventories, to establish transitions between land use categories. This would require repeatedly surveying the same points. As regards the presentation of the spatial units raster (grid) and polygon formats are specifically mentioned.

The concept of "approach" is closely related to the Reporting Method. Reporting Method 1 is used when a geographic unit contains multiple activities while for Reporting Method 2 each activity defines a single geographic unit.

The assignment of activities defining the Reporting Methods is graphically presented in Figure 1.

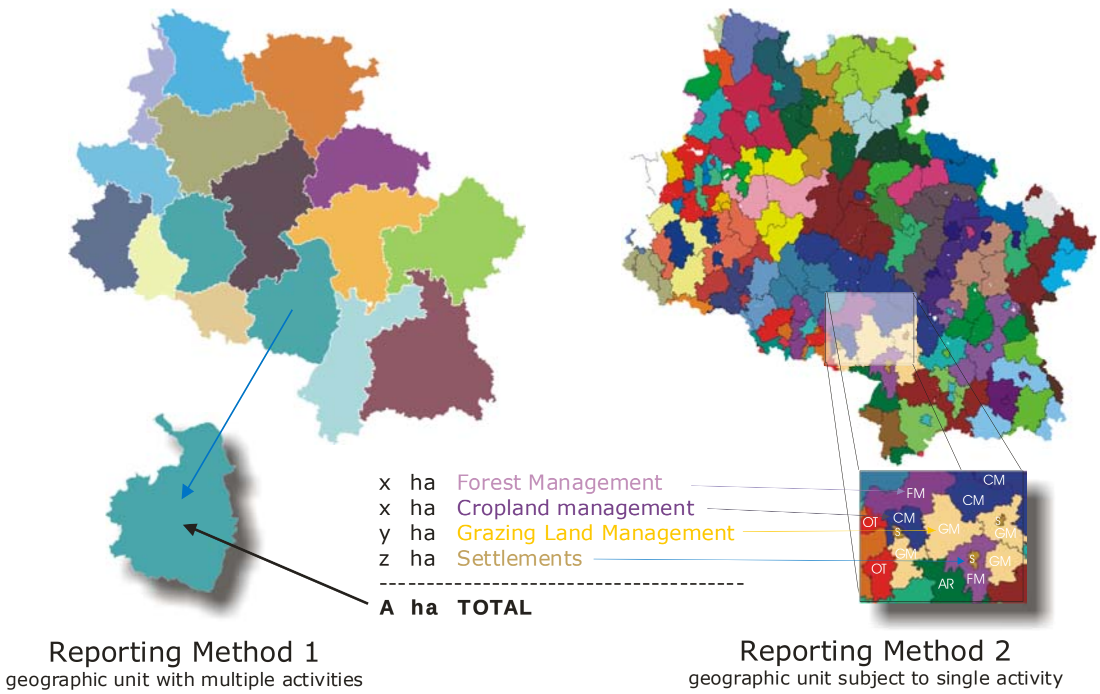


Figure 1: Reporting Methods for assigning activities to geographic units

Reporting Method 1 is loosely connected to Approach 2 while Reporting Method 2 is conceptually close to Approach 3. A noteworthy difference is that the "Reporting Method" concerns the extent of activities, whereas "Approach" covers the spatial extent of the change of an activity.

In [1] an advantage noted for Approach 3 is the possible use of a *Geographic Information System* (GIS) in which other spatial data can be linked to the layers of land use and land use conversion. The use of a GIS supports a better alignment with *"… strata mapped for classification of carbon stocks and emission factors by soil type, vegetation type*", which may improve emission estimates.

The description of Approach 3 in the *2006 National Greenhouse Gas Inventories* [1] leaves some aspects of an Approach 3 open. For once, the stratification of areas should be performed by climate region and soil type and the factors changing soil organic C-stocks are assigned to climate regions, not soil type. More critical is the specification of the land use category and conversion as the basis for the delineation of a spatial units. Changes in soil organic C-stocks also occur within a land use category and without conversion to another category. To make full use of a spatially explicit approach the extent of the analysis unit should concur with the area of the conditions that define the emission factors. For example, a change in tillage practice on long-term arable land does not lead to a change in land use category, but affects soil organic C-stocks and is likely to occur only on part of the area of the category.

When using a GIS to processing spatial data for estimates of GHG emissions and removals from changes in soil organic C-stocks for CM and GM the spatial detail of the data and the analysis of change should be the area of any of the parameters defining soil organic C-stocks. The detail of the spatial unit may be taken to extremes since soil types could differ even within a field. It may be considered reasonable to limit the spatial detail to the size of a field or a grid unit that provides a representative picture of the situation within a land use category of the reporting unit.

Estimates of GHG emissions and removals from CM and GM are based on a uniform grid where land use, management and inputs are tracked at all positions and over time. The approach to processing spatially explicit data is shown Figure 2.

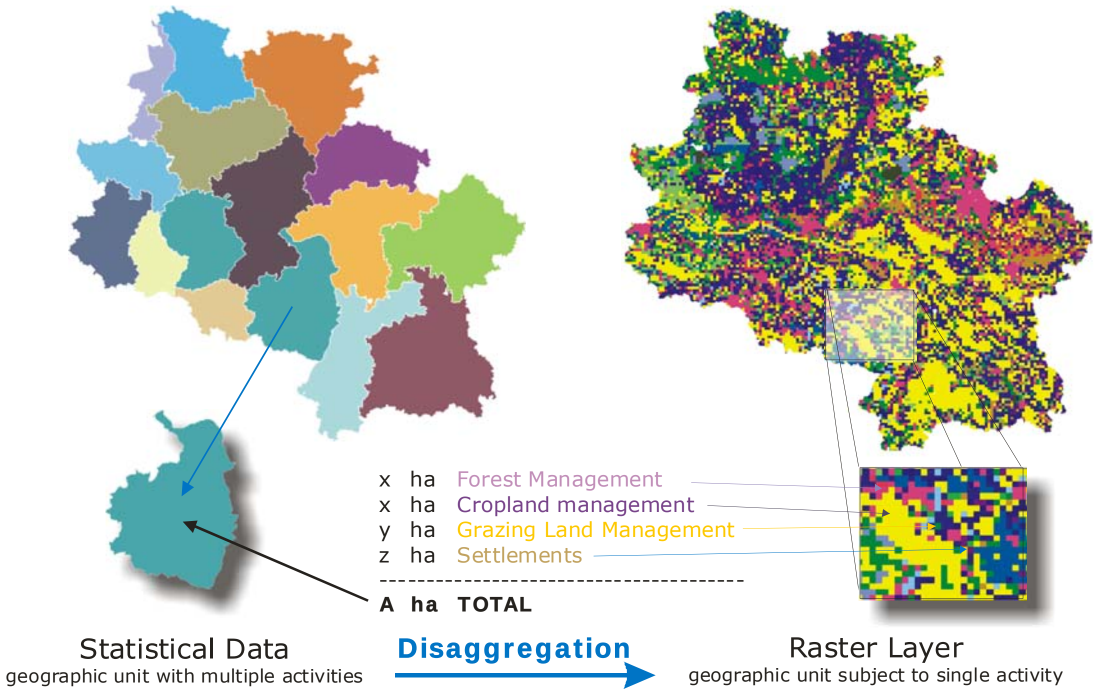


Figure 2: Spatial grid layer for tracking land use, management and input parameters

By using gridded data for climate regions, soil type and all other parameters the stratification of the areas by these parameters is intrinsic to the data.

2.4 Soil Organic C-Stock Change and CO_2 Emission

With respect to estimating CO_2 emissions and removals from changes in soil C-stocks there is no difference in the equations specified for CM and GM activities. The basic equations are presented in Figure 3.

$$\Delta C_{SOIL} = \Delta C_{mineral} + L_{organic} + \Delta C_{inorganic}$$

Mineral Soils: annual change in SOC stock

$$\Delta C_{mineral} = \frac{SOC_0 - SOC_{0-T}}{D}$$

$$SOC_t = \Sigma(SOC_{REF} \cdot F_{LUS} \cdot A)_{c,s}$$

$$F_{LUS} = F_{LU} \cdot F_{MG} \cdot F_I$$

Organic Soils: annual loss of carbon

$$L_{organic} = \sum_{C}(A \cdot EF)_c$$

mineral	CM, GM mineral soil
organic	CM, GM organic soil
SOC_{REF}	default reference soil organic C-stock
F_{LU}	modifying land use factor
F_{MG}	modifying management factor
F_I	modifying input factor
A	land area of stratum defined by c, s and i history
c,s	climate region (c), soil type (s)
SOC_0	soil organic C-stock, last year of an inventory period
SOC_{0-T}	soil organic C-stock at of an inventory period
T	number of year over inventory period

Figure 3: Basic Equations for Estimating CO_2 Emissions from Cropland and Grazing Land Management

A clear distinction is made between mineral and organic soils. For mineral soils changes in SOC stocks are computed whereas for organic soils annual emissions are used. For the emission total the emissions and removals of CO_2 from mineral soils are combined with the losses from managed organic soils for a number of years in relation to a default time period for transition of SOC stocks to equilibrium. Changes in SOC stocks are translated into removals or emissions of atmospheric CO_2 by applying a factor of the molecular weight of 44/12 (≈3.67).

The method of Tier 1 relies on the use of default reference values and equations published in the IPCC Guidance documents. The principle of the computations is to establish the characteristics of common default conditions and to modify these default conditions using changes in the areas of management factors for the conditions. The defining characteristics under two main aspects of the computations are:

- **Default Conditions**
  - Soil type
  - Climate Region
  - Default Reference Soil Organic C-stocks (SOC_{REF})
- **Factors Modifying Areas**
  - Land use category (F_{LU})
  - Management (F_{MG})
    practice applied, which influences level of C-stocks;
  - Input (F_I)
    level of input to production, such as mineral and organic fertilizer application and organic amendments.

The parameters characterizing the default conditions are invariable and are identical for both, CM and GM activities. Hence, there are no adaptations of the climate regions to changing climatic conditions. For modifying factors the number of conditions characterizing a level of management or input are left open.

2.4.1 Computing Emissions from Organic Soils

Emissions from managed organic soils are based on applying an emission factor to the area of drained organic soils for each climatic region as:

$$L_{Organic} = \sum_{c} (A \cdot EF)_c \quad [Mg\ C\ yr^{-1}]$$

where

$L_{Organic}$	annual loss of carbon from drained organic soil [$Mg\ C\ yr^{-1}$]
EF	emission factor for climate region c [$Mg\ C\ ha^{-1}\ yr^{-1}$]
c	climate region
A	area of organic soils [ha]

Managed organic soils use an *emission factor* (EF) which is not varied by other management measures.

Decision schemes and parameters used in the equation are defined as:

- **IPCC Climate Regions**
  Defined in classification scheme of Figure 3A.5.2 (p. 3.39; see also section of "*Climate Regions*" under mineral soils).

- **Emission Factors**
  Parameter values are given in look-up tables for cultivated organic soils in Table 5.6 (p. 5.19) and for drained grassland on organic soils in Table 6.3 (p. 6.17).

- **Organic Soil**
  The area of cultivated organic soils or drained grassland on organic soils has to be determine using ancillary data.

Cultivated organic soils are assumed to be always drained. In order to grow crops on organic soils, which are part of wetlands, generally requires lowering the water table through drainage. Grassland or grazing land is often drained when on organic soils.

2.4.2 Computing Organic Carbon Stock Changes in Mineral Soils

Emissions and removals of CO_2 from activities on mineral soils are directly related to the changes in SOC stocks over a number of years as:

$$\Delta C_{Mineral} = \frac{SOC_0 - SOC_{0-T}}{D} \quad [Mg\ C]$$

where

SOC_0	soil organic C-stock, last year of an inventory period [$Mg\ C$]
SOC_{0-T}	soil organic C-stock, beginning of an inventory period [$Mg\ C$]

T	number of year over inventory period [*years*]
D	default time period for transition to equilibrium [*20 years*]

These SOC stocks are determined for a base year and for the conditions after *n* years. For mineral soils changes in SOC stocks, and as a consequences in CO_2 emissions, are then calculated as the difference in SOC stocks between the two points in time.

The basic value in the computation for estimating SOC stock changes in mineral soils is the *default reference value for the soil organic carbon stock* (SOC_{REF}), which is the typical value of SOC density for a soil type under native vegetation. This default value of SOC density is modified by factors defining a *Land Use System* (LUS). When applied to an area of interest SOC density translates into SOC stock of the area of interest as:

$$SOC_{LUS} = \sum \left(SOC_{REF} * F_{LUS} * A_{LUS} \right) \quad [Mg\ C]$$

where

SOC_{LUS}	equilibrium SOC stock for a Land Use System [*Mg C*]
SOC_{REF}	default reference SOC stock, native vegetation [$Mg\ C\ ha^{-1}$]
F_{LUS}	combined Land Use System factor [*dimensionless*]
A_{LUS}	area covered by Land Use System [*ha*]

The land use system factors considered under Tier 1 to modify SOC stocks are:

- land use type factor(F_{LU});
- management practice factor (F_{MG});
- level of input factor (F_I).

Changes in any of the defining factors lead to subsequent changes in SOC stocks.

Under Tier 1 and 2 it is assumed that the fluxes to and from organic C-stocks are in equilibrium if no disturbances to the fluxes occur over more than 20 years. After a disturbance the conversion to the new equilibrium organic C-stock is linear, i.e. has a constant annual increment. This is graphically presented in Figure 4.

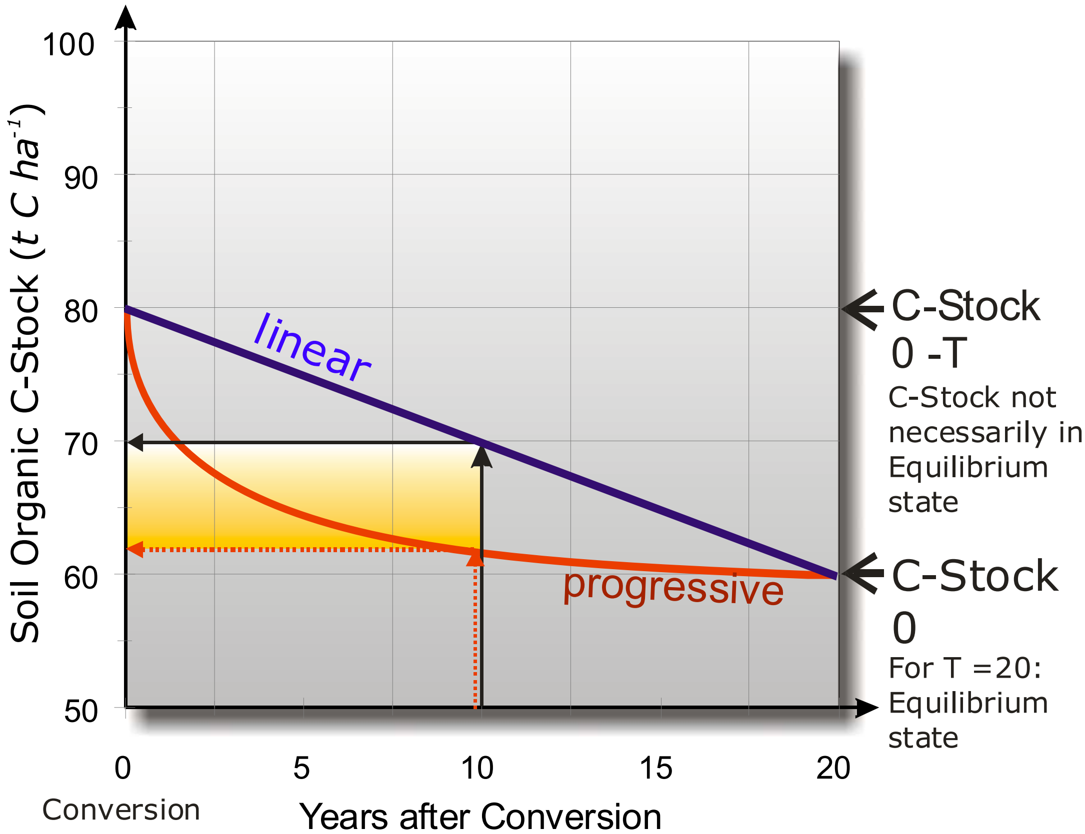


Figure 4: Changes in soil organic C-stocks after disturbance to equilibrium for mineral soils (IPCC Tier 1 and 2)

There is no difference between the direction of the change in soil organic C-stock, differentiation of the factors disturbing the equilibrium or consideration for residual effects of a previous disturbance. The conversion simply starts with the soil organic C-stock as estimated at the time of the disturbance.

The difference in SOC stocks *n* years after a change is thus calculated as:

$$\Delta SOC_a = (SOC_{LUS1} - SOC_{LUS2}) * \frac{n}{20} \quad [Mg\ C]$$

where

SOC_a	annual change in SOC stock [*Mg C*]
SOC_{LUS1}	equilibrium SOC stock for LUS1 [*Mg C*]
SOC_{LUS2}	equilibrium SOC stock for LUS2 [*Mg C*]
n	years since change from LUS1 to LUS2 [*<20 years*]

This annual change in SOC stock is added to the estimated SOC stock at time *t* for 20 years after a change occurred. In case any of the elements of the LUS changes before the equilibrium SOC stock is reached the corresponding annual rate of change in SOC stocks is applied to the level of SOC stocks reached at the time of change.

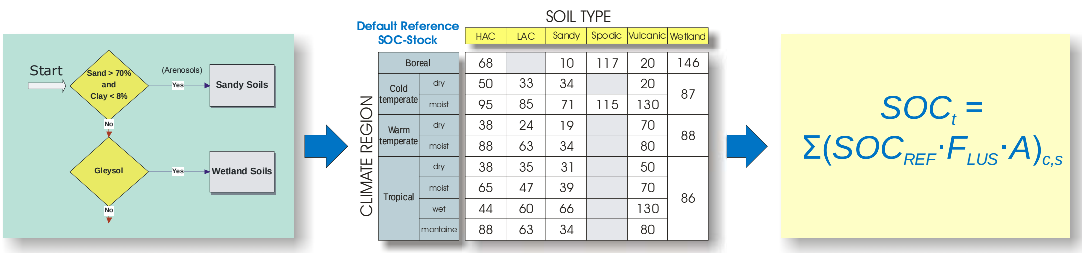
3 Data for Parameters and Factors

Data used to compile the National Greenhouse Gas Inventories should be adequate, consistent, complete and transparent ([1]; p3.5). These general provisions for data would also apply to the data used for estimating CO_2 sources and sinks from changes in soil organic C-stocks for CM and GM.

The Guidelines lay down a common sequence of steps to compute estimates of CO_2 emissions and removals for CM and GM:

1. structure more complex data through classification schemes;
2. quantify classes by assigning set default values in look-up tables;
3. combine default values with affected areas in equations.

A graphical presentation of the sequence is given in Figure 5.



1. Classification Scheme: structure data into classes — 2. Look-up Table: quantify classes as factors — 3. Equation: combine factors with areas

Figure 5: General Steps to Identify Input Data Sets for IPCC Tier 1 Method

A classification scheme is used to define categorical data, such as the type of management activity or soil types. Look-up tables specify quantitative default values for the categorical data. The tables usually combine several parameters to form a matrix to define the default value, such as the "default reference C-stock". Equations combine the parameter values with the size of the areas affected to quantify the emissions or removals for the reporting unit.

For soil C-stocks a default reference state is defined by a look-up table of climate region and soil type. Climate and soil are thus considered invariable and need to be computed only once. Changes in land use, management and input are then applied as factors that modify the default reference state.

3.1 Conditions Defining Default State

The common and constant conditions used in estimating changes in soil C-stocks or emissions from organic soils are:

- **Climate Region**
- **Soil Type**

The parameters are combined in a look-up table to define the default reference soil organic C-stock, which is the foundation of all estimates of CO_2 emissions and removals from CM and GM from the soil.

3.1.1 Climate Regions

The classification scheme for the IPCC default Climate Regions is defined in Figure 3A.5.2 (p. 3.39). A slightly modified version of the classification scheme is presented in Figure 6.

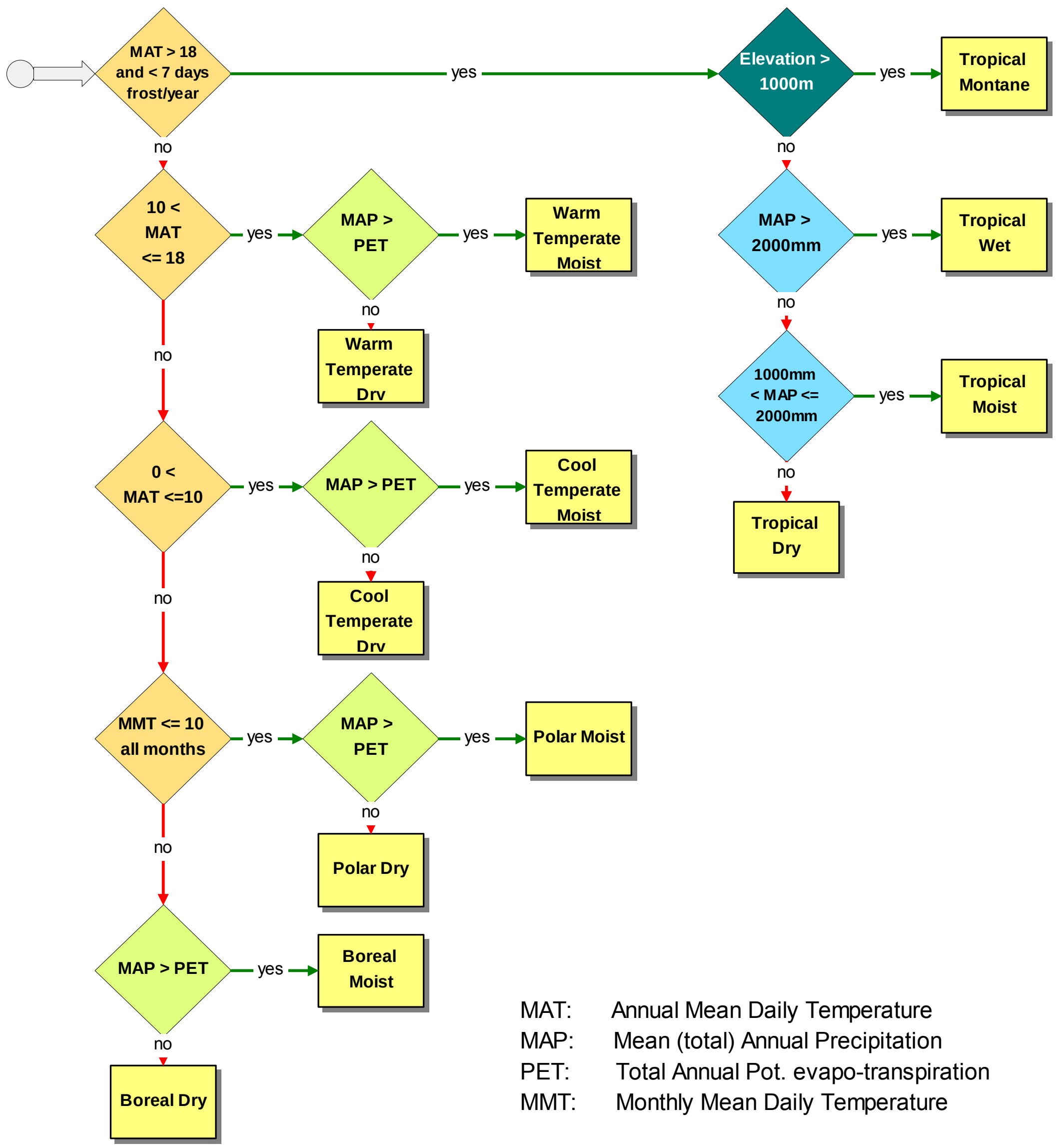


Figure 6: Amended Classification Scheme for Default Climate Region (after: Figure 3A.5.2; IPCC 2006 Guidelines)

A summary of the data needs for the classification scheme for the default climate regions are given in Figure 7.

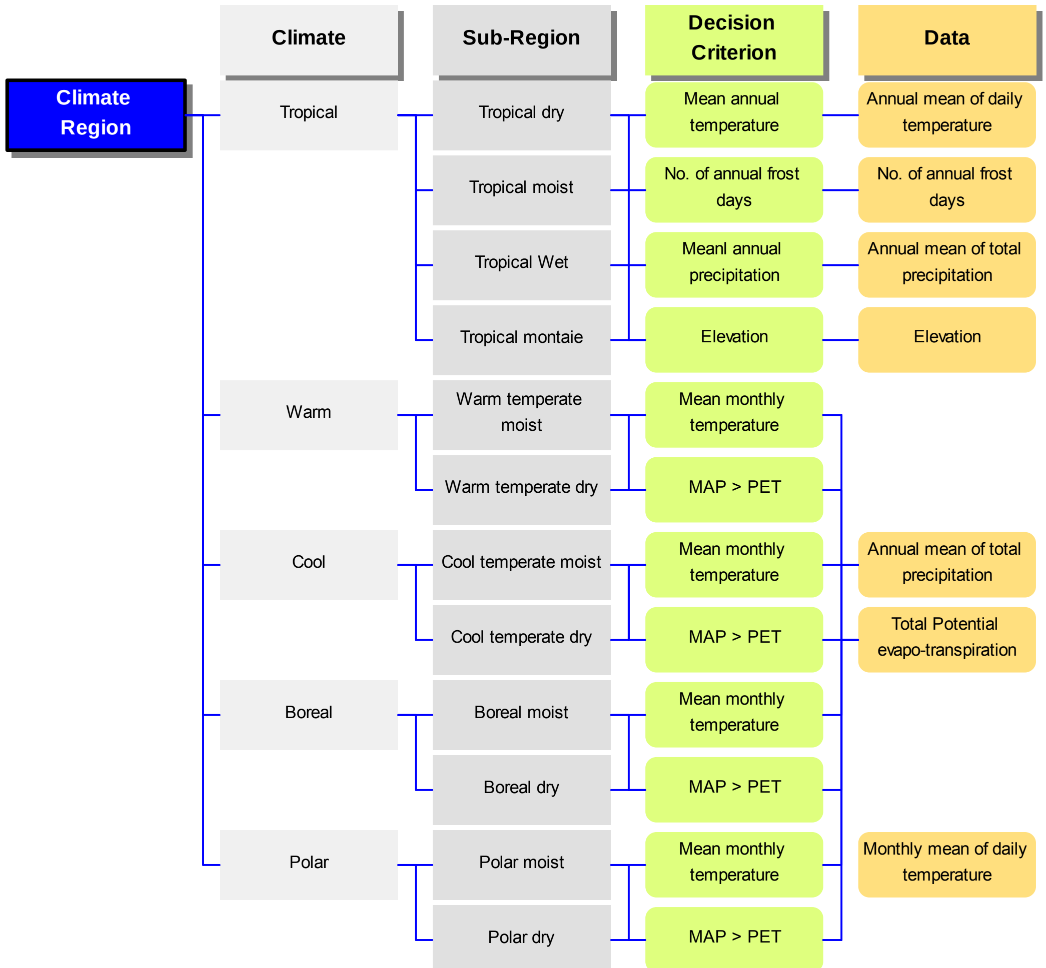


Figure 7: Data needs for the classification scheme for Climate Regions

The criterion of 7 days of frost per year is used to separate tropical regions from all other climate regions. Elevation is only used to define the "*Tropical Montane*" climate region (> 1 000 m). In the graph the IPCC criterion of *MAP:PET*>1 has been replaced by *MAP>PET*, which is congruent, but saves one step in the computations. To apply the classification scheme climate data has to be complemented by data on elevation. Where a "*Tropical Montane*" climate region does not exist the scheme can be applied without elevation data.

3.1.2 Soil Type

Throughout the procedures and methods described by the IPCC a very clear distinction is made between organic and mineral soils. The definition separating mineral form organic soils is consequential for CO_2 estimating emissions and removals from the soil:

- **Mineral soils**
  emissions of CO_2 are computed from changes in SOC stocks caused by changes of a land management activity by an annual increment;

- **Organic soils**
  emissions of CO_2 from drained organic soils are annual losses expressed by annual emission factor.

The differences between organic and mineral soil types go beyond separating another soil type. For **mineral soils** it is assumed that a new equilibrium of soil C-stocks is reached after 20 years after a change in land use, management or input. Without changes to any of the parameters specified to alter soil C-stocks during this period the SOC pool of mineral soils becomes neutral for CO_2 emissions and removals. For **drained organic soils** CO_2 emissions continue until the management practice of draining stops and re-wetting takes place.

With the distinct separation between in the treatment of CO_2 emissions from managed organic soils and emissions and removals from activities on mineral soils separating the two soils is quite fundamental. In the process of categorising soils the organic soils are separated from mineral soils before these are further sub-divided.

• Identifying Organic Soils

Organic soils under IPCC are defined in Annex 3A.5, Chapter 3, Volume 4 of the 2006 IPCC Guidelines as:

1. *Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm;*
2. *Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter); and*
3. *Soils are subject to water saturation episodes and have either:*
   a) *at least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or*
   b) *at least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or*
   c) *an intermediate proportional amount of organic carbon for intermediate amounts of clay.*

According to the specifications soils are classified as organic when they comply with either conditions 1 and 2 or conditions 1 and 3.

The conditions are graphically presented Figure 8.

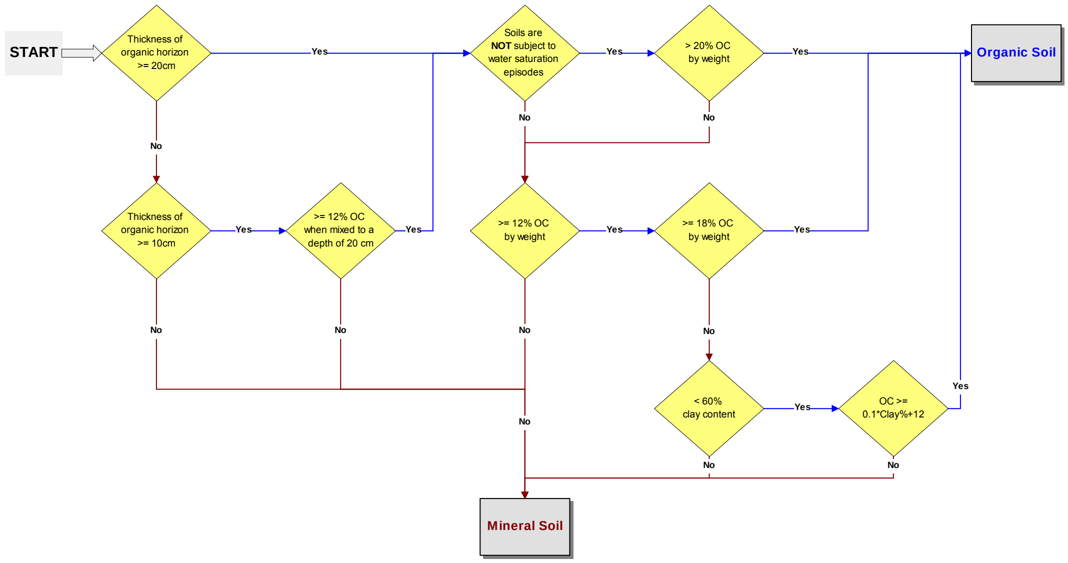


Figure 8: Classification Scheme of separating Organic from and Mineral Soils

This definition of organic soils with a minimum depth of the organic horizon of 10 cm is not completely in line with the definition given under the *World Reference Base for Soil Resources* (WRB). Under the WRB organic soils are classified as *Histosols*. *Histosols* are defined by

a) the presence of **organic soil material** and

b) the **thickness** of the organic material to a depth of 80 cm.

The WRB definitions of *Histosols* and soil organic material are:

o **WRB: Hisotsols (HS)**

Soils having 40 cm or more organic soil material (60 cm or more if the organic materials consist mainly of sphagnum or moss or have a bulk density of less than 0.1 Mg/m3) either extending down from the surface or taken cumulatively within the upper 80 cm of the soil.

The thickness of the organic surface horizon may be less if it rests on rock or on fragmental material in which the interstices are filled with organic matter.

o **WRB: Soil Organic Material**

Organic material must have one of the following:

1. if <u>saturated</u> with water for long periods (unless artificially drained), and excluding live roots,

EITHER

a) 18 % organic carbon (30 % organic matter) or more if the mineral fraction comprises 60 % or more clay; or

b) 12 % organic carbon (20 % organic matter) or more if the mineral fraction has no clay; or *c) a proportional lower limit of organic carbon content between 12 and 18 percent if the clay content of the mineral fraction is between 0 and 60 percent;*

OR

2. if never saturated with water for more than a few days, 20 percent or more organic carbon.

The IPCC definition of organic soils is basically the WRB definition of soil organic material (not to be confused with organic soil type) and excluding the WRB depth criterion. This variation may lead to different results in the classifications between IPCC and WRB organic soils. Some soils, such as organic gleysols, may have a surface layer with organic material, often peat, which would satisfy the condition for thickness of the IPCC definition, but not the definition of an organic soil under WRB (or *United States Department of Agriculture* (USDA)). The deviation in the definition of organic soils from the WRB was made to allow for country-specific definitions of organic soil.

The IPCC definition does not explicitly state where in the soil horizon the organic horizon should be found. To fully apply the IPCC definition detailed information on the soil profile is needed. Such information is not generally available from spatial soil databases which rely on soil taxonomy systems to describe soil properties.

- **Identifying Mineral Soils**

Mineral soils as defined by the IPCC Guidance documents as all soils not previously identified as organic soils. The classification scheme for soil types classified according to the USDA taxonomy is specified in a decision tree in Figure 3A.5.3 (p. 3.40). For soil types classified according to the WRB the decision tree of Figure 3A.5.4 (p. 3.41) is to be used.

The classification scheme for identifying mineral soil types using the WRB taxonomy is given in Figure 9.

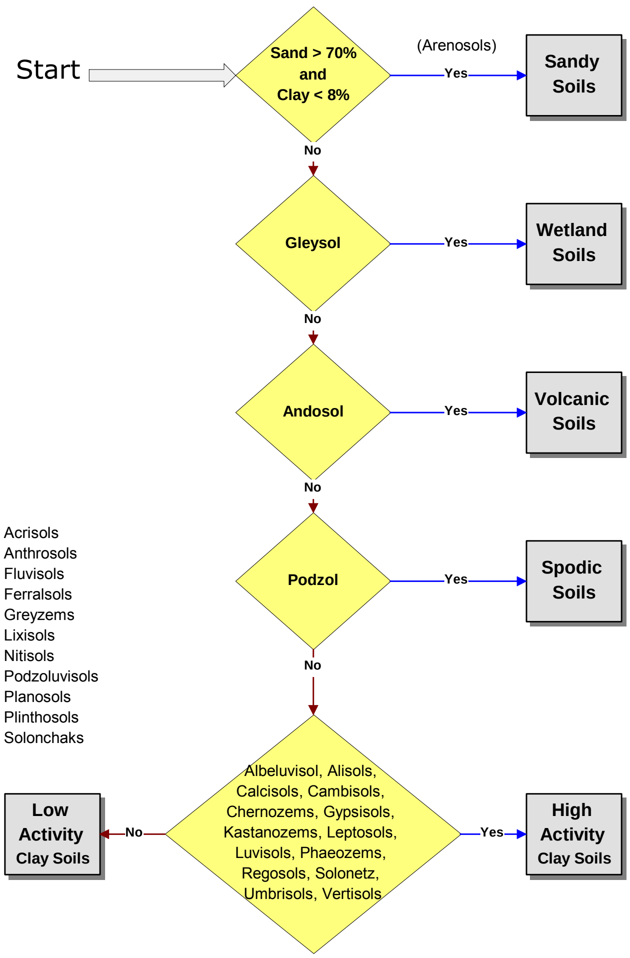


Figure 9: Decision Scheme for IPCC Soil Types from WRB Taxonomy (after: Figure 3A.5.4, 2006 IPCC Guidelines)

For the WRB taxonomy the IPCC soil types are mainly a rearrangement of the reference soil groups. Regardless of the soil taxonomy used the separation between of "*Sandy Soils*" from other mineral soil types is done on the basis of soil texture distribution (> 70% sand, < 8% clay), not the soil taxonomy name. Since the conditions use parameters defined on a ratio measurement scale soil databases using just the WRB reference soil groups is not suitable to discern the IPCC *Sandy Soil* type. The WRB reference soil group *Arenosol* of the HWSD is almost exclusively assigned to Sandy Soils, but the soil type also includes some occurrences of other soil groups. To be applied, the soil database used should also cover soil texture as ratio values rather than only soil texture classes.

A summary of the data needed to separate organic from mineral soils and the mineral soil types is presented in Figure 10.

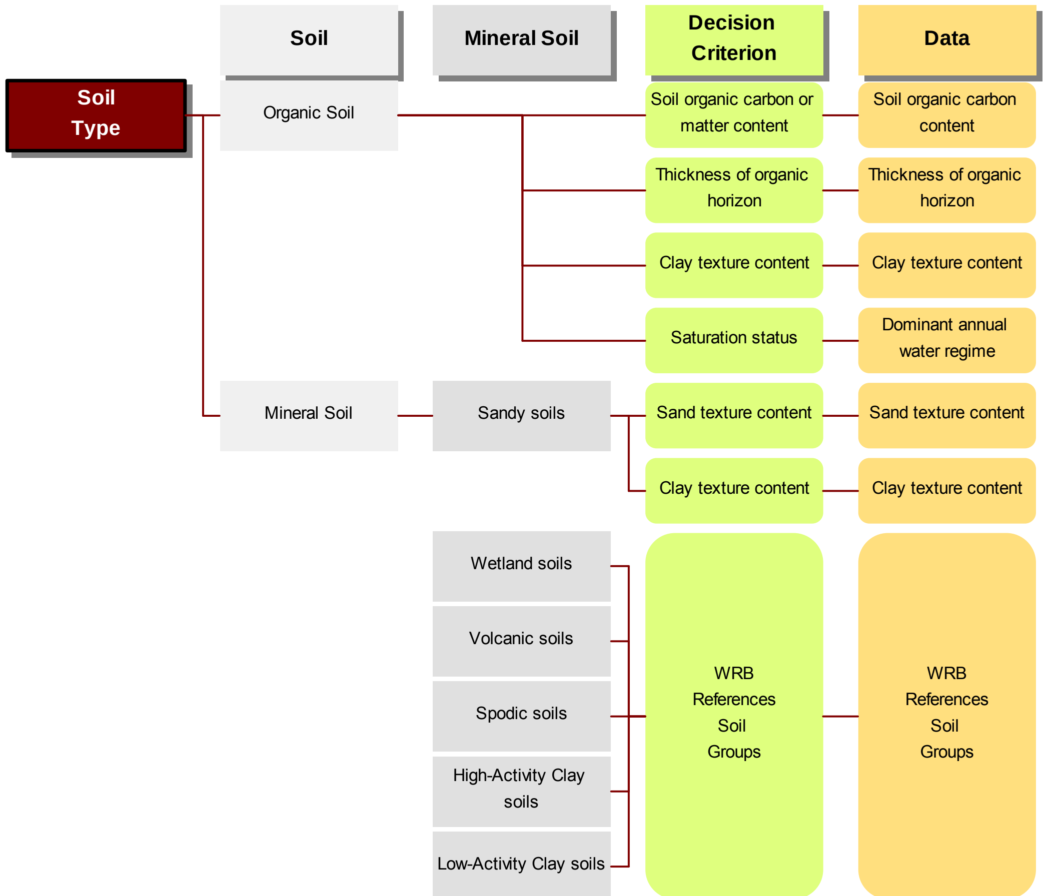


Figure 10: Data needs for Organic Soil and for Mineral Soil Types

To fulfil the criteria of the classification schema for soil types the soil database used should also cover soil texture as ratio values rather than only soil texture classes.

3.2 Separating Land Use Categories

In Volume 4 of the 2006 IPCC Guidelines six land use categories are distinguished. They have a rough correspondence to the activities for accounting under the Kyoto Protocol. An overview of the correspondence is given in Table 1.

Table 1: LULUCF Reporting and Accounting for Cropland and Grassland

UNFCCC Reporting LULUCF		**EU Kyoto Protocol Accounting LULUCF**
Forest Land	AF	Afforestation / Reforestation
	DF	Deforestation
Cropland	CM	Cropland Management
Grassland	GM	Grazing Land Management
Wetland	WM	Wetland Management
Settlement		
Other	RV	Re-vegetation

Under UNFCCC LULUCF reporting a land use category is assigned to all land within a country. Assigning land areas to one of the activities for KP accounting under Article 3.3 and 3.4 is less straight forward, not least because Parties have some flexibility in the definition of which land use category is to be included, for example for woody crops (see Figure 2.1.2, [2]). Since in the EU CM and GM are elected there should be more consistency in the areas assigned to either activity under conditions of transition between categories than for cases where only one activity is selected. 2

When assigning a land use category or an activity to land one should follow the order of categories listed, i.e. identifying forest areas first. Whether the forest areas are managed or unmanaged is not of relevance here. The second land use category is cropland, for which a classification scheme exists. Grassland, managed (GM) and unmanaged, is identified next on areas which are neither forest nor cropland. Areas are only assigned to wetlands in case they were not already assigned to land use categories previously identified. The remaining areas are assigned to settlements and other areas. Although reporting for GHG emissions and removals concerns only managed areas it is considered *good practice* to include also the areas of unmanaged lands on the KP reporting together will all other lands not subject to any activity under the UNFCCC [1].

When land use categories are derived from spatial data, such as classified remote sensing data, any differences between land use categories and land cover classes should be considered (Chapter 2.2.1.1, [3]). As regards activities, defined and used, the number of options is rather large and the choice made affects the management and input factors, which modify soil C-stocks.

3.3 Modifying Factors

The land management systems for CM and GM are defined by the land use, the type of management and the level of input applied. The *Land Use System* (LUS) factor for an activity is the product of the defining relative stock change factors:

$$F_{LUS} = F_{LU} * F_{MG} * F_I$$

2 LULUCF reports CO_2 emissions and removals, while under the sector Agriculture reports also CH_4 and N_2O from soils, livestock and manure. For burnt areas CO and NOx are considered, but not CO_2.

where

F_{LUS}	land use system factor
F_{LU}	land use factor
F_{MG}	management factor
F_I	input factor

While the factor types are the same for CM and GM the factor sub-categories are different and set to characterize the activity.

3.3.1 Cropland Management

Cropland is defined in the IPCC 2006 Guidelines as a "*system of practices on land on which agricultural crops are grown and on land temporarily set-aside from crop production*". The classification scheme for CM systems is given in Figure 5.1 (p. 5.21). In the following sections classifications schemes for the three system factors are presented separately.

- **Cropland Management: Factor Land Use (F_{LU})**

  The classification scheme defined for CM follows a hierarchical decision tree using all land use types. A modified version with only the decisions for the land use factor is resented in Figure 11.

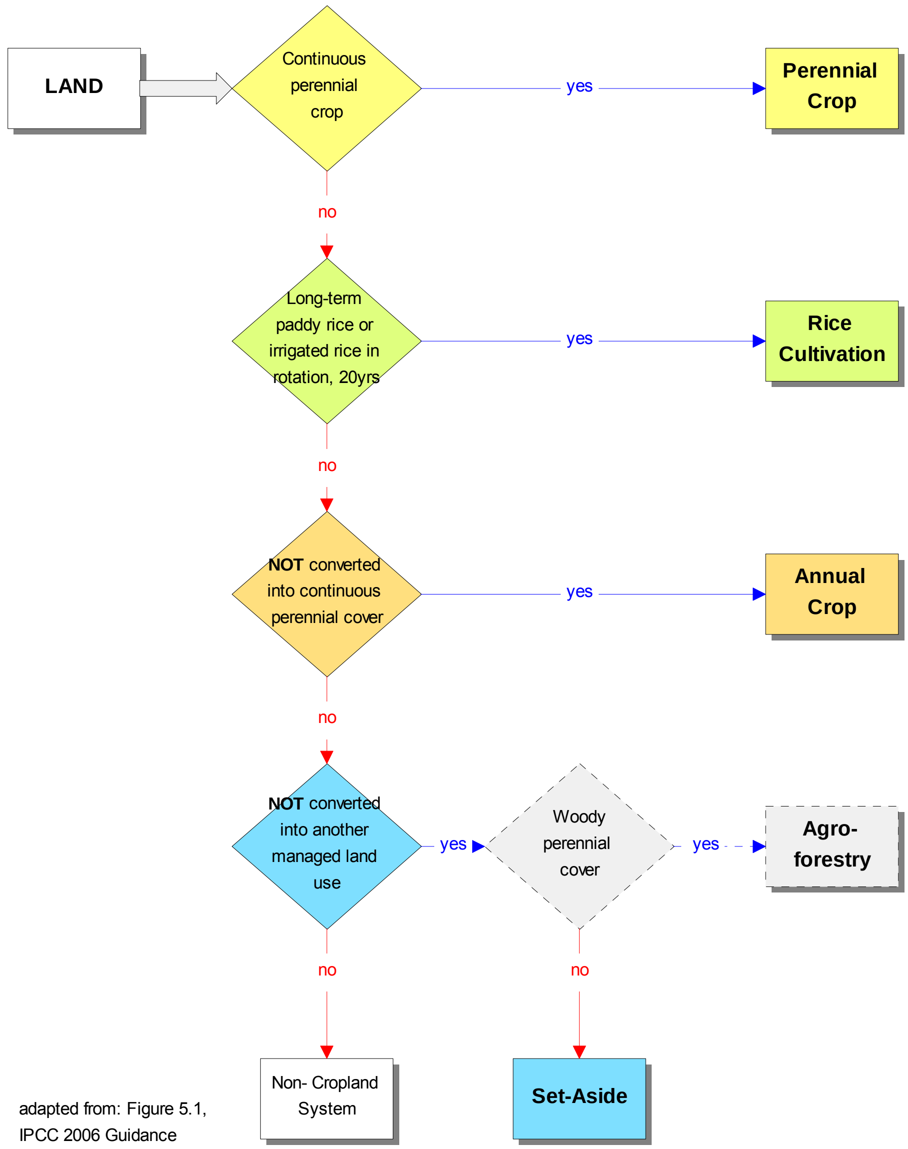


Figure 11: Adapted Classification Scheme for Cropland System Land Use Factor (after: Figure 5.1, 2006 IPCC Guidance)

The classification scheme presented in the figure defines as a binary decision tree only the land use. The basis for the classification is given by all land areas, not only cropland. All CM categories are positively identified. Remaining areas not identified as a cropland category are grouped into a single class (Non-Cropland System).

The four cropland sub-categories are defined at the same time as management and input factors in the order of:

- **perennial / tree crop**
  trees & shrubs with herbaceous crops, orchards, vineyards and plantations, except where these lands are *Forest Land*;

- **wetland rice (paddy)**
  long-term (>20 years) annual cropping of wetland (paddy rice);

- **long-term cultivated** (annual crop in figure)
  area that has been continuously managed for > 20 years, to predominantly annual crops;

- **set-aside (< 20 years)**
  land set at rest for one or several (<20) years before being cultivated again.

Areas not falling into any of the defined categories are aggregated into the category of "non-cropland systems".

• Cropland Management: Factor Land Management (F_{MG})

On cropland a management factor is defined only for the sub-category "*long-term cultivated*". The relative stock change management factor relates to the level and frequency of physical soil disturbance in form of tillage.

The IPCC 2006 Guidelines do not specify a classification scheme for the factor. A simple scheme is presented in

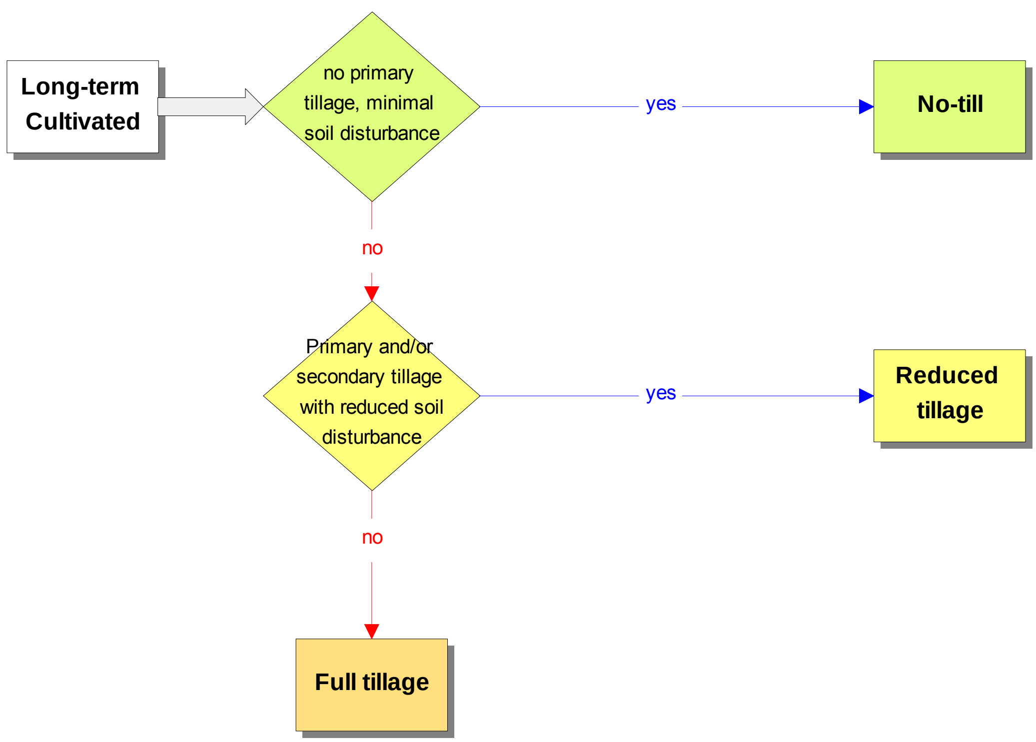


Figure 12: Classification Scheme for Cropland System Management Factor (tillage practice)

The level of the tillage practices are defied as:

- **full tillage**
  substantial soil disturbance with full inversion and/or frequent (within year) tillage operations;

- **reduced tillage**
  primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting;

- **no tillage**
  direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone.

The default value is "*full tillage*". Occasional reduced tillage or non-tillage is still regarded as "*full tillage*" when this is the main form of tillage practice.

- **Cropland Management: Factor Input (FI)**

For the cropland system an input factor is only defined for long-term cultivated areas. A classification scheme for this category based on Figure 5.1, but only for the level of input, is presented in Figure 13.

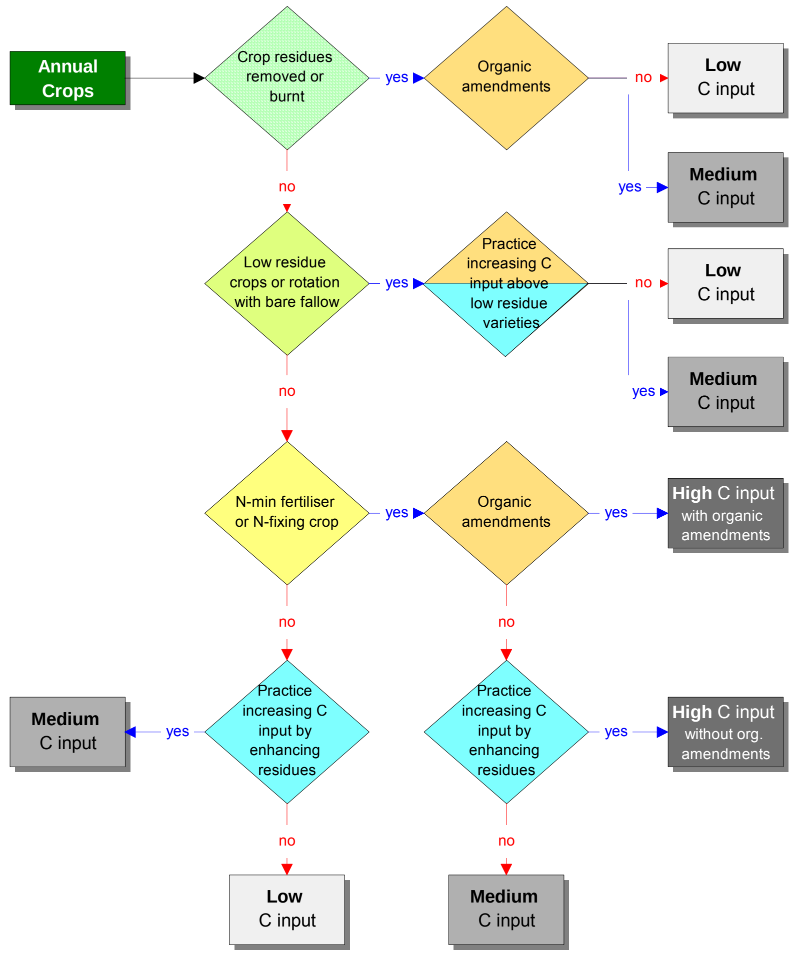


Figure 13: Classification Scheme for Cropland System Input Factor

The level of input of organic material to the soil is divided into four classes:

- o **low;**
- o **medium;**
- o **high, no manure;**
- o **high, with manure.**

The classes of input levels are characterize by the type of residue management, crop rotation practice and the amount of amendments:

- **Residues management**
  - residue yield from crops (classification in low and high residue yield); low residue crops are, e.g. cotton, green maize, vegetables, tobacco
  - use of residues
    removal of residues for energy, animal bedding, mushrooms, etc. ; burning of crop residues;

- **Practice increasing C-stock**
  - green manure, cover crops, vegetated fallow, irrigation, grass in crop rotation, N-fixing crops

- **Additions**
  - mineral fertiliser application rate
  - manure application rate
  - use of organic amendments

No differentiation in the level of input is made for the other cropland sub-categories.

- **Cropland Management: Data**

For cropland the system factors of management and input require much more detailed data on crops than the land use factor suggests. The area where changes to the management system occur may vary annually, such as crops. Yet, crops are often part of a rotation system with a fixed repeat cycle. The temporal interval of updates on area changes may thus depend on a more general management system.

The data needs for the classification scheme for cropland systems is summarized in Figure 14.

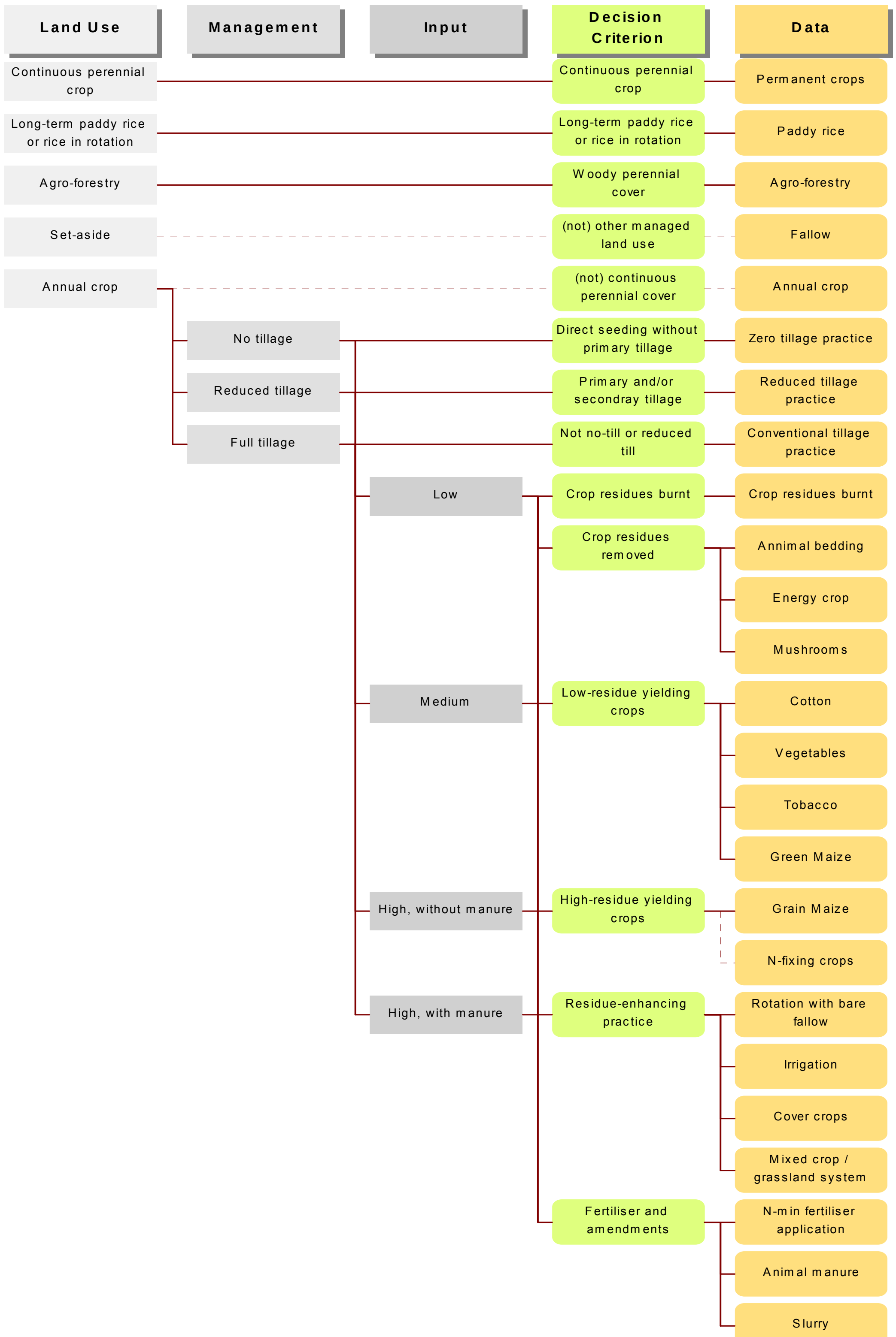


Figure 14: Data needs for classification scheme for Grassland / Grazing Land Systems

3.3.2 Grazing Land Management

The Grazing Land Management activity is closely linked to the grassland land cover. Grasslands are defined as generally having a vegetation dominated by perennial grasses, with grazing as the predominant land use ([4]). However, there are deviations from this definition [5].

The grassland / grazing land system is defined in Figure 6.1 (p. 6.18). The classification scheme (Figure 5.1, p. 5.21) significantly deviates from the classification scheme for the cropland system because it does not identify grassland or grazing land from as part of the scheme from other land use categories but starts with the category.

- **Grazing Land Management: Factor Land Use (F_{LU})**

  The land use for Grassland Management only identifies

  - **managed grassland**

  as the single land use factor. When compared to cropland the definition of the grassland / grazing land category is vague. What constitutes managed grassland / grazing land is only partially covered in Chapter 6, Volume 4 of IPCC 2006 Guidance:

  "*System of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced. Generally has vegetation dominated by perennial grasses.*"

  A description more adopted to identifying areas subject to GM is given in Chapter 2 of the IPCC Good Practice Guidance for LULUCF ([4]; p. 2.6). The category includes:

  - rangelands and pasture land that is not considered as cropland;
  - systems with vegetation that fall below the threshold used in the forest land category and are not expected to exceed, without human intervention, the threshold used in the forest land category;
  - recreational areas;
  - agricultural and silvi-pastural systems, subdivided into managed and unmanaged, consistent with national definitions.

  A graphical separation of grassland / grazing land is presented in Figure 15.

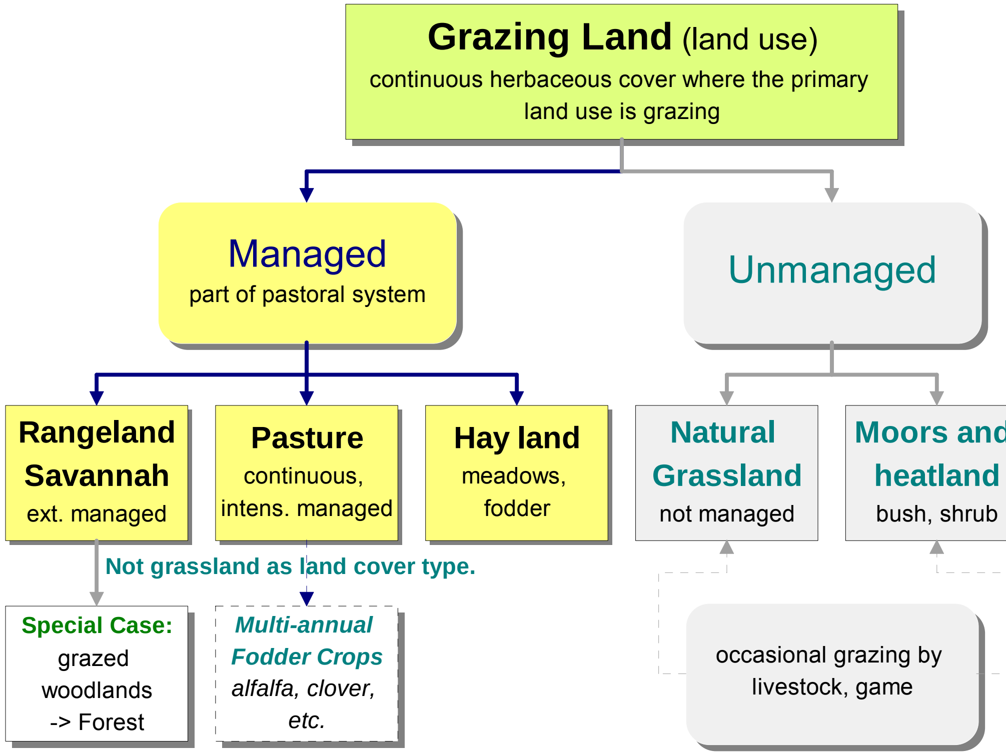


Figure 15: Managed and Unmanaged Grazing Land sub-categories

The drainage status or nutrient level of grassland / grazing land is not taken into consideration under the GM activity.

An area can only be assigned to one activity category. Land qualifying for the GM activity has to consider:

- **changes must be human-induced (managed vs. unmanaged)**
  - extensively managed rangelands and savannahs
    animal stocking rates and fire regimes are main management variables
  - intensively managed pastures and meadows
    with fertilization, irrigation, species changes
  - hayland
- **precedence / hierarch (among elected activities)**
  - annual forages -> cropland
  - grazing under forest -> forest

This would also classify that grazing on non-drained organic soils belongs to the Wetland activity. Also not covered by GM is occasional seasonal grazing on grassland not otherwise managed.

- **Grazing Land Management: Factor Land Management (F_{MG})**

A modified version of the grassland/grazing land system classification scheme is presented in Figure 16.

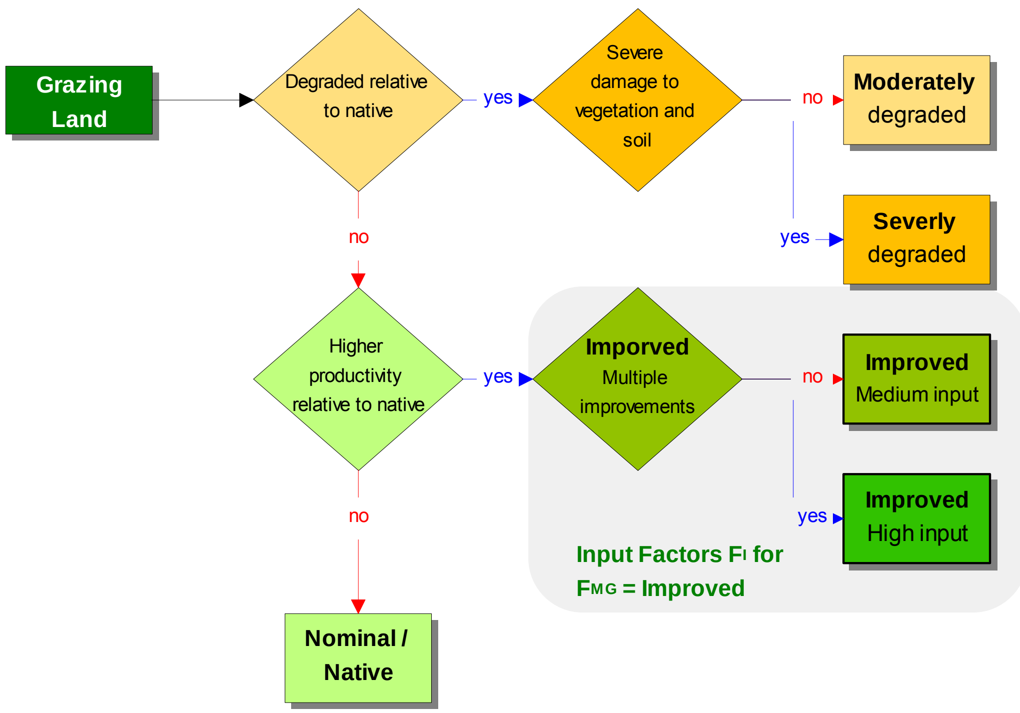


Figure 16: Adapted Classification Scheme for Grassland System Management and Input Factors (after: Figure 6.1, 2006 IPCC Guidance)

The classification scheme starts from identified grazing land. The scheme as shown combines the decisions for management factor F_{MG} with the decisions for the input factor F_I, because the latter only applies to an improved status which only distinguishes between two levels.

On managed grassland / grazing land 4 degrees of management are distinguished, which relate to the productive status:

- **improved**
  C-input to soil > native
- **nominal / non-degraded**
  default status if not improved or degraded
- **moderately degraded**
  C-input to soil < native
- **severely degraded**
  C-input to soil << native

The default value is "*nominal / non-degraded*".

Degraded grassland systems are characterized long-term heavy grazing or planting less productive species.

C-inputs above the native input can be brought about by fertilization and/or applying organic amendments, irrigation, planting more productive varieties, liming, or seeding legumes.

- **Grazing Land Management: Factor Input (F_I)**

The classification scheme for the input factor is presented in Figure 15. Levels of input are only defined for managed grassland / grazing land where the management status is "*improved*" and differentiate two levels:

- **Medium input**
  a single improvement measure is applied.

- **High input**
  multiple improvements are applied.

Measures of improvements are e.g. irrigation, re-seeding, fertilisation.

- **Grazing Land Management: Data**

The system factors for grazing land management concentrate on the management factor. Contrary to cropland for grassland / grazing land also the land use factor contains as a condition the level of management as an indicator of anthropogenic influence. A summary of the data needs used as decision criteria is given in Figure 17.

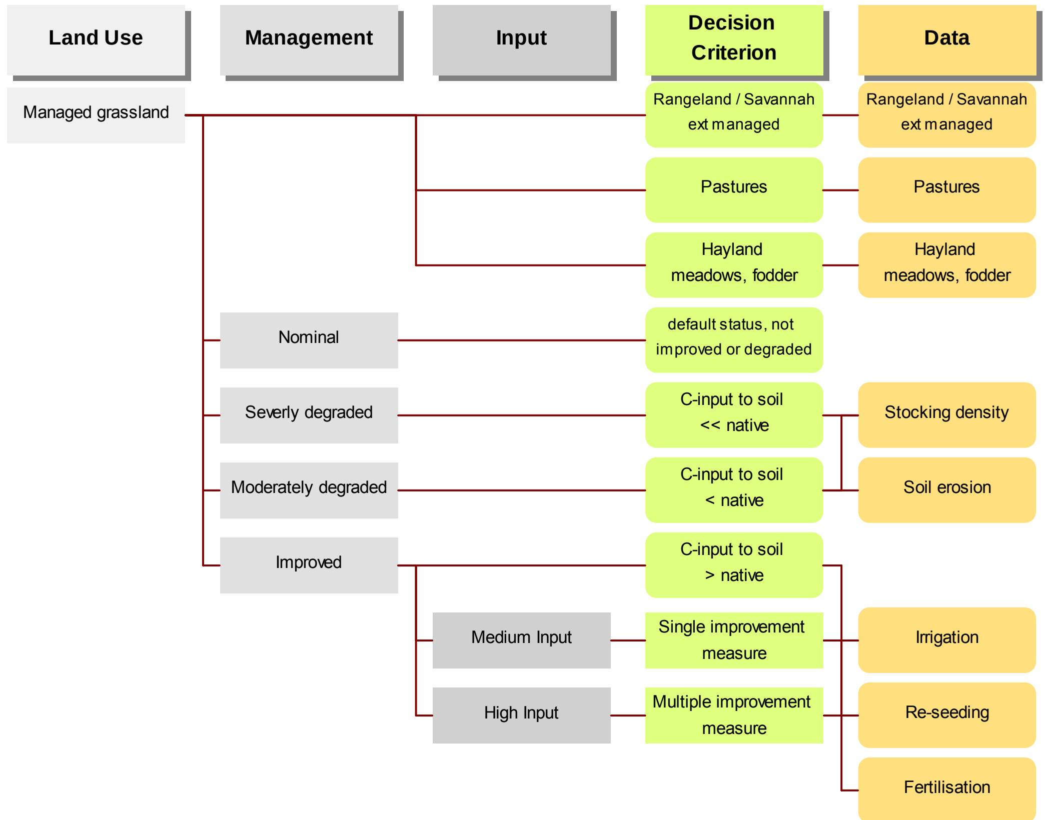


Figure 17: Data needs for classification scheme for Grazing Land Management

With four management and two input classes the data needs for GM seems to be modest when compared to those for CM. However, the decision criteria are indistinct and data on some of the deciding factor can be elusive, such as re-seeding.

4 Data

The data used to estimate changes in soil organic C-stock are of different types and stored in a variety of formats. A main differences between the data are the spatial extent and temporal period to which the data refer.

a) Parameters and Factors

Parameters and factors are as such spatially unaware and constant over time. The parameters defining Climate Regions, such as temperature, define an area when applied to a spatial layer of such data. The default soil organic C-stocks are attributes of the cross-classification of climate regions and soil type. The values are not dependent on the climate or soil data used. Similarly, the factors modifying the organic C-stocks in the soil differ by climate region, but not overtime.

b) Areas

The temporal element of change in the equations for estimating changes in soil organic C-stocks is provided by the areas where a change occurs.

For the approach of estimating changes in soil organic C-stocks is based on data with full spatial cover of a continuous surface with pan-European coverage. This not only applies to the factors modifying default reference soil organic C-stocks (F_{LU}, F_{MG} and F_{I}), but implicitly also to the default reference soil organic C-stock, i.e. climate and soil data. By extension, any condition leading to a change in a modifying factor have to be spatially explicit as well.

4.1 Parameters and Factors

For parameters and factors the values published by IPCC are used. The data to which these parameters and factors are applied are presented hereafter.

4.1.1 Default Reference Soil Organic C-Stock

The Tier 1 *default reference soil organic carbon stock* (SOC_{REF}) for mineral soils is the SOC density under conditions of native vegetation. The values are defined for the topsoil layer from 0 to 30 cm, where most of the changes in SOC are expected to be found. Values are specified for a combination of 6 soil types of mineral soils and 9 climate regions.

The parameter matrix for the SOC_{REF} is given in Figure 18.

Default Reference Organic C-Stock

Climate Region		Soil Type: HAC	LAC	Sandy	Spodic	Vulcanic	Wetland
Boreal		68	70*	10	117	20	146
Cold temperate	dry	50	33	34	65*	20	87
	moist	95	85	71	115	130	
Warm temperate	dry	38	24	19	63*	70	88
	moist	88	63	34	70*	80	
Tropical	dry	38	35	31	53*	50	86
	moist	65	47	39	65*	70	
	wet	44	60	66	87*	130	
	montaine	88	63	34	93*	80	

* Estimated from Harmonized World Soil Database V.1.2 and Global Climate Regions Data

Figure 18: Soil Type and Climate Region Matrix for Default Reference Soil Organic Carbon Stock (SOC_{REF})

For some combinations of Soil Type x Climate Region no default reference values are given in the Guidelines. In cases such combinations occur in the area of interest the table was completed by overlaying a global Climate Region data with soil types derived from the Harmonized World Soil Database. The cases of lacking a value of a default reference C-stock for a combination of Climate Region and Soil Type are rare, but exist in practice probably due to minor irregularities in the spatial data.

4.1.2 Default Emission Factors for Organic Soils

Organic soils are roughly correlated with lower temperatures and higher rainfall. Hence, in Europe organic soils are more prevalent at higher latitudes. When organic soils are subject to cropland or grazing land management they are generally drained. This lowering of the water table results in exposure of the soil organic material to oxygen which in turn leads to the loss of organic material in form of mainly CO_2. Because the material is lost the method of estimating CO_2 emissions from changes in soil C-stock over a fixed depth, as for mineral soils, is not appropriate for organic soils. Instead, IPCC provides emission factors which vary by land use categories and broad climate region.

The emission factors for drained cropland and grazing land organic soils per year are given in Table 2.

Table 2: Annual Emission Factors for Drained Cropland and Grazing Land for Organic Soils

Climate Region	**Cropland** Emission Factor *t C ha⁻¹ yr⁻¹*	**Grazing Land** Emission Factor *t C ha⁻¹ yr⁻¹*
Tropical Wet	20.0	5.00
Tropical Moist	20.0	5.00
Tropical Dry	20.0	5.00
Tropical Montane	20.0	5.00
Warm Temperate Moist	10.0	2.50
Warm Temperate Dry	10.0	2.50
Cool Temperate Moist	5.0	0.25
Cool Temperate Dry	5.0	0.25
Boreal Moist	5.0	0.25
Boreal Dry	5.0	0.25

Polar Regions: not specified in IPCC, 2006.

While for tropical and warm temperate climate regions the emission factors are 4 times higher for cropland than for grazing land organic soils, the ratio increases to a factor of 20 cool temperate and boreal climates.

4.1.3 Cropland Management Factors

The basic arrangement of factors defining changes in soil organic C-stocks for CM is given in Figure 19.

Cropland Management		F_{LU} Land Use				F_{MG} Management			F_I Inputs			
Climate Region		Paddy rice	Perennial tree crop	Set-aside (>20yrs)	Long-term cultivated	Full tillage	Reduced tillage	No tillage	Low	Medium	High, no manure	High, with manure
Boreal		1.10	1.00	0.93	0.80	1.00	1.02	1.10	0.95	1.00	1.04	1.37
Cold temperate	dry	1.10	1.00	0.93	0.80	1.00	1.02	1.10	0.95	1.00	1.04	1.37
	moist	1.10	1.00	0.82	0.69	1.00	1.08	1.15	0.92	1.00	1.11	1.44
Warm temperate	dry	1.10	1.00	0.93	0.80	1.00	1.02	1.10	0.95	1.00	1.04	1.37
	moist	1.10	1.00	0.82	0.69	1.00	1.08	1.15	0.92	1.00	1.11	1.44
Tropical	dry	1.10	1.00	0.93	0.58	1.00	1.09	1.17	0.95	1.00	1.04	1.37
	moist	1.10	1.00	0.82	0.48	1.00	1.15	1.22	0.92	1.00	1.11	1.44
	wet	1.10	1.00	0.82	0.48	1.00	1.15	1.22	0.92	1.00	1.11	1.44
	montaine	1.10	1.00	0.88	0.64	1.00	1.09	1.16	0.94	1.00	1.08	1.41

Figure 19: Land Use System Factors for Cropland Management

For the sub-categories "Set-aside" and "Long-term cultivated" the factors for "Land Use" (F_{LU}) vary with Climate Region, while a single value is specified for "Paddy rice" and "Perennial tree-crops".

The factors for "Management" (F_{MG}) and "Inputs" (F_I) only apply to the land use "Long-term cultivated". The default factor for "Management" (Full tillage) and for "Inputs" (Medium) are invariable with Climate Region.

4.1.4 Grazing Land Management Factors

The three factors modifying the default soil organic C-stocks (land use, management and input) vary with Climate Region. A summary of the factors is given in Figure 20.

Grazing Land Management		F_{LU} Land Use	F_{MG} Management				F_I Inputs	
Climate Region		Grazing Land	Nominal / non degr.	Moderately degraded	Severely degraded	Improved	Medium	High
Boreal		1.00	1.00	0.95	0.70	1.14	1.00	1.11
Cold temperate	dry	1.00	1.00	0.95	0.70	1.14	1.00	1.11
	moist	1.00	1.00	0.95	0.70	1.14	1.00	1.11
Warm temperate	dry	1.00	1.00	0.95	0.70	1.14	1.00	1.11
	moist	1.00	1.00	0.95	0.70	1.14	1.00	1.11
Tropical	dry	1.00	1.00	0.97	0.70	1.17	1.00	1.11
	moist	1.00	1.00	0.97	0.70	1.17	1.00	1.11
	wet	1.00	1.00	0.97	0.70	1.17	1.00	1.11
	montaine	1.00	1.00	0.96	0.70	1.16	1.00	1.11

Figure 20: Land Use System Factors for Grazing Land Management

For the factors "Land Use" (F_{LU}) and "Inputs" (F_I) the values are constant for all Climate Regions. For the factor "Management" (F_{MG}) only the levels "Moderately degraded" and "Improved" are sensitive to different Climate Regions.

The factor related to "Inputs" is only applied when the management level is "improved".

4.1.5 Example of Applying Land Use System Factors to Default Reference Soil Organic C-Stocks

The computations of applying LUS factors to the SOC_{REF} values under Tier 1 are straight forward. As an example the following conditions for the LUS factors for Cropland Management is assumed:

CONDITION	STATE A		STATE B
Climate region:	cold temperate, moist		cold temperate, moist
Soil type:	high activity clay soil		high activity clay soil
Land use type (F_{LU}):	long-term cultivated		long-term cultivated
Management (F_{MG}):	**full tillage**	➔	**reduced tillage**
Input (F_I):	low		low
Time after change:	10 years		

A procedure to estimating the change in soil organic C-stocks after a change in one of the conditions modifying as factor may follow the subsequent steps:

1. Default Reference Soil Organic C-Stock

To find the appropriate value for SOC_{REF} the soil type for the area concerned has to be provided. In this example it is assumed that the change occurs on a soil of type *High Activity Clay* soil (HAC). The value for SOC_{REF} found from intercepting the climate region (Cold temperate, moist) with the HAC soil type is presented in Figure 22.

Default Reference Organic C-Stock — Soil Type

Climate Region		HAC	LAC	Sandy	Spodic	Vulcanic	Wetland
Boreal		68	70*	10	117	20	146
Cold temperate	dry	50	33	34	65*	20	87
	moist	**95**	85	71	115	130	
Warm temperate	dry	38	24	19	63*	70	88
	moist	88	63	34	70*	80	
Tropical	dry	38	35	31	53*	50	86
	moist	65	47	39	65*	70	
	wet	44	60	66	87*	130	
	montaine	88	63	34	93*	80	

Figure 21: Example of Default Reference Soil Organic C- Stocks for Cold Temperate, moist Climate Region and High Activity Clay Soil Type

In the example the default reference soil organic C-stock value SOC_{REF} is 95 $t\ C\ ha^{-1}$.

2. Soil Organic C-Stock in Base Year

It is assumed that the soil organic C-stock in the base year is in a state of equilibrium.

For these conditions the LUS factor comes to:

$$F_{LUS} = F_{LU} * F_{MG} * F_{I}$$

$$F_{LUS} = 0.69 * 1.00 * 0.92 = 0.63$$

The equilibrium SOC stock after 20 years is found by multiplying the value for SOC_{REF} with the LUS factors individually or the combined factor F_{LUS} as:

$$SOC_{a0} = 95 \text{ t C ha}^{-1} * 0.63 = 60.3\ t\ C\ ha^{-1}$$

This value forms the basis for the calculation of changes in soil organic C-stocks.

3. Soil Organic C-Stock after 10 years of change

In the example it is then hypothesize that the management system changes from full tillage to reduced tillage. All other conditions remaining unchanged the LUS factor is calculated as:

$$F_{LUS} = F_{LU} * F_{MG} * F_I$$

$$F_{LUS} = 0.69 * 1.08 * 0.92 = 0.69$$

The selection of the appropriate IPCC default values for the relevant factor types is presented in graphical form in Figure 22.

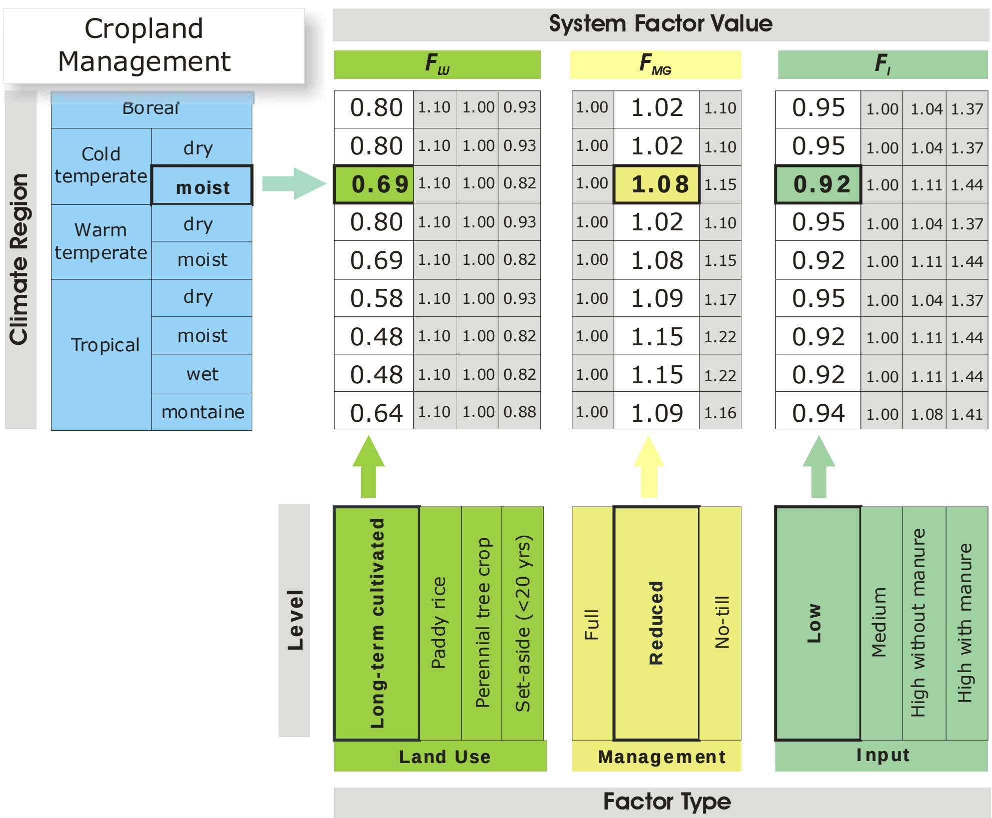


Figure 22: Example of Selecting Factor Values for Change of Management System from Full to Reduced Tillage

For equilibrium status the soil organic C-stocks would come to:

$$SOC_{a+20} = 95 \text{ t C ha}^{-1} * 0.69 = 65.1\ t\ C\ ha^{-1}$$

The difference between the two equilibrium soil organic C-stocks is:

$$\Delta(SOC_{a+20} - SOC_{a0}) = 65.1 - 60.3\ t\ C\ ha^{-1}$$

$$= 4.8\ t\ C\ ha^{-1}$$

Thus, over a period of 20 years, i.e. until the new equilibrium is reached, the soil organic C- stocks increase by an estimated 4.8 $t\ C\ ha^{-1}$. As Tier 1 uses a linear rate of change over 20 years the change from full to reduced tillage amounts to an annual increase in soil organic C-stocks of 0.24 $t\ C\ ha^{-1}\ y^{-1}$, or an increase of 2.4 $t\ C\ ha^{-1}$ after 10 years.

4.2 Areas

Climate and soil conditions are assumed to be stable over time. Therefore, only one layer needs to be generated for Climate Region, Soil Type and Default Reference Soil Organic C-Stock. For activity factors the values for specific conditions remain constant, but the location of the conditions change. As a consequence, for each condition annual layers are produced.

4.2.1 Default Reference Soil Organic C-Stock

The table of default reference soil organic C-stocks was translated into a continuous spatial layer by classifying a combination of spatial layers on climate regions and soil type.

In the classification of the soil type and climate region the process follows the guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC3. These guidelines follow closely the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* ([1]). Differences between the data used for the purpose of Annex V to Directive 2009/28/EC and this study concern the spatial resolution of the data. While the data used previously had a grid-spacing of 5 arc minutes (data were not projected), the data of this study uses a grid-spacing of 1 km in a projection of the *European Terrestrial Reference System 1989* (ETRS89) *Lambert Azimuthal Equal Area* (LAEA) Coordinate Reference System [6]). The soil data were derived from the same databases (European Soil Database and Harmonized World Soil Database), but the data were prepared using different processing techniques.

- **Climate Regions**

  The IPCC classification scheme for the default climate regions is presented in *Figure 3A.5.2 Classification scheme for default climate regions* [1]. The meteorological data used to generate the *Climate Region* layer is the *WorldClim Global Climate Data4*. The information on elevation was provided by the *SRTM 30 arc second v2.1* data5.

  Given the characteristics of the source data (monthly averages) the classification scheme for default climate regions was modified with respect to separating tropical from other climate regions. The aggregated climate data does not allow to fully comply with the first condition of the classification scheme, i.e. using the threshold of 7 days of frost per year to delineate tropical climates. For Europe this should not lead to any deviations in the delineation of climate regions since there are practically no tropical regions.

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3 Commission Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC (2010/335/EU), OJ L151 17.06.2010 pp. 19-41.

4 Download page: http://www.worldclim.org/current

5 Download page: http://dds.cr.usgs.gov/srtm/version2_1/SRTM30/

Applying the conditions of the classification scheme to the 30 arc second data in the projected layer of 1 km grid resolution provides the climate regions presented in Figure 23.

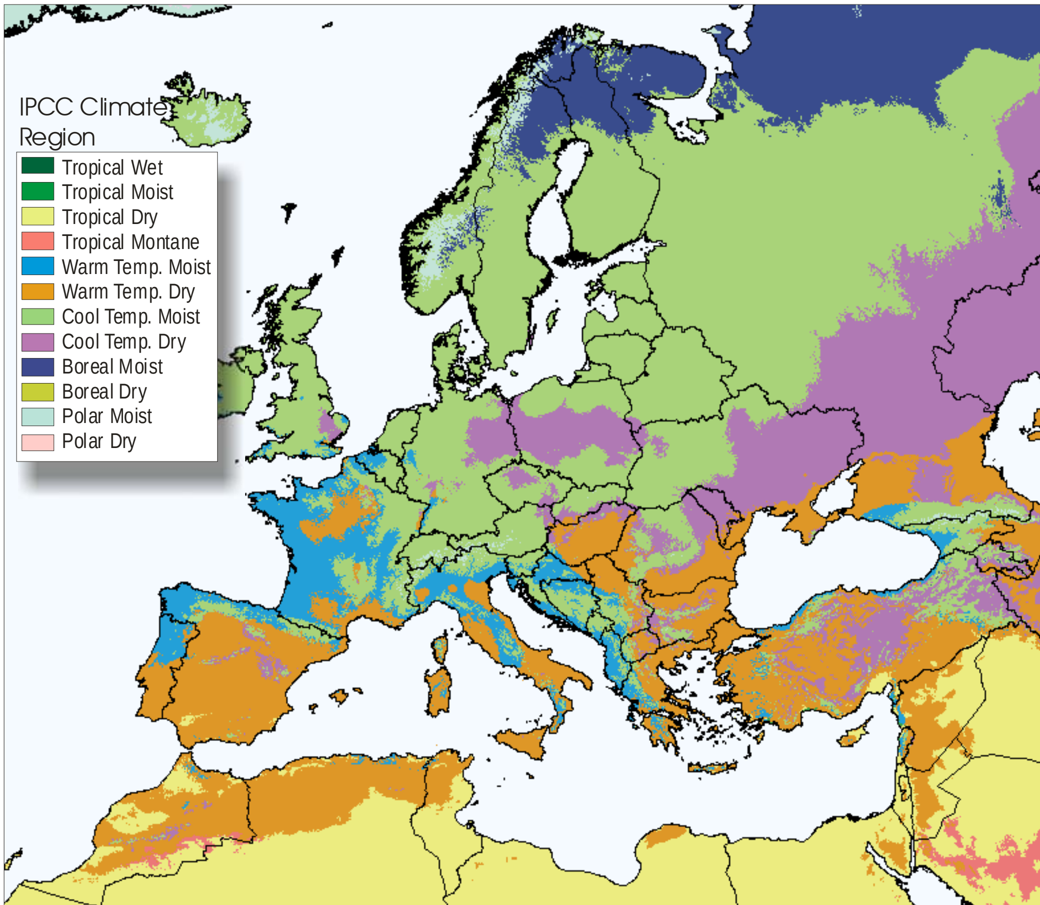

Figure 23: IPCC Climate Regions for Europe

The climate regions derived by applying the classification scheme to the source data leads to a delineation of climate regions, which slightly differs from the map presented as *Figure 3A.5.1 Delineation of major climate zones, updated from the 1996 IPCC Guidelines* (page 3.38 of [1]). The main difference concerns the extent of the climate region *Cool Temperate Dry* at the expense of climate region *Cool Temperate Moist*. The condition separating a *Cool Temperate Dry* from a *Cool Temperate Dry* climate is a *Mean Annual Precipitation* (MAP) : *Potential evapo-transpiration* (PET) ratio > 1. While the two data layers agree in identifying an area in East Anglia as *Cool Temperate Dry* there is disagreement in other areas, such as Eastern Germany and central Poland. The MAP:PET ratio in this region is generally < 0.9, which clearly defines the area as dry rather than moist.

Using a different source data may lead to other delineations of climate regions. This may also happen when using a different temporal period.

- **Soil Type**

In the procedure for estimating GHG emissions from the soil IPCC distinguishes between organic and mineral soils. The distinction made between organic and mineral soil type is more than identifying another soil type. There is a fundamental difference in the method used to estimate C emissions between the two soils:

- For mineral soils emissions are estimated based on the difference in soil organic C-stocks before and after a change to the LUS.
- For organic soils annual emission and removals of carbon are estimated in form of CO_2 flux.

The procedure used to separate mineral form organic soils is therefore consequential to estimating the emissions of C from the soil.

a) Organic Soils

The definition of what constitutes organic soils is given in *Chapter 3 Annex 3A.5* of [1]. When generating a spatial layer of IPCC soil types from soil maps classified according to the *World Reference Base for Soil Resources* (WRB) classification the difference in the definition of what constitutes organic soils (*Histosols*) become important. Some soils, such as organic gleysols, may have a surface layer with organic material, often peat, which would satisfy the condition for thickness of the IPCC definition, but not the definition of an organic soil under WRB (or UDSA).

The IPCC definition of organic soils is thus not fully aligned with the definitions of either WRB or USDA. When suggesting to follow internationally accepted definitions, such as those from FAO, it would seem appropriate to use the definition of WRB (or USDA) to distinguish between organic and mineral soils. This also allows using sources of soil data that lack quantitative information on organic carbon content by soil depth, but contain information on soils classified according to WRB.

b) Mineral Soil Types

Mineral soil types are classified according to the decision tree Figure 3A.5.4 *Classification scheme for mineral soil types based on World Reference Base for Soil Resources (WRB) classification* [1]. In the decision scheme most soil types are identified by a reference soil group. The only exception is the classification of *Sandy Soils*. This IPCC mineral soil type is defined based on texture content for sand (>70%) and clay (<8%). Since the conditions use parameters defined on a ratio scale soil databases using just the WRB soil classes are not suitable to discern the IPCC *Sandy Soil* type. The WRB reference soil group *Arenosol* of the HWSD is almost exclusively assigned to Sandy Soils, but the specifications for the IPCC soil type also includes some occurrences of other soil groups. The ESDB contains information on soil texture only in form of classes. The class "*Coarse*" comes close to the condition set for *Sandy Soils*, but is not identical (Coarse: 18% < clay and > 65% sand).

The IPCC soil type "*Sandy soil*" is therefore defined based on the topsoil sand and clay fractions of the HWSD. All other soil types are identified by the WRB reference soil group.

In this study the spatial layer for the IPCC organic and mineral soil types are derived from combining the ESDB and the HWSD V.1.2.1. To make use of all information of the soil databases a version was employed where soil typologies were mapped to a single spatial layer instead of only the dominant typological unit for an area [7].

First, organic and mineral soils were separated according to the WRB classification. The group of organic soils was composed of all *Histosols* of the ESDB. Second, areas corresponding to the "Sandy Soil" type were separated based on the HWSD texture data. All remaining soil types were identified by their WRB reference soil group name.

The resulting map of the distribution of the IPCC soil types is presented in Figure 24.

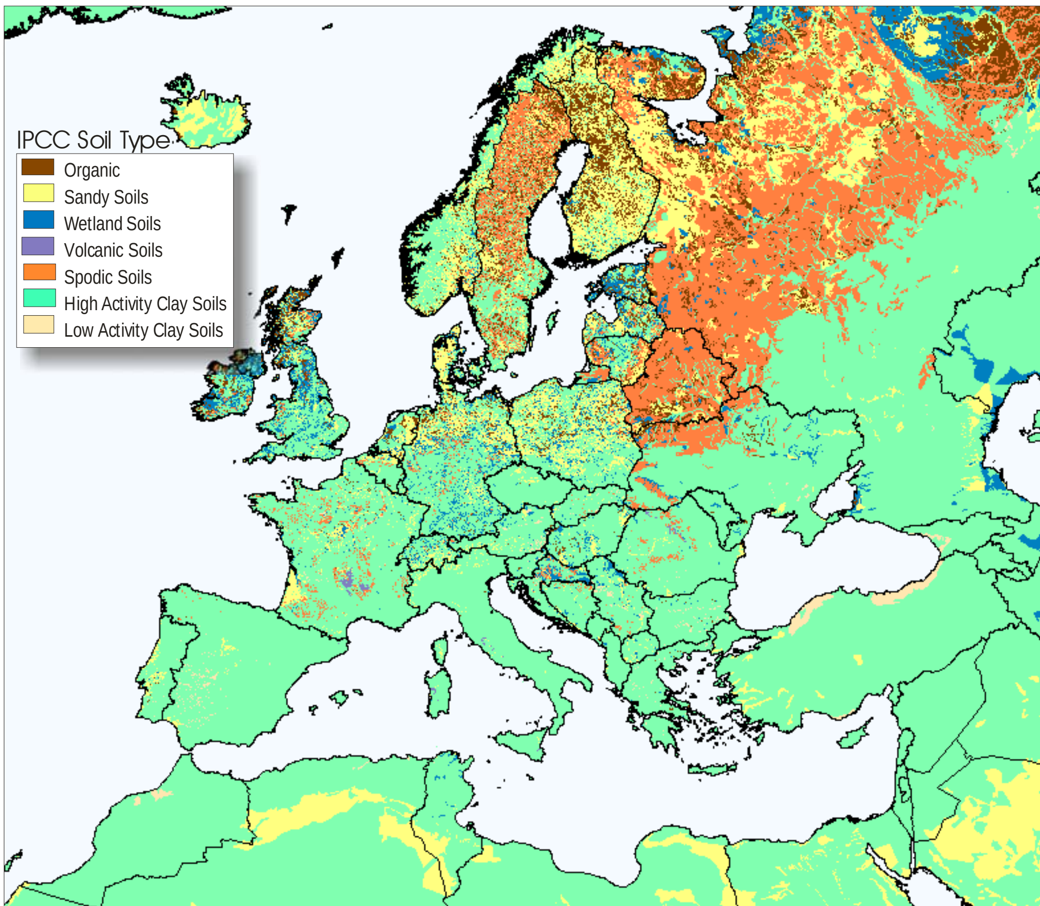

Figure 24: Distribution of Organic Soils and IPCC Mineral Soil Types

Compared to using only WRB reference soil groups the map shows more areas belonging to the *Sandy Soil* type. Notable is also the more detailed distribution of IPCC soil types in northern European countries. This is a consequence of the comparatively large spatial mapping units in these regions in the source data.

- **Default Reference Soil Organic C- Stocks**

A spatial layer of *Default Reference Soil Organic C- Stocks* is generated from combining the soil types with the climate region layers and assigning the corresponding C-stock values to the combinations. The resulting spatial layer is presented in Figure 25.

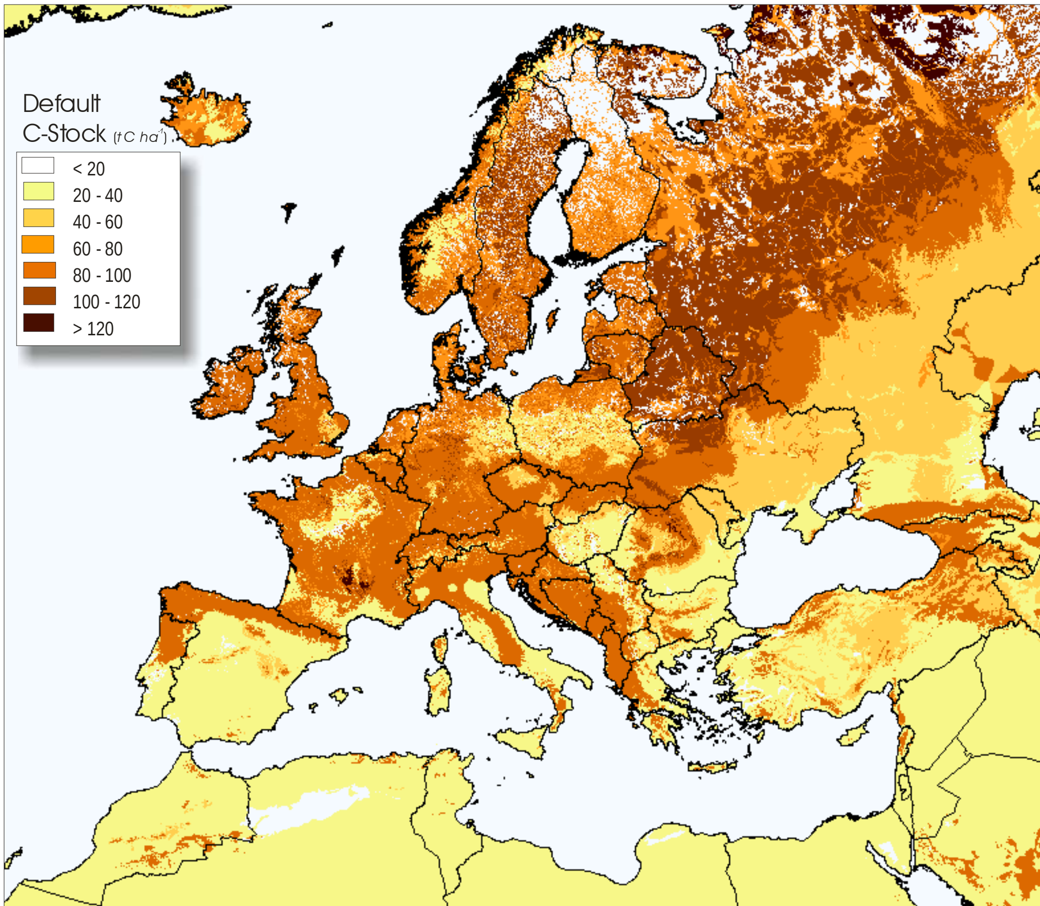

Figure 25: Default Reference Soil Organic C- Stocks

In Europe the spatial allotment of *Default Reference Soil Organic C-Stock* values is dominated by the climate regions. This is largely the consequence of the wide distribution of *High Activity Clay* soil types. By definition the layer shows no values for areas without soil and where organic soils are present.

For organic soils equivalent spatial layers of annual emission factors according to Table 5.6 (cultivated) and Table 6.3 (drained grassland) are produced. The layers are derived from the interception of the spatial layers of the distribution of Histosols with the climate regions.

4.2.2 Land Use Categories

For reporting under the *United Nations Framework Convention on Climate Change* (UNFCCC) the 6 land use classes are designed to cover all managed land. The Kyoto Protocol distinguishes 7 activities on land for reporting GHG emissions. Both classifications have in common that they only concern managed areas. However, there are also areas considered to be in their native state and land that has been abandoned. To allow for changes between land use categories all land areas have to be covered, not just the areas where cropland and grazing land management takes place. Land may also be subjected to more than one activity. An example is livestock grazing in forest. Yet, land can only be account for once and therefore has to belong to only one activity. In these cases a hierarchical system is applied to solve the conflict.

The spatial approach to estimating GHG emissions from changes in soil organic C-stocks for CM and GM uses full spatial coverage for all areas. This implies that also areas not under CM and GM are to be identified. The land area is classified into 9 major categories according to land use factor for estimating variations in soil C-stocks. The classes distinguished in the spatial data for land use are listed in Table 3:

Table 3: Classes in Spatial Layer for Land Use

IPCC	Land Use		
ID	**Code**	**Legend**	**Type**
1	GRASS	Grassland/grazing land	LU
2	CULT	Long-term cultivated	CROP
3	RICE	Paddy rice	CROP
4	PEREN	Perennial / tree crops	CROP
5	SETA	Set aside (<20 years)	CROP
6	NAT	Native Ecosystems	LU
7	WET	Wetlands	LU
8	ART	Artificial	LU
9	OTHER	Other areas	LU

The spatial land use layer contains the main land use categories, but also the sub-categories for cropland. Other land use categories are not further separated into sub-categories. The sub-division of GM is not at the level of land use, but management.

Examples of international land cover data sets are given in [1]; Table 3A.1.1. There are now more products available but the data set which offer the most appropriate combination of spatial resolution, temporal cover and thematic detail is probably the Corine Land Cover (CLC) data.

The spatial layer of land use categories was derived from Corine Land Cover data for 2000[6] (CLC2000). The assignment of CLC2000 land cover classes to IPCC land use categories is presented in Table 4.

[6] Download page: http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-raster

Table 4: Assigning CLC2000 Land Cover Classes to IPCC Land Use Categories

CLC CODE	CLC LABEL	IPCC CODE	CLC CODE	CLC_LABEL	IPCC CODE
111	Continuous urban fabric	ART	311	Broad leaved forest	NAT
112	Discontinuous urban fabric	ART	312	Coniferous forest	NAT
121	Industrial or commercial units	ART	313	Mixed forest	NAT
122	Road and rail networks and associated land	ART	321	Natural grassland	GRASS
123	Sea ports	ART	322	Moors and heathland	WET
124	Airport	ART	323	Sclerophylous vegetation	NAT
131	Mineral extraction site	OTHER	324	Transitional woodland-scrub	NAT
132	Dump	OTHER	331	Beaches, dunes, sand	OTHER
133	Construction site	ART	332	Bare rocks	OTHER
141	Green urban areas	ART	333	Sparsely vegetated areas	OTHER
142	Sport and leisure facilities	ART	334	Burnt areas	OTHER
211	Non-irrigated arable land	CULT	335	Glacier and permanent snow fields	OTHER
212	Permanently irrigated land	CULT	411	Inland marshes	WET
213	Rice fields	RICE	412	Peat bogs	WET
221	Vineyards	PEREN	421	Salt marshes	WET
222	Fruit trees and berries plantations	PEREN	422	Salines	OTHER
223	Olive groves	PEREN	423	Intertidal flats	OTHER
231	Pastures	GRASS	511	Stream courses	OTHER
241	Annual crops associated with permanent crops	CULT	512	Water bodies	OTHER
242	Complex cultivation patterns	CULT	521	Coastal lagoons	OTHER
243	Land principally occupied by agriculture + sig. nat. veg	CULT	522	Estuaries	OTHER
244	Agro-forestry areas	PEREN			

A map illustrating the geographic distribution of cropland and grazing land for EU 28 is presented in Figure 26.

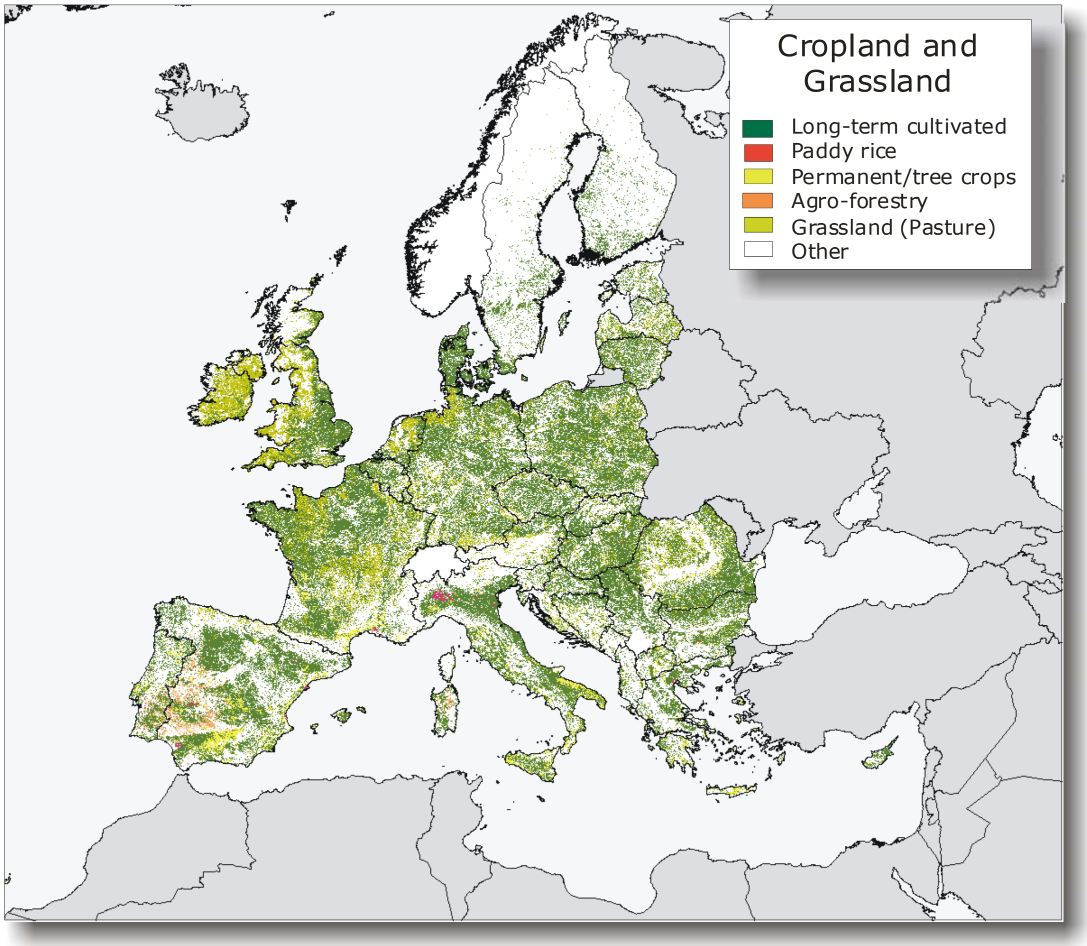

Figure 26: Land Use for Cropland and Grazing Land Management from CORINE Land Cover 2000

Using Corine data for the purpose of identifying the major land use categories is not without ambiguity. Particular items are:

a) Land Cover vs. Land Use

Corine data represents land cover rather than land use. This is not so much an issue for cropland, because any cropland is managed and the purpose for planting a crop is not a deciding factor in the estimation of C-stock changes.

Quite different is the situation for identifying grazing land from land cover data. The same land cover may have very different levels of anthropogenic influence. Signs of management activities of land with herbaceous vegetation cover are inherently difficult to detect from the data used to generate Corine data (satellite images). The Corine legend distinguishes between "2.3.1. Pastures" and "3.2.1. Natural grassland". Natural grassland is mostly assigned to areas "…in high mountains, on steep slopes with difficult access, in territories under nature conservation, or in military areas" [8].

Areas other than grassland may also be grazed, such as heathland ("3.2.2. Moors and heathland" in Corine legend), but are considered unmanaged as long as grazing is occasional.

b) Land Cover Mosaics

Another source of ambiguity are the classes of land cover mosaics in the Corine legend (under 2.4. Heterogeneous agricultural areas). The classes are intended to characterize areas of heterogeneous landscapes at scale 1:100,000 [8]. However, it was found that the extent of these areas is frequently overestimated [9].

For estimating soil C-stocks from changes in land use an area has to be assigned to one and only one land use category. Using proportions of land use categories assigned to an area would result in an unwieldy system when applying a matrix of spatially explicit conversions between land use categories. Assigning a landscape mosaic to a particular land use can be aided by comparing the areas to Eurostat statistical data on land use by region[7]. Specific conditions for assigning CLC classes to IPCC land use categories are:

- **Grassland / Grazing Land**

  Grazing land is land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced. Generally has vegetation dominated by perennial grasses[8].

  For the spatial land use layer CLC classes "Pastures" and "Natural Grassland" are combined. The reason for this deviation from the definition of the category is the ambiguity in separating the managed from non-managed grassland in the source data. CM is identified during a later processing step with the aid of ancillary data.

- **Cropland Categories**

  Cropland is land on which agricultural crops are grown and land temporarily set-aside from crop production[9].

  Cropland is sub-divided into four CM land use types:

  - *Long-term Cultivated*

    Area that has been continuously managed for > 20 years, to predominantly annual crops.

  - *Wetland (paddy) rice*

    Long-term (>20 years) annual cropping of wetland (paddy rice).

  - *Perennial / Tree crop*

    Trees & shrubs with herbaceous crops, orchards, vineyards and plantations, except where these lands are Forest Land.

  - *Set-aside*

    Land set at rest for one or several (<20) years before being cultivated again.

  In the classification scheme the land use type "*perennial cropland*" is divided into "*perennial crop*" and "*perennial cover*". In the text of Chapter 5 – Cropland of the 2006 IPCC GNGHGI this distinction is not obvious. Table 5.4 lists as examples of broad perennial cropland subcategories fruit orchards, plantation crops and agro-forestry systems. The CLC class "*Agro-forestry areas*" was taken to represent the "*Perennial cover*" category of the classification scheme, which in turn corresponds

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[7] Download site: http://ec.europa.eu/eurostat/data/database

[8] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6

[9] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 5.1

to the broad perennial cropland subcategory "*Agro-forestry systems*"[10]. In the CLC classification scheme those areas may include cropland under trees, which could also be classified as cropland.

Not considered for EU28 are "shifting cultivation and fallow rotation systems".

The cropland sub-categories are set at the same level as other major land use categories for conceptual and computational reasons. Only the cropland activity is divided into sub-categories (for estimating C-stocks from land use changes on mineral soils). The major categories are therefore the land use types to which management and input factors apply where specified.

In statistical data the CM land use sub-category "Wetland (paddy) rice" is part of cultivated areas or arable land. To be consistent with IPCC the land use layer is aligned to the land use categories and not the statistical hierarchy of crops on crop land.

- **Native Ecosystem**

  This category contains non-managed areas, but also managed forest land. The latter is included because for mineral soil C-stocks IPCC Tier 1 uses a single activity factor.

- **Wetlands**

  Wetlands contains mainly non-managed areas. Wetlands used for grazing or cropland are generally drained and hence fall under one of these categories. Wetlands may in some cases be used without drainage, such as paludi-culture.

- **Artificial Land**

  Artificial areas are separated from other land areas to better assess the effect of scenario that aim specifically at evaluating the effect of urbanisation. Not included are CLC classes "'Mineral extraction site" and "Dumps", which are assigned to other areas.

- **Other Areas**

  This category contains any land areas not assigned to one of the defined categories.

While the basis for the spatial data is taken from Corine LC layers the temporal coverage is not sufficiently frequent to allow estimating annual changes between land use categories. Moreover, the information concerns land cover, which implies that aspects of land management are scarcely covered.

In addition to the land use categories and sub-categories specified by IPCC more detailed information is required on the crops grown and the use of grassland to support evaluating management and input practices. As a consequence, the data needs for annual areas of land occupation largely exceed the broad land use categories. The land use category and crop items for which area data are processed are given in Figure 27.

10 IPCC, 2006: Volume 4, Chapter 5.1:
Perennial crops include trees and shrubs, in combination with herbaceous crops (e.g., agroforestry) or as orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees, and bananas, except where these lands meet the criteria for categorisation as Forest Land.

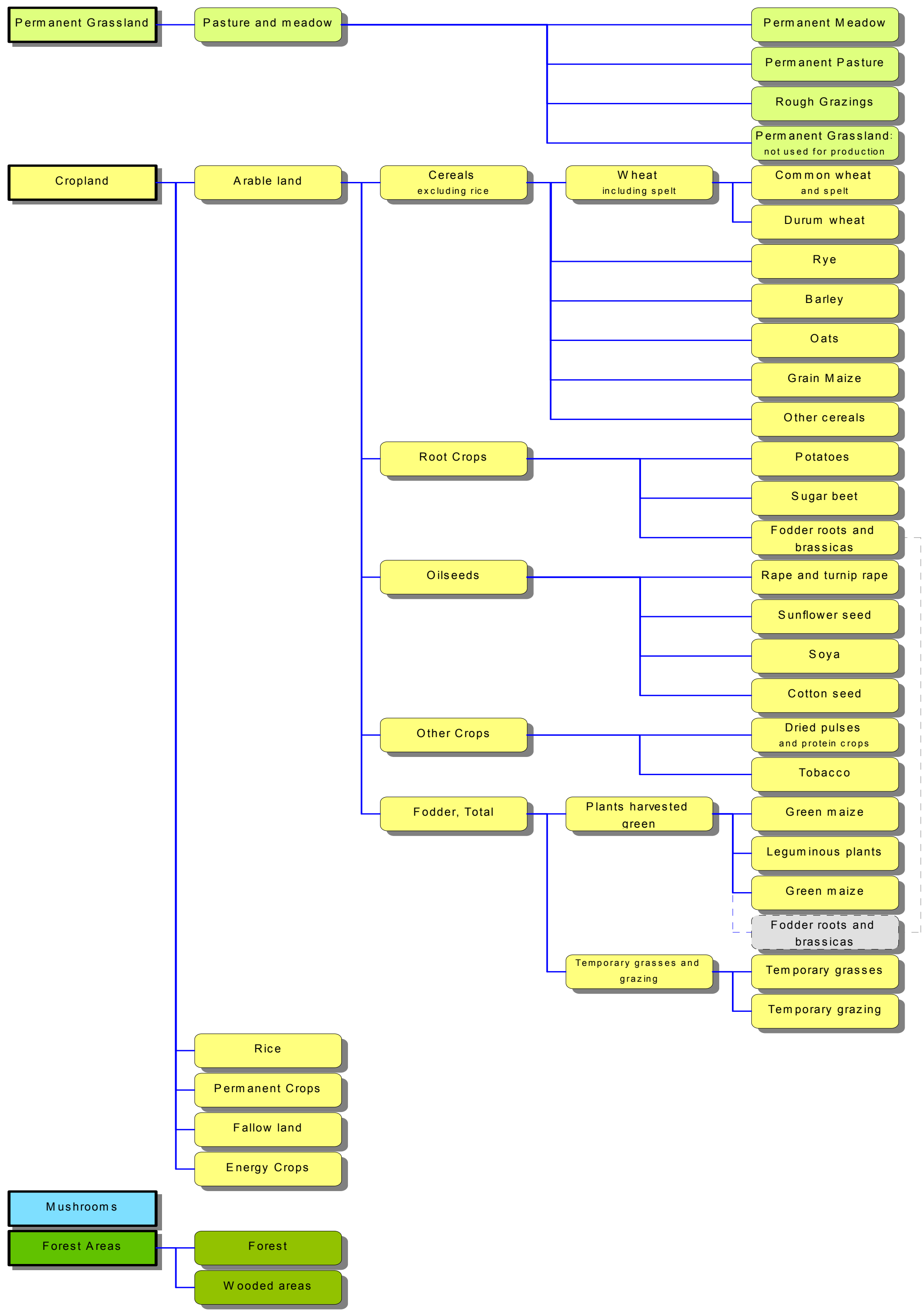

Figure 27: Land Use Categories, sub-categories and crops for which data on Areas are processed

The land use category "Grassland" approximates the area covered by the activity GM. GM not only contains areas grazed by livestock, but more generally areas with permanent herbaceous cover used to raise livestock. Some data sources distinguish between different types of managed grassland, which can be utilized to better disaggregate management and input factors.

Areas of long-term cultivation and under CM are considered to be represented by the label "Arable land" frequently used in statistical databases. This class was further subdivided into groups of crops and individual crop types. The crop groups are used to align areas from data sources with diverse detail and temporal coverage. The item "Energy crops" is explicitly specified as an additional land occupation. It has been added to cover new energy crops on arable land, such as multi-annual herbaceous and ligneous plants. The item "Mushrooms" was added to support estimates of crop residues removed from the field.

- **Statistical Data Sources**

An overview of the items for statistical data on areas of land occupation is presented in Table 5.

Table 5: Land Use Categories and Crops for Area Statistics

LAND OCCUPATION		Eurostat AGR_R				Eurostat EF						Eurostat APRO_CPP				FAOSTAT			
		CROP		LANDUSE		R_NUTS		LU_OV		OLU_UAA		CROP		LANDUSE		CROP		LAND	
ID	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label
1	Permanent grassland			L0002	Permanent grassland	78	permanent pasture and meadows (F) (in ha)	F	Permanent grassland (pastures and meadows)	B_3_HA	Total: Permanent grassland and meadow	C0002	Permanent grassland (pastures and meadows)	L0002	Permanent grassland (pastures and meadows)			6655	Permanent meadows and pastures
2	Arable land			L0001	Arable land	39	Arable land (in ha)	D	Arable land	B_1_HA	Arable land			L0001	Arable land	6621	Arable land	6621	Arable land
3	Rice	C1250	Rice	L1250	Rice	56	Rice (D/07) (in ha)	D07	Rice	B_1_1_7_HA	Rice	C1250	Rice	L1250	Rice	27	Rice, paddy		
4	Permanent crops			L0003	Permanent crops	80	Permanent crops (G) (in ha)	G	Permanent crops	B_4_HA	Permanent crops			L0003	Permanent crops	6650	Permanent crops	6650	Permanent crops
5	Fallow land			L2696	Fallow land			D21 or I08	Fallow land	B_1_12_HA	Fallow land - total (with and w/o subsidies)			L2696	Fallow land			6640	Fallow land
9	Utilised agricultural area (UAA)			L0005	Utilised agricultural area (UAA)					AGRAREA_HA	Utilised agricultural area					1709	Agricultural Soils + (Total)	6610	Utilised agricultural area (UAA)
10	Cereals					42	Cereals (D/01-D/08) (in ha)	D01_08	Cereals	B_1_1_HA	Cereals	C1040	Cereals for the production of grain (including rice and seed)			1717	Cereals,Total + (Total)		
11	Cereals (excluding rice)	C1050	Cereals (excluding rice)	L1050	Cereals for the production of grain (including seed but excluding rice)							C1050	Cereals (excluding rice)	L1050	Cereals for the production of grain (including seed but excluding rice)				
12	Wheat (including spelt)	C1100	Wheat (including spelt)									C1100	Wheat (including spelt)			15	Wheat		
13	Common wheat and spelt	C1120	Common wheat and spelt			44	Common wheat and spelt (in ha)	D01	Common wheat and spelt	B_1_1_1_HA	Common wheat and spelt	C1120	Common wheat and spelt						
14	Durum wheat	C1130	Durum wheat			46	Durum wheat (D/02) (in ha)	D02	Durum wheat	B_1_1_2_HA	Durum wheat	C1130	Durum wheat						
15	Rye	C1150	Rye			48	Rye (D/03) (in ha)	D03	Rye	B_1_1_3_HA	Rye	C1150	Rye			71	Rye		
16	Barley	C1160	Barley			50	Barley (D/04) (in ha)	D04	Barley	B_1_1_4_HA	Barley	C1160	Barley			44	Barley		
17	Oats					52	Oats (D/05) (in ha)	D05	Oats	B_1_1_5_HA	Oats	C1180	Oats			75	Oats		
18	Grain maize	C1200	Grain maize			54	Grain maize (D/06) (in ha)	D06	Grain maize	B_1_1_6_HA	Grain maize	C1201	Grain maize and corn-cob-mix			56	Maize		
19	Triticale					58	Other Cereals	D08	Other Cereals	B_1_1_99_HA	Other Cereals	C1212	Triticale			97	Triticale		
20	Dried pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses)	C1300	Dried pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses)	L1300	Dried pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses)	60	Dried vegetables (D/09 (in ha)	D09	Pulses - total	B_1_2_HA	Pulses - total	C1300	Dried pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses)	L1300	Dried pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses)	1726	Pulses,Total + (Total)		
21	Root crops			L1350	Root crops	62	Root crops (D/10-D/12) (in ha)					C1350	Root crops			1720	Roots and Tubers,Total + (Total)		
22	Potatoes (including early potatoes and seed potatoes)	C1360	Potatoes (including early potatoes and seed potatoes)			64	Potatoes (D/10) (in ha)	D10	Potatoes	B_1_3_HA	Potatoes	C1360	Potatoes (including early potatoes and seed potatoes)	L1360	Potatoes (including early potatoes and seed potatoes)	116	Potatoes		
23	Sugar beet (excluding seed)	C1370	Sugar beet (excluding seed)			66	Sugar-beet (D/11) (in ha)	D11	Sugar beet	B_1_4_HA	Sugar beet	C1370	Sugar beet (excluding seed)	L1370	Sugar beet (excluding seed)	157	Sugar beet		

LAND OCCUPATION		Eurostat AGR_R				Eurostat EF						Eurostat APRO_CPP				FAOSTAT			
		CROP		LANDUSE		R_NUTS		LU_OV		OLU_UAA		CROP		LANDUSE		CROP		LAND	
ID	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label
24	Fodder roots and brassicas					68	fodder roots and brassica (D/12) (in ha)	D12	Fodder roots and brassicas	B_1_5_HA	Fodder roots and brassicas	C1380	Other root crops n.e.c.						
25	Oilseeds	C1410	Oilseeds									C1410	Oilseeds						
26	Rape and turnip rape	C1420	Rape and turnip rape					D13D1A	Rape and turnip: Other oil-seed or fibre plants	B_1_6_4_HA	Rape and turnip	C1420	Rape and turnip rape			270	Rapeseed		
27	Sunflower seed	C1450	Sunflower seed					D13D1B	Sunflower: Other oil-seed or fibre plants	B_1_6_5_HA	Sunflower	C1450	Sunflower seed			267	Sunflower seed		
28	Soya	C1470	Soya					D13D1C	Soya: Other oil-seed or fibre plants	B_1_6_6_HA	Soya	C1470	Soya			236	Soybeans		
29	Cotton seed	C1490	Cotton seed					D13C	Cotton	B_1_6_3_HA	Cotton	C1490	Cotton seed			328	Seed cotton		
30	Tobacco	C1550	Tobacco					D13A	Tobacco	B_1_6_1_HA	Tobacco	C1550	Tobacco			826	Tobacco, unmanufactured		
31	Fodder, Total					76	Forage plants (D/18 (in ha)	D18	Forage plants - total	B_1_9_HA	Fodder crops - total	C2600	Fodder, Total						
32	Plants harvested green			L2610	Plants harvested green (grown on arable land)							C2610	Plants harvested green	L2610	Plants harvested green				
33	Green maize	C2625	Green maize					D18B1	Green maize: Other green fodder: Forage plants	B_1_9_2_1_HA	Green maize: Other green fodder: Fodder crops	C2625	Green maize			446	Maize, green		
34	Leguminous plants							D18B2	Leguminous plants: Other green fodder: Forage plants	B_1_9_2_2_HA	Other fodder crops: leguminous plants: Fodder crops	C2670	Leguminous plants						
35	Temporary grasses and grazing							D18A	Forage plants - temporary grass	B_1_9_1_HA	Fodder crops - temporary grass	C2680	Temporary grasses and grazing					6633	Temporary meadows and pastures
36	Temporary Grass											C2681	Temporary Grass						
37	Temporary Grazing											C2682	Temporary Grazing						
38	Pasture and meadow							F01	Pasture and meadow: Permanent grassland and meadow	B_3_1_HA	Pasture and meadow: Permanent grassland and meadow								
39	Permanent Meadow											C2710	Permanent Meadow						
40	Permanent Pasture											C2720	Permanent Pasture						
41	Rough grazings: Permanent grassland and meadow							F02	Rough grazings: Permanent grassland and meadow	B_3_2_HA	Rough grazings: Permanent grassland and meadow								
42	Permanent Grassland: not used for production									B_3_3_HA	Permanent Grassland: not used for production							6659	Perm. meadows & pastures - Nat. growing
43	Energy Crops									B_6_3_HA	Energy Crops	C1590	Energy Crops						
61	Forest			L0016	Forest area									L0016	Forest			6661	Forest
62	Wooded Area			L006	Wooded Area	84	Woodland (H/02)							L0006	Wooded Area				

LAND OCCUPATION		Eurostat AGR_R				Eurostat EF						Eurostat APRO_CPP				FAOSTAT			
		CROP		LANDUSE		R_NUTS		LU_OV		OLU_UAA		CROP		LANDUSE		CROP		LAND	
ID	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label	Code	Label
91	Mushroom							I02	Mushrooms	B_6_1_HA	Mushrooms					449	Mushrooms and truffles		

Eurostat Database: http://ec.europa.eu/eurostat/data/database

AGR_R: Regional Agricultural Statistics
Areas harvested, yields, production by NUTS 2 regions [agr_r_crops]
Land use by NUTS 2 regions [agr_r_landuse]

EF: Farm Structure
Structure of agricultural holdings by NUTS 3 regions - main indicators [ef_r_nuts]
Land use: number of farms and areas of different crops by agricultural size of farm (UAA) and NUTS 2 regions [ef_oluaareg]
Farmland: number of farms and areas by size of farm (UAA) and NUTS 2 regions [ef_lu_ovcropaa]

APRO_CPP: Agricultural Production, crop products
Crops products - annual data [apro_cpp_crop]
Land use - 1 000 ha - annual data [apro_cpp_luse]

FAOSTAT:
Crop: Domain Production, Crops http://faostat3.fao.org/browse/Q/QC/E
Land: Domain Inputs, Land http://faostat3.fao.org/browse/R/RL/E

Note: state June, 2016

The main source of data on areas is offered by Eurostat[11]. Data on areas, but also crop yield and production, are covered in various tables. The database underwent substantial changes in structure and content which resulted in different data available in 2015 and 2016. The database for processing land areas was compiled from 2012 to 2015 and contains some data that are listed in Table 5 but are no longer available from the database. Other tables with more recent data have become available after 2015 but the nomenclature has not been changed and the links between the land occupation and the database items remain valid. The spatial detail of the tables is generally in administrative units of "*Nomenclature des Unités territoriales statistiques*" (NUTS) at level NUTS 0, NUTS 1 and NUTS2, in some cases also NUTS 3.

A second source of data is FAOSTAT. The database goes back 1961 in some cases with a wide range of land uses and crops. However, the data are available only at national level (NUTS 0). The database has been mentioned by PCC as a possible source of data for Tier 1, but is not particularly adapted to allocate spatially explicit changes of Approach 3.

- *Set-aside*

  Areas under set-aside are reported for the period of the 1988 legislation (1990-2007) under "Land use – Other farmland" in table "Fallow land and set-aside land: number of farms and areas by size of farm (UAA) and size of arable area" [ef_lu_ofsetasid)].

- *Mushrooms*

  Data on the area used for cultivating mushrooms are more specifically covered in the table "Mushrooms, energy crops, GMO: number of farms and areas by size of farm (UAA)" [ef_pomengmo] of the FSS.

o Spatial Data Sources

There is a considerable number of spatial data on land cover. Some products offer general land cover information, while others specialise on specific categories, such as forest or cropland. To be useful in the context of allocating land use for implementing a Tier 1 method the classification scheme should allow the unambiguous identification of the IPCC land use categories, relate to conditions of a specific year and have a spatial resolution that allows assigning a single factor to a spatial location. Spatial data with other characteristics may serve as ancillary data to support the spatial allocation procedure.

- *Arable land, crop areas*
  - M3-Crops Data
    A global set of data on the areas harvested for is available from the data "Harvested Area and Yields of 175 crops (M3-Crops Data)"[12] [10]. The spatial resolution of the data is 5 arc min. with a single temporal reference.
- *Cropland vs. Grassland*
  - M3-Cropland and M3-Pasture Data
    A spatial layer of global coverage for cropland and pastures is provided by the dataset "Agricultural Lands in the Year 2000 (M3-Cropland and M3-

[11] Download site: http://ec.europa.eu/eurostat/data/database

[12] Download site: http://www.earthstat.org/data-download/

Pasture Data)" [11]. The spatial resolution of the data is 5 arc min. with a single temporal reference.

- ESA Climate Change Initiative Land Cover dataset
  The ESA land cover map is available at a spatial resolution of 300m and three temporal periods (2000, 2005 and 2010)[13]. The classification scheme follows the FAO/UNEP Land Cover Classification System which does not cover individual crops. It can be used to aid separating the main land use classes.

- Corine Land Cover (CLC)
  Land cover data from the Corine project are available for 1990 (nominal year, data from 1986-1998), 2000 and 2006 from the European Environment Agency[14]. The spatial raster layers are available in 100m and 250m resolution. A complete cover of EU28 Member States is provided by Corine LC2000. The CLC90 and CLC06 data lack data from one or more countries.

  A CLC2012 product is available from the Copernicus Land monitoring Services site for pan-European data[15]. The site also provides CLC products from other years with up-dated versions not available from the EEA site.

- Land Degradation in Drylands (LADA) Land Use System
  The LADA data contains classes on unmanaged areas (Class 7: Grassland unmanaged; Class 13: Shrub cover unmanaged) as opposed to managed areas with livestock.

- FAOSTAT
  Under the Domain "Inputs" the category "Land"[16] contains information on the main land use types. The database contains also data on the areas of temporary grassland and natural grassland. The temporal range covers 1961 to 2013 (status: June, 2016).

4.2.3 Management Factors (F_{MG})

The conditions defining management factors for CM and GM are very different in character. For CM the deciding element is the level disturbance of the soil, which affects soil organic C-stocks, but not necessarily productivity. For GM the deciding element is the actual level of productivity relative to a native state. Contrary to CM such practices includes irrigation.

- **CM Management Factor**

  The management options for CM concern the level of tillage intensity. All other practices, including irrigation, are treated as input, not management.

[13] Project site: http://www.esa-landcover-cci.org/?q=node/158

[14] Project site: http://www.eea.europa.eu/publications/COR0-landcover

[15] Project site: http://land.copernicus.eu/pan-european

[16] Download site: http://faostat3.fao.org/download/R/RL/E

- **Statistical Data Sources**
  - *Tillage Practice*
    - Eurostat
      The main data source is the Eurostat "Survey on Agricultural Production Methods" (SAPM), table [ef_pmtilaa] contains "Tillage methods: number of farms and areas by size of arable area and NUTS 2 regions".

      The database provides areas for conventional, conservation and zero tillage with definitions comparable to those used by IPCC. The data are available only for the year 2010. To provide a measure of the trend in tillage practices other sources need to be explored.
    - FAO Aquastat
      Under the heading "Conservation agriculture and water harvesting" the FAO Aquastat database contains areas and shares of arable land of "conservation agriculture"[17]. Aquastat defines "conservation agriculture" by parameters similar to those used by IPCC for "reduced tillage" and "no-till"[18]. However, some uncertainty remains with respect to the scope of the Aquastat data when quoted in the literature.

      Data are at national level starting in 1960. Not all EU28 Member States are covered with data and the years with data are infrequent.
    - Literature
      An overview over the adaptation of conservation agriculture is provided in several articles, for example [12], [13] or [14]. The data of [12] very much match those published in Aquastat.

- **Spatial Data Sources**

  No spatially explicit sources of data on tillage practice were found. The maps presented by Eurostat[19] are representations of the SAPM NUTS Level 2 data.

- **GM Management Factor**

For GM the management factor expresses the productive status of the managed grassland relative to the native status. A range of conditions indication either degradation or improvements are provided. Where these condition are not present a status comparable to the nominal or native condition is assumed.

Conditions leading potentially to a degradation are long-term over-grazing or planting less productive plants. Conditions leading potentially to an improvement are fertilization, irrigation, planting more productive varieties or legumes and liming.

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[17] Download site: http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

[18] Definition: http://www.fao.org/nr/water/aquastat/data/glossary/search.html?submitBtn=-1&termId=7468

[19] Statistics explained: http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_tillage_practices#Data_sources

- **Statistical Data Sources**

  - *Separating managed from non-managed grassland*

    - FAOSTAT
      Under the Domain "Inputs" the category "Land"[20] contains information on the main land use types. The database contains also data on the areas of temporary grassland and natural grassland. The temporal range covers 1961 to 2013 (status: June, 2016).

  - *Number of grazing animals*

    - Eurostat
      Table "Animal grazing on the holding: number of farms and area grazed by duration, economic size of farm (SO in euros) and NUTS 2 regions" [ef_pmgrazecs]

    - FAOSTAT
      Under the Domain "Production" the category "Live animals"[21] FAOSTAT contains information on the number (Heads) of various types of livestock. Statistics on the livestock type "cattle" are only available for the group without further details. The temporal range covers 1961 to 2013 (status: June, 2016).

  - *Irrigation*

    - Eurostat
      For the period 1988 legislation (1990-2007):
      Under theme "Land use – Other farmland" table "Irrigation: number of farms, areas and equipment by size of farm (UAA) and NUTS 2 regions" [ef_lu_ofirrig]. The table contains as an indicator the area of "Irrigated once a year: Fodder plants".

      For period 2005 legislation (2005 onwards):
      Under theme "Farm land use – permanent crops, other farmland, irrigation" table "Irrigation: number of farms, areas and equipment by size of irrigated area and NUTS 2 regions" [ef_poirrig]. The table contains irrigated areas of "Temporary and permanent grass".

    - FAO Aquastat
      The FAO Aquastat database[22] includes some data on "Permanent meadows and pastures irrigated" by country. The temporal range is limited and mainly 2003 or later.

  - *Fertiliser use*

    - FAO FertiStat
      The FAO FertiStat database[23] on fertilizer application rates includes as a commodity "Fodder" (code 827). The commodity is a collection of all fodder crops, including alfalfa, clover, fodder legumes, fodder beet, fertilized grassland and pastures, green manure, green maize, etc. The fertilizer application rate for grassland can be estimated by removing the rates from the other crops.

[20] Download site: http://faostat3.fao.org/download/R/RL/E

[21] Download site: http://faostat3.fao.org/download/Q/QA/E

[22] Download site: http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

[23] Project site: http://www.fao.org/ag/agp/fertistat/index_en.htm

- **Spatial Data Sources**

- *Level of Productivity*

  - Net Primary Productivity

    The level of productivity compared to the productivity under native conditions is estimated by comparing Net Primary Productivity (NPP) from different land use categories. NPP data for the years 2000 and onwards are available from the product "*Terra/MODIS Net Primary Production Yearly L4 Global 1km (MOD17A3)*[24]". The NASA product was further processed by the Numerical Terradynamic Simulation Group of the University of Montana [15]. The data are improved over the NASA data to version 55 and available in different formats for public download[25].

    NPP global data for the period 1981 to 2000 are available from the AVHRR Global Production Efficiency Model (GloPEM) project[26]. The spatial resolution of the data is 8 km. For years preceding 2000 the average of the years 2000 to 2010 is used.

- *Grazing animal density*

  - Land Degradation in Drylands (LADA) Land Use System

    Some conditions indicating the status of grasslands and grazing intensity can be derived from the data "Land Use Systems of the World"[27] the spatial resolution of the data is 0.08333 deg. or 5 arc min. the data were compiled as part of the FAO project "Land Degradation Assessment in Drylands" (LADA)[28].

- *Soil retention*

  - Land-Use-based Integrated Sustainability Assessment modelling platform (LUISA)

    Soil retention is the soil loss without vegetation cover minus soil loss including the current land use/cover pattern. The data take into account climate data, topographic aspects, soil properties and the vegetation cover [16].

    Data on soil retention is available as part of the indicators used by (LUISA)[29]. A spatial layer of aggregated values to NUTS 0 and NUTS 2 of soil retention are available for public download[30]. These data are used in preference to soil erosion data to align the input data with impact assessments performed under LUISA.

- *Seeding legumes or introducing other varieties*

  No data on improvements of the grassland species composition were found. Related improvements in productivity are covered by the NPP data.

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[24] Data download: https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod17a3

[25] Project site: http://www.ntsg.umt.edu/project/mod17

[26] Project site: http://glcf.umd.edu/data/glopem/
Data download: ftp://ftp.glcf.umd.edu/glcf/GLOPEM/Summed_Annual

[27] Download site: http://www.fao.org/geonetwork/srv/en/metadata.show?id=37139&currTab=simple

[28] Project site: http://www.fao.org/nr/lada/index.php?option=com_content&view=frontpage&Itemid=75&lang=en

[29] Project Site: http://data.jrc.ec.europa.eu/dataset/jrc-luisa-lf522-soil-retention-ref-2014/resource/d9e7e90d-fc0d-4331-9381-22d4db7bc4d4

[30] Data download: http://data.jrc.ec.europa.eu/dataset/jrc-luisa-lf522-soil-retention-ref-2014/resource/9dbf983b-cdf0-440f-9187-d464f76885f1

- *Irrigation*
    - Global Map of Irrigation Areas (GMIA)
      Various indicators for the irrigated areas are available for download[31]. One set of data provides is the percentage of land irrigated within a grid cell. The grid data are made available at 5 arc min. resolution with a single temporal reference [17]. The data does not distinguish between the type of areas irrigated, i.e. annual or permanent crops or grassland.

4.2.4 Input Factors (F_I)

The nature of input differs between CM and GM.

- **CM Input Factor**

For CM the conditions defining the status of inputs on cropland are largely defined directly in the classification tree. Ancillary data are needed to determine practices increasing C input.

The factors for CM for high inputs with manure range from 1.37 to 1.44, depending on the moisture regime, which is considerable more than the input factors to be used where manure is not applied (1.04 to 1.11)[32]. While Table 5.5 refers to manure, the classification scheme for cropland systems (Figure 5.1) uses the term "organic amendments" instead of "manure" to distinguish between the two high-input classes.

The effect of CM practices on soil organic C-stocks (e.g. irrigation, residue burning/removal, mineral fertilizers, N-fixing crops, organic amendment, cover crops/green manures, low residue crop, or fallow) should only be considered, "…if used in at least 1/3 of cropping rotation sequence."[33]

- o **Statistical Data Sources**
- *Crop residues removed*
    - Eurostat
      An estimate for removed crops and residues is the indicator "bare soil" (code: M_2_1_4) of the "Survey on Agricultural Production Methods" (SAPM) of table "Soil conservation: number of farms and areas by size of arable area and NUTS 2 regions" [ef_pmsoilaa].

      Whether crop residues are removed is further estimated from alternative uses as animal bedding material or used to grow mushrooms. The amount of crop residues removed from the field for animal bedding is estimated as part of the estimates for farm yard manure.

      An estimate for the use as growing material for mushrooms is derived from the mushroom production.

      Another purpose of removing crop residues is for use as fuel.

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[31] Download data: http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm

[32] IPCC, 2006; Table 5.5

[33] IPCC, 2006; Figure 5.1

- *Crop residues burnt*
  - IPCC NGHGI
    IPCC, 2000 documents provide a default for the areas burnt in developed countries as 10%, although cautions that the value may be too high[34]. Given the regulations on burning residues in the field the value of 10% was used as an initial value and gradually reduced to 0% for the year 2010 and following.
- *Low residue crops*
  - Eurostat
    Crops yielding low residues are root crops in general, green maize, vegetables, cotton and tobacco [1].
- *Rotation with bare fallow*
  - Eurostat
    An estimate for bare fields is the indicator "bare soil" (code: M_2_1_4) of the "Survey on Agricultural Production Methods" (SAPM) of table "Soil conservation: number of farms and areas by size of arable area and NUTS 2 regions" [ef_pmsoilaa]. This is not directly the information on bare fallow. An indicator for bare fallow can be derived from combining annual data on NPP with areas on bare arable land.
- *Organic amendments*

  Organic amendments are e.g. farm yard manure, slurry, compost, industrial products, sludge, etc. Not included here are the incorporation of organic material from cover crops, straw or green manure.

  The practices that are included in "organic amendments" are not treated uniformly in the guidelines. For CH_4 emissions from rice cultivation practices, such as the incorporation of straw or green manure, are regarded as of endogenous origin, while compost, farmyard manure, etc. are of exogenous origin. Still, both are treated as organic amendments[35] when estimating CH_4 emissions from rice cultivation. By contrast, when estimating changes in sol organic C-stocks for mineral soils the practices are treated separately depending on their origin.

  - Eurostat
    A collection of data on various nutrients are available from the category "Gross Nutrient Balance (aei_pr_gnb)" which is located under the theme "Agri-environmental Indicators (aei)".

    The data contains the items:

    - Consumption of organic fertilisers (except manure) (tonnes of nutrient) (Code: I_FRT_ORG)
    - Manure input (tonnes of nutrient) (Code: I_MNR)
    - Other nutrient inputs (tonnes of nutrient) (Code: I_OTH)

    The nutrients are N and P. From the data the mass of the source material can be estimate by standard values for N content.

[34] "Currently, it is estimated that 10% of the total agricultural residue is burned in the field in developed countries and 25% in developing countries. These figures may be too high. Good practice suggests that an estimate of 10% may be more appropriate for developing countries." IPCC, 2000, 4A.2.1.1 Choice of Method

[35] IPCC, 2006; BOX 5.2: Conditions influencing CH_4 emissions from rice cultivation

Data on the application of manure can be obtained from the SAPM database ("Solid manure application as % of the UAA: number of holdings and UAA by economic size (SO in euros) and agriculture size (UAA) of farm" [ef_pmmanapaa). The way the item is constructed means that the area of cultivated land on which manure is applied can only be approximated. The data are only available at country level and for the year 2010.

- *N-fertiliser*

  Addition of mineral N-fertiliser. Statistical data contain the total consumption of fertiliser, not the application rate.

  - Eurostat
    One of the conditions used to estimate grassland improvements is the use of inorganic fertilizer. Broad data are provided under the theme of Agro-environmental indicators - Farm Management in table "Use of inorganic fertilizers" [aei_fm_usefert]. The data are available at the level of NUTS 2, starting in 2000 and without distinction of the use of fertilisers.

    Another Eurostat table is "Consumption estimate of manufactured fertilizers (source: Fertilizers Europe)" [aei_fm_manfert]. The data go back to 1985, but only at NUTS 0 and without distinction of the use. Some care should be taken using this data which is associated with the production of fertilisers more than consumption.

  - FAO FertiStat
    Statistics on the use of fertilisers are available by country and with some temporal cover in the FAO FertiStat database[36]. Not all EU28 member states are covered. In contrast to Eurostat data the FertiStat data provide application rates of fertilizer for crops.

  - International Fertilizer Industry Associations (IFA)
    Historical data on fertilizer production, trade and consumption are available from the IFA database[37]. The database contains statistics by country, going back to 1961 in cases.

  - Literature
    For some crops fertilizer application rates are detailed in the report from "Fertilizer Use by Crop at the Country Level (1990–2010)" [18]. Statistical data are available from the Appendix[38] as total amount used and application rate.

- *Practice increasing C-input*

  Practices may increasing C input either by

  a) lifting the level above the amount typically generated by the low residues yielding varieties;

  b) enhancing residue production.

  The examples given for practices that increase C input are grouped into those concerning crop types, soil cover and additional measures.

  - Crops increasing C-input
    The use of high residue-yielding crops, such as cereals, rape seed, sunflower, and N-fixing crops can be derived from crop land occupation (see

[36] Project site: http://www.fao.org/ag/agp/fertistat/index_en.htm

[37] Download site: http://ifadata.fertilizer.org/ucSearch.aspx

[38] Download site: http://www.card.iastate.edu/publications/synopsis.aspx?id=1178

land use factor). Likewise, the presence of grasses in the crop rotation can be found from the share of temporal grass in the sequential development of areas of land occupation.

- ❖ Eurostat
  The practices can be derived from the distribution of crops that are classified as having a high C-input. See data for CM Factor Land Use.

- Soil cover

  The practices enhancing C residue production overlap with those of soil conservation and are often combined with reduced tillage practices, but also applied where conventional tillage is employed. The use of cover crops, green manure or periods of fallow land may be found under this category.

  - ❖ Eurostat

    The table "Soil conservation: number of farms and areas by size of arable area and NUTS 2 regions" [ef_pmsoilaa] contains areas on practices of:

    - cover or intermediate crop
    - plant residues
    - share of Arable Area out of crop rotation
    - normal winter crop
    - bare soil

    The presence of normal winter crops or any other plant cover is taken as absence of bare soil in winter.

- Irrigation

  - ❖ Eurostat
    For the period 1988 legislation (1990-2007):
    Under theme "Land use – Other farmland" table "Irrigation: number of farms, areas and equipment by size of farm (UAA) and NUTS 2 regions" [ef_lu_ofirrig].

    For period 2005 legislation (2005 onwards):
    Under theme "Farm land use – permanent crops, other farmland, irrigation" table "Irrigation: number of farms, areas and equipment by size of irrigated area and NUTS 2 regions" [ef_poirrig].

  - ❖ FAO Aquastat
    The area under irrigation for a wide range of crops is available from the FAO Aquastat database under the variable: Irrigated crop area and cropping intensity. However, data are only reported for a limited number of years.

o **Spatial Data Sources**

- *Irrigation*

  - Corine Land Cover
    The CLC data contains in the classification scheme the class "Permanently irrigated land". Yet, the spatial expression of the class is rather limited.

  - ESA Climate Change Initiative Land Cover
    The ESA land cover map separated rain fed from irrigated cropland in the classification scheme. This allows some indication of irrigated areas, which include flooded rice fields, but not irrigated grassland.

- Land Degradation in Drylands (LADA) Land Use System
  The classification scheme for LADA contains two classes indicating large-scale irrigation of croplands (Class 22 and Class 23). The spatial resolution of the data is limited to 5 arc min.

  A separate layer with the classes of irrigation intensity is available from the layer IRRIT[39], which can be downloaded from the FAO GeoNetwork server.

- *Residue burning*
  - MODIS Burnt Area
    MODIS Burnt Area is available with global coverage as Product MCD45[40]. Data are available for years 2000 and later at monthly intervals (except for 2000 and 2001). With Collection 5.1 data are now at 500m resolution. As regards burning of crop residues the areas are catalogued as QA "Class 5: burned areas detected in agriculture". This class is given the lowest level of confidence of all burnt areas in the QA data.

- *N-Fertiliser*
  - Global Fertilizer and Manure, V1
    Global data on N and P fertilizer application rates between 1994 and 2001 are described by Potter et al., 2010. Spatial data are available at 0.5 deg. for global and continental data[41] [19]. The data are not specific for individual land use types or crops.

- *Organic Amendments*
  - Global Fertilizer and Manure, V1
    Global data N in manure production between 1994 and 2001 are described by [20], which is the companion data to the fertilizer database. Spatial data are available at 0.5 deg. for global and continental data[42] [19] [20].

• GM Input Factor

A factor modifying GM for levels of input is only applicable where the management is classified as "improved". Two levels of input are distinguished:

a) medium

b) high

Effectively, only one input level modifies soil organic C-stocks from the "improved" management level, which is the multiple application of practices that led to classifying the status as "improved" management conditions.

o Statistical Data Sources

See: GM management (multiple application of management practice)

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[39] Download site: http://www.fao.org/geonetwork/srv/en/resources.get?id=37139&fname=irrit.zip&access=private

[40] Project site: http://modis-fire.umd.edu/pages/BurnedArea.php

[41] Download site: http://sedac.ciesin.columbia.edu/data/set/ferman-v1-nitrogen-fertilizer-application/data-download

[42] Download page: http://sedac.ciesin.columbia.edu/data/set/ferman-v1-nitrogen-in-manure-production/data-download

- **Spatial Data Sources**

  See: GM management (multiple application of management practice)

4.2.5 Special Note on Indicator Practices Related to Livestock

Data on livestock number, housing and manure storage facilities form the basis for the evaluation of a number of conditions that influence soil organic C-stocks. Factors used in the estimate of CM and GM practices influenced by livestock are:

Activity	Factor	Indicator Practice
CM	F_I	removal of crop residues (animal bedding)
		organic amendments (farm yard manure)
GM	F_{MG}	long-term heavy grazing (stocking density)
		organic amendments (farm yard manure)

The amount of residues removed from the field is closely linked to the number of animals and the type of housing. Crop residues may be used as roughage in the diet of ruminants or bedding material. The bedding material may be returned to the field as part of farm yard manure applied. The need for bedding material, such as straw from cereals, can be estimated from the form of the manure storage facilities used.

- *Livestock*

  The number of livestock animals is available from several tables of the Eurostat database and from FAOSTAT. A summary of the livestock categories and sources of data is presented in Table 6.

Table 6: Livestock Statistics

LIVESTOCK	**Eurostat AGR_R**	**Eurostat APRO**	**Eurostat EF**		**FAOSTAT**
	ANIMAL	**MT**	**LS_OVLSUREG**	**OLS_LSLUREG**	**PRODUCTION**
IDLABEL	*CodeLabel*	*CodeLabel*	*CodeLabel*	*CodeLabel*	*CodeLabel*
1Cattle	A2000Live bovine animals	A2000Live bovine animals	J02_08Cattle	C_2_HEADSCattle - total	1746Cattle and Buffaloes
2Cows	A2300Cows	A2300Cows			866Cattle
3Mature Dairy Cow	A2300FDairy cows	A2300FDairy cows	J07Dairy cows	C_2_6_HEADSDairy cows	960Dairy cattle
4Other Mature Cattle	A2300GNon dairy cows	A2300GNon dairy cows	J08Other cows, bovine 2 years old and over	C_2_99_HEADSOther cows, bovine 2 years old and over	961Non-Dairy cattle
5Growing Cattle					
6Bovine animals, less than 1 year	A2010Bovine animals, less than 1 year	A2010Bovine animals, less than 1 year	J02Bovine <1 year old - total	C_2_1_HEADSBovine <1 year old - total	
7Bovine animals, 1 year	A2020Bovine animals, 1 year	A2020Bovine animals, 1 year			
8Bovine 1-<2 years - males			J03Bovine 1-<2 years - males	C_2_2_HEADSBovine 1-<2 years - males	
9Bovine 1-<2 years - females			J04Bovine 1-<2 years - females	C_2_3_HEADSBovine 1-<2 years - females	
10Bovine animals, 2 years or over	A2030Bovine animals, 2 years or over	A2030Bovine animals, 2 years or over			
11Bovine 2 years and older - males			J05Bovine 2 years and older - males	C_2_4_HEADSBovine 2 years and older - males	
12Heifers, 2 years and older			J06Heifers, 2 years and older	C_2_5_HEADSHeifers, 2 years and older	
13Buffaloes	A2400Buffaloes	A2400Buffaloes			946Buffaloes
14Live Swine, domestic species	A3100Live swine, domestic species	A3100Live swine, domestic species	J11_13Pigs	C_4_HEADSPigs	1034Pigs
15Mature Swine					
16Breeding sows	A3120Breeding sows	A3120Breeding sows	J12Pigs - breeding sows over 50 kg	C_4_2_HEADSPigs - breeding sows over 50 kg	
17Breeding boars	A3133Breeding boars	A3133Breeding boars			
18Growing Swine					
19Piglets, less than 20 kg	A3110Piglets, less than 20 kg	A3110Piglets, less than 20 kg	J11Pigs - piglets under 20 kg	C_4_1_HEADSPigs - piglets under 20 kg	
20Pigs, from 20 kg to less than 50 kg	A3131Pigs, from 20 kg to less than 50 kg	A3131Pigs, from 20 kg to less than 50 kg			
21Fattening pigs, 50 kg or over	A3132Fattening pigs, 50 kg or over	A3132Fattening pigs, 50 kg or over			
22Pigs - others			J13Pigs - others	C_4_99_HEADSPigs - others	
23Sheep	A4100Live sheep	A4100Live sheep	J09Sheep	C_3_1_HEADSSheep - total	976Sheep
24Goats	A4200Live goats	A4200Live goats	J10Goats	C_3_2_HEADSGoats	1016Goats
25Poultry			J14_16Poultry (1000 heads)	C_5_1000_HEADSPoultry - total	2029Poultry Birds + (Total)
26Chicken					1057Chickens
27Broilers			J14Poultry - broilers (1000 heads)	C_5_1_1000_HEADSPoultry - broilers	
28Laying hens			J15Laying hens (1000 heads)	C_5_2_1000_HEADSLaying hens	
29Poultry, other			J16Poultry - others (1000 heads)	C_5_3_1000_HEADSPoultry - others	
30Equidae			J01Equidae	C_1_HEADSEquidae	

Eurostat Database: http://ec.europa.eu/eurostat/data/database

AGR_R: Regional Agricultural Statistics
Animal populations (December) by NUTS 2 regions [agr_r_animal]
Land use by NUTS 2 regions [agr_r_landuse]

EF: Farm Structure
Livestock: number of farms and heads by livestock units (LSU) of farm and NUTS 2 regions [ef_ls_ovlsureg]
Livestock: number of farms and heads of animals by livestock units (LSU) of farm and NUTS 2 regions [ef_olslsureg]

APRO_MT: Agricultural Production, meat
Cattle population - annual data [apro_mt_lscatl
Pig population - annual data [apro_mt_lspig]
Sheep population - annual data [apro_mt_lssheep]
Goats population - annual data [apro_mt_lsgoat]

FAOSTAT
Domain Production, Live animals http://faostat3.fao.org/browse/Q/QA/E

Note: state June, 2016

The livestock categories and sub-categories follow the Eurostat nomenclature and are largely compatible with IPCC. The category "Equidae" is not sub-divided because sub-categories, such as horses, asses or mules, are not represented in the Eurostat Farm Livestock tables [ef_ols].

The statistical unit may be the number of animals or heads present on a specific date or expressed as *Livestock Units* (LSU). LSU are used to better compare livestock of different species and ages. For data used by Eurostat coefficients to convert animals (heads) to LSU are given for most farm animals[43].

LSU are used as part of the Livestock Density Index[44]. In combination with information on animal housing and fodder production the index can serve as an indicator for pressure on grazing land. In Eurostat data this is accounted for by the Grazing Livestock Density Index[45]. Data on the Livestock Density Index are available from Eurostat[46]. The data are at the level of countries and no data are prepared before 2005. To improve the spatial and temporal coverage the index was calculated from the source tables.

- *Housing*

Data on animal housing are available from the SAPM survey in table "Animal housing - cattle: number of farms and places by cattle size class, agricultural size of farm (UAA) and NUTS 2 regions" [ef_pmhouscatlaa].

The time spent in the field, and therefore periods when housing facilities are not used and manure is not stored, is provided in the table "Animal grazing on the holding: number of farms and area grazed by duration, economic size of farm (SO in euros) and NUTS 2 regions" [ef_pmgrazecs].

The information is restricted to cattle. One may assume that other grazing animals (sheep, goats) are kept on grassland all year.

For pigs the share between the type of animal housing (types: partially slatted floors, completely slatted floors, straw beds and other) can be obtained from the table "Animal housing - pigs: number of farms and places by pig size classes, economic size of farm (SO in euros) and NUTS 2 regions" [ef_pmhouspigec].

For laying hens the database provides statistics on places or heads for straw beds, battery cages with manure belt, with deep pit, with stilt house and housing other than straw beds in table "Animal housing - laying hens: number of farms and places by laying hens size classes, economic size of farm (SO in euros) and NUTS 2 regions" [ef_pmhouslhenec].

The tables provide data on animal housing by holdings, places and the number of animals (head), but only for the livestock category, not sub-categories, and for the survey year 2010. More spatial (NUTS 3) and temporal (2000, 2003 and 2010) detail an animal housing is available form table "Manure storage facilities by NUTS 3 regions" [aei_fm_ms]. However, the table item are holdings. Since a holding can contain more than one type of storage facility the use of the facilities is not evident from the data.

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43 URL: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU)

44 URL: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_density_index

45 URL: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Grazing_livestock_density_index

46 URL: http://ec.europa.eu/eurostat/data/database?node_code=tsdpc450

An assessment of data from a different source (expert group and questionnaire) of the types of animal housing and manure management systems in Europe is presented in a publication from [21].

- *Manure storage facilities*

  An indication of the distribution of manure storage facilities may be obtained from the Eurostat SAPM table "Manure storage and treatment facilities: number of farms and areas by economic size (SO in euros), agriculture size (UAA) of farm and NUTS 2 regions" [ef_pmmanstoaa]. The data concern the existence of a type of storage facility at a farm rather than the actual use. A holding may well be equipped with more than a single storage facility and the proportion of a single facility is not available from the data.

  The type of animal housing and the manure storage facilities are closely related to the concept of the IPCC Manure Management System (MMS). A spatially unrefined distribution (Eastern and Western Europe) of MMS Usage for the main livestock categories (Dairy cows, Other cattle, Buffalo, Market swine and Breeding swine) is presented in the tables of "Annex 10A.2: Data underlying methane default emission factors for Manure Management" [1]. The data for Western and Eastern Europe are reported to originate from national GHG inventories submitted to the secretariat UNFCCC in 2004.

- *Removal of crop residues (animal bedding)*

  The amount estimate of crop residues removed from the fields to be used as animal bedding can be estimated from the number of animals and the type of animal housing.

  Bedding material is used in "solid storage" and "deep bedding" manure management systems (MMS)[47]. For the regional distribution of MMS by livestock category IPCC, 2006 Guidelines, Annex 10A.2 only lists values for "solid storage". For Western Europe the share is 35.7%. The use of a regional value without an indication for changes over renders these values very vague. There are large differences in the use and classification of livestock housing systems between countries, but also over time. For example, in Germany the share of solid storage MMS for dairy cattle was estimated to drop from 33% in 1990 to 8% in 2010 [22]. In France, the share of solid manure with litter for dairy cattle was 73.9% in 2003 [23]. This shows that due to the semantics it is not easy to compare data from different sources.

  As litter only straw is considered here, although other materials are used. The amount of straw required depends on the type of resting place in a stall and strongly varies. For dairy cows kept in a bedded yard 20 $kg\ straw\ animal^{-1}\ day^{-1}$ are quoted and 2.5 $kg\ straw\ animal^{-1}\ day^{-1}$ for a straw mat [24]. For deep bedding in cubicles the amount of straw is estimated to range between 0.3 and 0.8 $kg\ animal^{-1}\ day^{-1}$, while for raised bedding 0.15 to 0.5 $kg\ animal^{-1}\ day^{-1}$ are recommended [25]. For the UK the amount of straw used as bedding material was estimated at 8.3 $kg\ animal^{-1}\ day^{-1}$ (1,500 $kg\ straw\ animal^{-1}$ for 6 months; [26]). In the estimates the type of animal housing was not specified.

[47] IPCC, 2006: EQUATION 10.34

Based on an N-content of 0.6 % N of dry matter straw[48] and the dry matter fraction of the harvested product[49] the amount of bedding material that corresponds to the quantity of N in litter is:

dairy cow:	2.0 t straw animal^{-1} year^{-1}
other cattle:	1.2 t straw animal^{-1} year^{-1}
breeding swine:	1.5 t straw animal^{-1} year^{-1}
market swine:	0.2 t straw animal^{-1} year^{-1}
sheep:	0.2 t straw animal^{-1} year^{-1}
goats:	0.1 t straw animal^{-1} year^{-1}
equidae:	1.4 t straw animal^{-1} year^{-1}

These figures are rough guides to estimate average conditions. According to [1]; p. 10.66 the amount of bedding material needed for deep bedding systems could be twice as much as for other solid manure systems. This indicates the large uncertainties in the values.

The amount of crop residues that is removed annually from the field to serve as livestock bedding material can then be estimated from the number of animals in housing and MMS that use straw and the time spent under these conditions. For grazing animals the time spent on pastures (from Eurostat table [ef_pmgrazecs]) correspondingly reduces the demand for bedding material. As an indicator combining the use of the MMS and the time spent in the system, i.e. not grazing, is given by the fraction of the MMS in Annex 10A.2 [1].

- *Organic amendments (farm yard manure)*

The area where manure is applied is provided for 2010 in the Eurostat table "Solid manure application as % of the UAA: number of holdings and UAA by economic size (SO in euros) and agriculture size (UAA) of farm" [ef_pmmanapaa]. The area of slurry application is presented in table "Slurry application as % of the UAA: number of holdings and areas by economic size (SO in euros) and agriculture size (UAA) of farm" [ef_pmslurapaa]. The data are only available at national level. For more detailed data the amount of manure and slurry from livestock can be estimated based on the data that were also used to estimate removals of crop residues as bedding material.

The quantity of managed manure N (*kg N year^{-1}*) available for application to soils, or other purposes, is estimated following Equation 10.34 of IPCC, 2006. The equation provides an estimate of the amount of N from manure, but not where it is applied or the application rate.

- *Long-term heavy grazing (stocking density)*

The pressure on grassland from grazing is estimated by the index of grazing intensity. Grazing intensity is the grazing livestock stocking rate for the period of grazing. The grazing livestock stocking rate gives the number of grazing livestock (in *LSU*) over the grazed area.

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[48] IPCC, 2006; Table 11.2 for wheat straw
The N-content used by Webb, 2001 was 0.5% N in dry matter straw, which leads to the differences in the figures of the amount of bedding material used here and quoted by Webb, 2001.

[49] IPCC,2006: Table 11.2

The grazing intensity is moderated by the duration of grazing duration relative to the length of growing period of grassland. The length of the grassland growing period is a spatial data layer and the moderation is only performed in the spatial domain.

Grazing takes place not only on grassland belonging to a holding, but also on common land. The share of grazing on common land can be expected to vary between regions, but also between livestock categories and age group within a category. Data on grazing on common and is not directly available from Eurostat tables. The Eurostat table [EF_PM_COMLECS] concerns only marginally common land, since it provides only statistics on the livestock of holdings that practice grazing on common land.

- **Spatial Data Sources**

- *Livestock Density*

  - Gridded Livestock of the World (GLW)
    Spatial data on livestock densities with global cover at 30 arc sec. has been processed by [27]. The reference year of the updated global livestock density data is 2010. Data are available from the Geo-Wiki[50] and the FAO GeoNetwork[51] servers. The FAO GeoNetwork server also contains data from previous processing and with earlier reference years. The notes on extracting temporal changes in local livestock densities from the various data sets are available from the meta-data.

  - Land Degradation in Drylands (LADA) Land Use System
    The classification scheme for LADA contains three levels of livestock density (low, moderate and high) for forest, grasslands, shrub, agriculture, sparsely vegetated areas and bare areas.

    The distribution of livestock species, but not density, is available from the layer LVSTSP available from the FAO GeoNetwork server[52]. The spatial resolution of the LADA data is limited to 5 arc min.

  - Manure Production
    A global spatial data set on N in manure production is available as a single layer covering the period 1994 to 2001[53] ([20]; [19]). Direct use of the data is made disadvantageous by the rather coarse resolution of the data. By reversing the computations the amount of animal manure produced by location can be estimated from the nutrient content and the excretion rates used.

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[50] Download site: http://www.livestock.geo-wiki.org/

[51] Download site: http://www.fao.org/geonetwork/srv/en/main.home

[52] Download site: http://www.fao.org/geonetwork/srv/en/resources.get?id=37139&fname=lvstt.zip&access=private

[53] Download site: http://sedac.ciesin.columbia.edu/data/set/ferman-v1-nitrogen-in-manure-production/data-download

5 Processing Data

Statistical and spatial data need to be further processed to comply with the requirements for data, which are to be

- adequate (representing land use categories and changes);
- consistent (all land within a country should be included);
- complete (time-series) and
- transparent (detailed meta-data).

The aspects of being adequate and complete are more widely satisfied than those of consistency and transparency. For statistical data the land use categories are generally well represented, which is not necessarily the case when using spatial land cover data for the purpose of representing land use. However, for realizing an Approach 3 the use of spatial land cover data to estimate spatially explicit changes is almost unavoidable. Issues of data consistency become important when merging data from different sources. This is often necessary to establish a complete time series without reverting to an extrapolation of trends, i.e. estimate beyond the range of the available data. In particular, differences in the nomenclature used or the sampling strategy applied can lead to largely different data and in cases also trends.

In the context of this work data processing is divided into two distinct phases:

a) processing statistical data;
b) processing spatial data.

Statistical data here means data representing an administrative unit. The data may be either reported for that unit or aggregated to that unit from smaller administrative units or spatial data. The objective of processing statistical data is to provide a complete time-series of data, without missing data or discontinuities.

Spatial data are processed to provide information with complete and consistent coverage for land use, management and input factors and changes in any of the factors. Statistical and spatial data should be consistent with one another in the representation of the various activity categories.

For the largest part data are processed in a GIS. Only the task of importing statistical data from the various sources is implemented in a dedicated database management system. For the treatment of statistical data by the database and the GIS a simple data structure was created that can be processed in either environment. Instances of the structure are created for each item of the data collection. A structure comprises of a stack of 2-dimesional tables. Each table contains as rows / records the NUTS units of a given level and as columns / fields the years. The tables contain the data for a single NUTS level and the stack is the arrangement of the tables in order of NUTS level. Ancillary files further define the arrangement of the data in the tables. When processed in the GIS the data are stored in the same file format used for spatial data. While the file is that of spatial data the content is statistical data. There is no spatial correlation between the data of a table and spatial analysis tools should not be applied. Rather, the statistical data is used as attributes to spatial units. The advantages of using the structure tables in ASCII format for statistical data are that a single environment can be used for a seamless integration of statistical data with spatial data and considerable savings in file size and processing time. The same could not be achieved when leaving the statistical data in a database format.

5.1 Processing Statistical Data

The purpose of processing statistical data is to provide a consistent and complete time-series of data from which land use, management and input factors for estimating changes in soil organic C-stocks can be derived. The statistical data used to process is a summary of information collected through surveys, inventories, reports, etc. The information is processed to represent a situation for a given year and representative for a defined and invariable statistical unit. In case data cover other temporal periods or statistical unit estimates of annual data for the statistical units are used.

5.1.1 Statistical Unit

The statistical units are areas of the NUTS units defined by Eurostat[54]. The spatial data are publicly available for download[55] up to Level 3 (small regions for specific diagnoses).

The most general administrative unit processed is a country. IPCC at times uses generic or default data for whole regions, for example for the shares of manure management systems. Such regional units are not processed at this stage. The amount of data below Level 2 (basic regions for the application of regional policies) is very limited in the Eurostat database. As a consequence, the processing of statistical data is limited to country, NUTS 1 and NUTS 2.

5.1.2 Data Collections

The data available from the various sources are divided into collections. The collections used to process statistical data are:

1. Land Areas
    1.1. Land use, aggregated from Corine LC
    1.2. Land use, areas
    1.3. Crops, areas
    1.4. Crops, production
    1.5. Crops, yield
2. Livestock, head
3. Tillage practices, area
4. Fertiliser
    4.1. Mineral, consumption
    4.2. Organic, consumption
    4.3. Manure, input
    4.4. Other, input

[54] Project site: http://ec.europa.eu/eurostat/web/nuts/overview

[55] Download site: http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts

5. Irrigated areas
6. Soil conservation, area
7. Fertiliser application N-rates
8. Grazed areas
9. Farm yard manure application, area

Statistics for crops not only cover areas, but also include data on production and yield. Yield is required to characterise some conditions for setting management and input factors, such as the amount of residues removed from the field. There is generally more data available on production than yield. For this reason production statistics for crops are included to increase the number of data for yield.

The data of each collection are subjected to several stages of processing. The stages are:

- Import
- Fuse
- Complete

There is a distinct difference between the data import and the fuse and complete stages: the import is realised using a database while for the data fusion and completion a GIS is used.

5.1.3 Data Import

The purpose of the data import stage is to adjust data from the various sources to a common and consistent typology and save the results in a standardised structure.

The options for downloading data from the web-sites of data providers, such as Eurostat or FAOSTAT, are quite varied. Hence, all data are downloaded manually. When selecting items the download may be limited to the number of records or a maximum file size. Usually such limits do not exist when an option for bulk download is offered[56].

Where possible data are exported to a *comma-separated values* (CSV) file. The data exported may comply with the CSV specifications, but may also be just store the data in ASCII code as a text file with a separator. Particular items to observe are the number format, here the separators for thousands and decimals, and the coding for alpha-numeric data. Where the original alpha-numeric data contains non-ASCII characters they may not be represented in the data and a Unicode character set should be used. The use of a comma as a field separator can lead to ambiguities when the character is used as part of alpha-numeric data, such as labels, and the fields are not delimited. Where possible the use of a semicolon or tabulator as field separator is preferable to a comma. All line endings are set to CR+LF (0D 0A), indicators for empty fields are removed to set empty data to NULL (00).

These data are imported as tables into a *Relational Database Management System* (RDBMS) to create consistent data in standardised structure and format. The import of the text files

[56] Eurostat bulk download site:
http://ec.europa.eu/eurostat/estat-navtree-portlet-prod/BulkDownloadListing

The imported data is then transferred to a normalised data model. One task in the process is to reverse any pivoting of data, which occurs frequently for years, i.e. years form individual fields under which data for that year are reported. To automate and systematise importing the files graphical interface are created for each data source. An example for the form used to import data from the Eurostat Eurofarm (Farm Structure) data is presented in Figure 28.

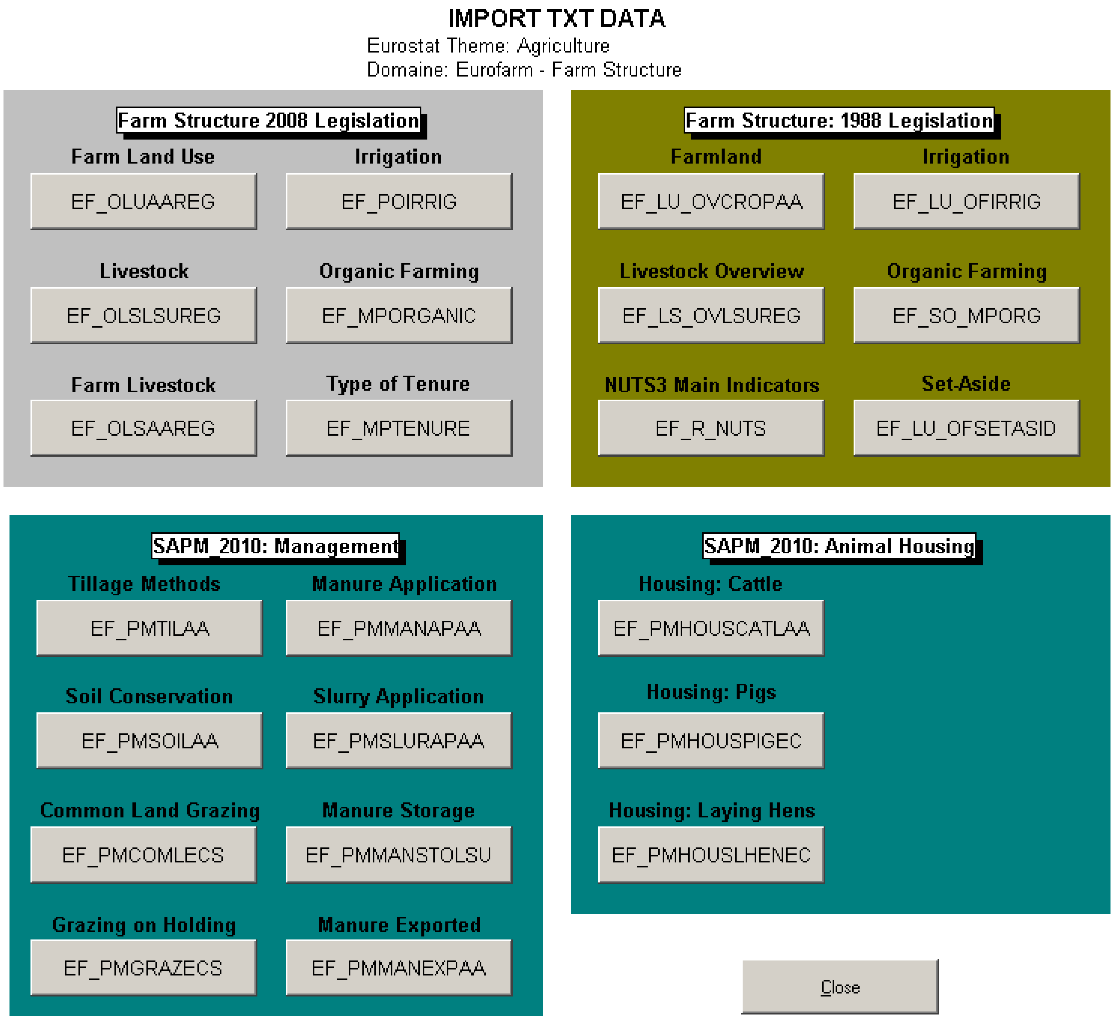

Figure 28: Form used to import Eurostat Farm Structure data to database format

The procedures for importing the data from text files are very simple. The data are arranged to a common structure and field names and types to facilitate integrating the data into a database. During the import stage data values are not evaluated or modified other than the format type.

In the database data are adapted to comply with set standards for:

- consistent categories for comparability of data from different sources;
- common classification of typological data;
- standard data units for numerical data;

- defined data format types;
- assigned to reference administrative units.

From the database the data are exported to a standardised file structure and fixed format for further processing as spatial data. The export function uses forms to access the procedures. For each group of data general forms are defined, which are independent of the data source. An example of the general data form for exporting land use and crop data in design mode is given in Figure 29.

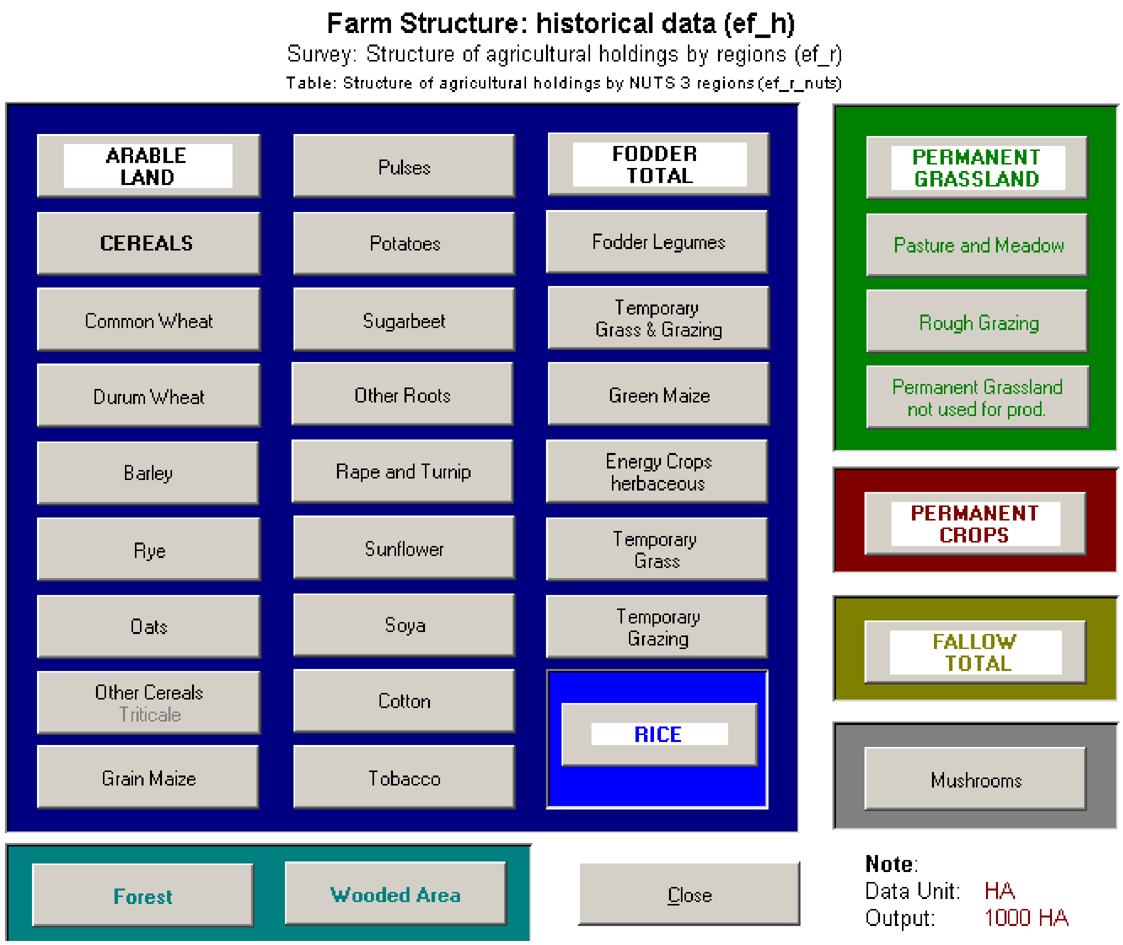

Figure 29: General form for exporting Land Use and Crop data from database to data exchange structure

These general forms are then adapted to the specific characteristics of the source of data and use look-up tables to standardise categorical data. Items not available from the source data are simply masked when running the form. The options available for exporting the historical data of the Farm Structure Survey from table [ef_r_nuts] at runtime are presented in Figure 30.

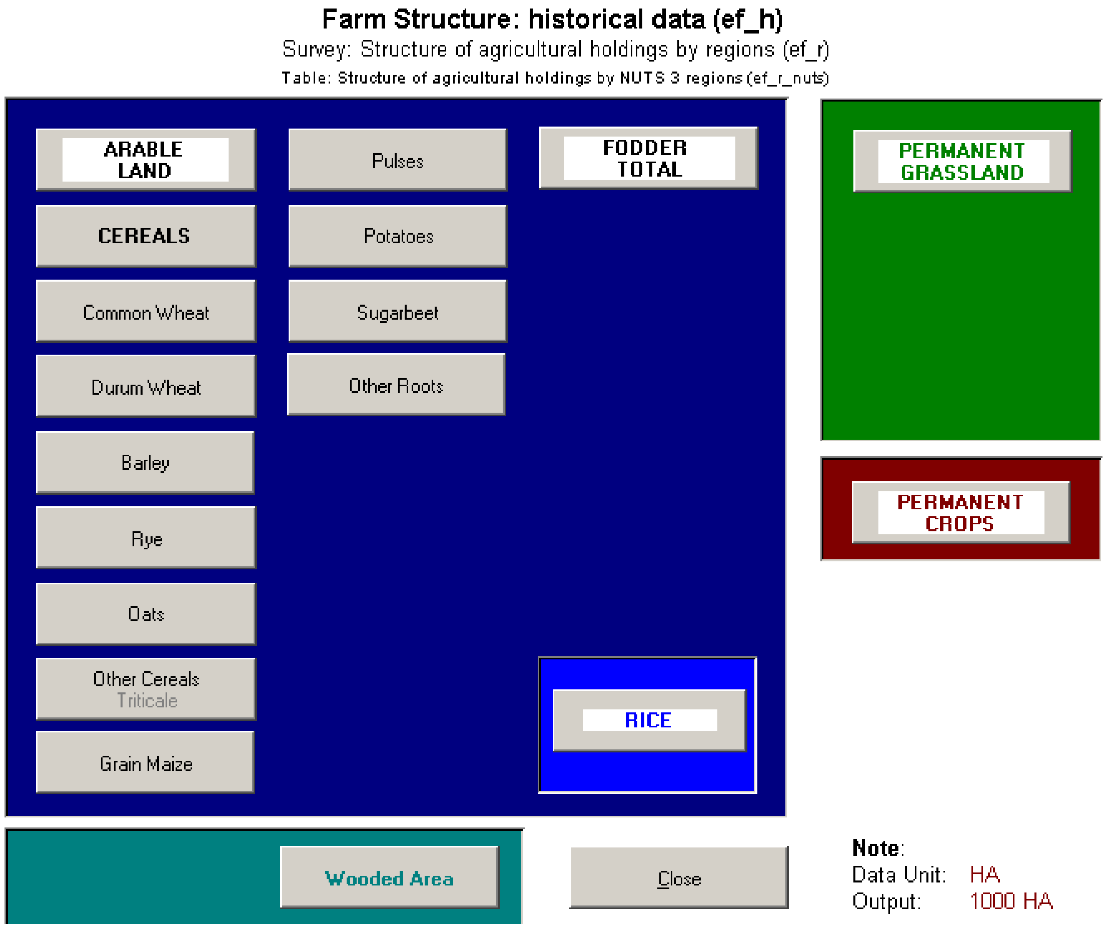

Figure 30: Form for exporting Land Use and Crop data from historical Farm Structure Survey to data exchange structure at run-time

The use of largely automated procedures for importing data from the various sources to a database and transferring the data to a structure than can be readily accessed has a notable demand for resources in the initial implementation phase of the task. However, it greatly reduces the risk of accidental errors when processing the source data and improves the transparency of the whole process. The processing applied are simply the procedures and methods attached to the form. The initial investment provides returns when the source data change or additional data are added. It further offers a relatively undemanding and schematised path to extending the temporal range of data in the processing database.

5.1.4 Data Fusion

None of the databases of statistical data were found to provide adequate, consistent and complete data covering all aspects of implementing a Tier 1 method. Data from the different sources forming a collection are therefore fused to a single set.

When combining data from different sources some potentially problematic conditions are assessed:

a) more than one value for the same item;

b) missing data in one data set filled with data from another source;

c) no data for an item.

Where more than one value for an item and date is available from different sources these values may not be identical. Such differences may have many causes, minor differences may be caused by rounding data, larger differences from the use of different measurement units. The issue is addressed simply by defining a strict hierarchy for fusing data. As primary source data from the Eurostat database is used, which is for many items the Farm Structure [EF] domain. Data from more recent tables are given priority over data from older versions, hence data reported under the 2008 legislation takes precedence over data reported under the 1988 legislation when reported for the same year.

In case data are missing in the primary source but available from another source the data are preliminarily added. Where none of the sources offers data for an item and a date the conditions is marked by assigning a code for missing data. The preliminary fused data is then subjected to a statistical assessment to validate the structure of NUTS levels, identify outliers and complete a time-series for NUTS 2.

5.1.5 Complete Data

The data for each collection are completed by assessing the following aspects:

- Consistency of structure
- Time series
- Change analysis
- Completeness of entity

On overview of the steps performed for processing statistical data is given in Figure 31.

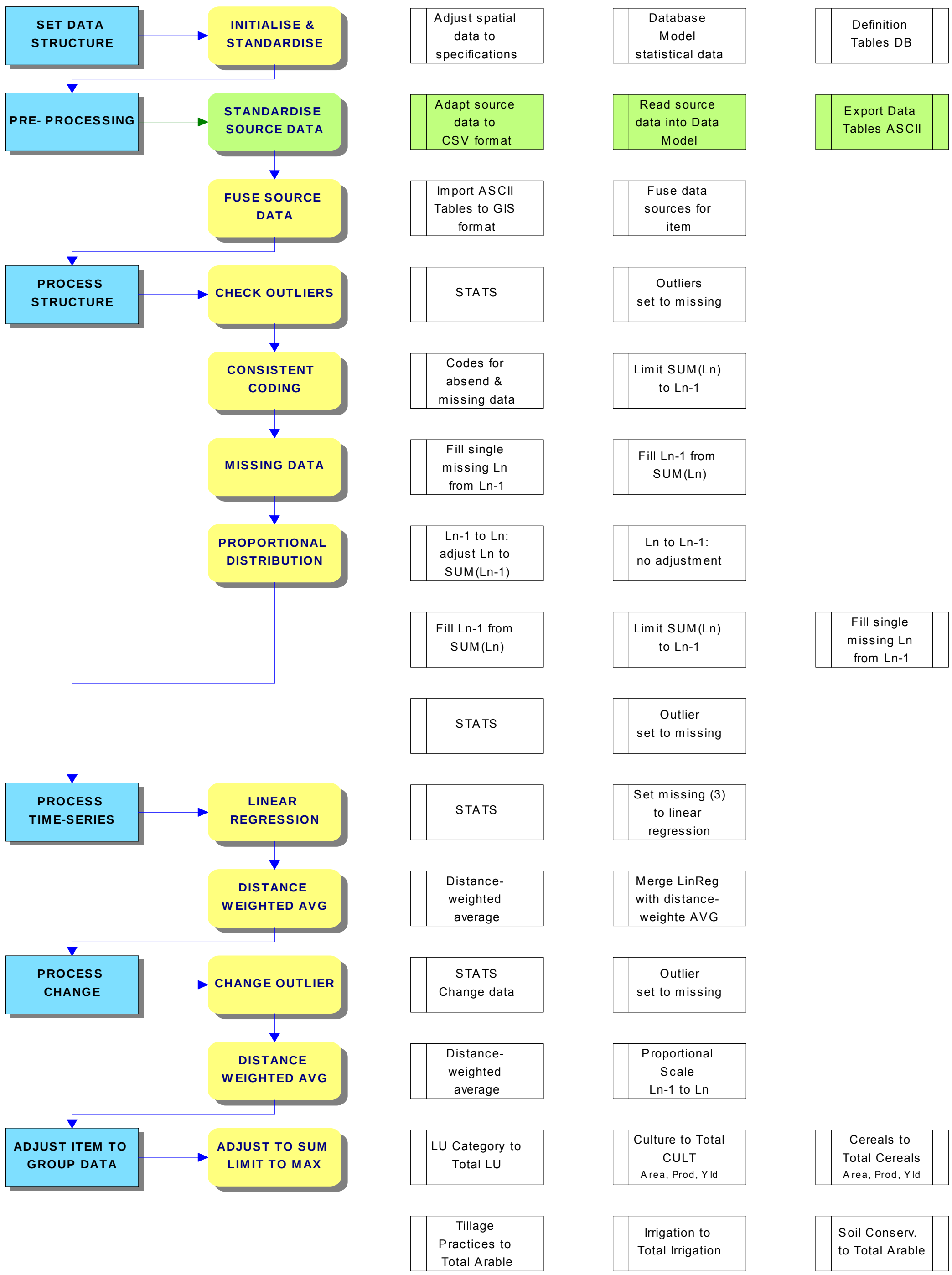

Figure 31: Steps of processing statistical data

The steps are the same for all types of data, but the procedures applied for areas and production with respect to analysing the structure are more extensive than those for yield. The reason is that a yield for one level can rarely be estimated from yield data for another level without data on area and production. In this case yield data may be recovered directly from area and production data.

- **Consistency of Structure**

The NUTS levels form a nested structure where a higher level unit is unambiguously linked to one or more units of the next level. The link is usually *1:many*, but in some cases also 1:1. The important part is that a NUTS unit exists at all levels with a unique code for the unit at that level, even when the spatial element of the units of a lower level is that of the higher level. As a consequence, the area (production) of a land use category of a level should be the sum of the areas (production) of that land use category of the units of the next lower level. The units formed by countries is considered the top unit of level 0.

Data are more readily available for national statistical databases, both in thematic variety and temporal coverage. The procedure therefore aims to produce a consistent structure of values for all NUTS units and between levels.

The steps of processing are:

a) Process within level

The data fused from the various sources is assessed for distinct deviations from the general range of values, which are treated as outliers. The indicators calculated to highlight possible outliers are:

- standard deviation (2.0);
- distance-to-mean (0.2);
- Mahanalobis distance (3.0).

The statistics are only used when more than a minimum number of values (6) are available. The implementation allows setting parameters for all statistical indicators. From experience the range limits given above are used at this stage for most data. The limits are fairly generous and intended to identify values reported in different units.

b) Process between levels

Next, the consistency of values between levels for a given year is assessed. The NUTS data model implies that for a given category the area of a higher level is the sum of the areas of the next lower level. In the assessment data for a higher level is given priority. The conditions assessed are:

i. For a given year the use of values set to mark absent data and missing values are assessed and adjusted. Coding instances of missing data with a zero (0) value is a widespread practice. The data processing treats zero values as a reported absence, e.g. that a crop is not grown within the administrative unit and the area for the crop is thus zero (0). This is an essential step which affects all subsequent processing.
Identifying zero values set for missing data is based on the presence of non-zero values within the NUTS structure:

⇨ If a non-zero value is reported at a Level n+1 the value for Level n cannot be zero. If it is the value for Level n is set to "missing data".

⇨ If a non-zero value is reported at Level *n* the values at Level n+1 cannot all be zero. If this is the case all values at Level n+1 are set to "missing data".

⇨ If the value at Level n is set to zero and the values at Level n+1 are zero or missing all values for Level n+1 are set to zero.

ii. For a given year and Level n values exists for all units of the next Level n+1 except for one:

⇨ The value of the unit at Level n+1 is set to the difference of the area for the unit at level n and the sum of all areas with data at Level n+1.

iii. For a given year and Level n a value exists, but values for Level n+1 are only available from other years:

⇨ For the given year the values of the units at Level n+1 are set by proportionally distributing the average of the Level n+1 for years with data by changes in the values for Level n values.

- **Time series**

A complete time series of data is constructed by estimating values for instances of missing data. The values are estimated for each NUTS within a level. The means used are a weighted average and a linear regression.

a) Weighted average

Values for years with missing data are estimated from values of years with valid data by computing a distance-weighted average. The distance is the number of years of a year with missing data to the previous and next years with valid data.

c) Linear regression

A linear regression is computed from valid values over a whole period. The values are used as estimates for missing data only under the following conditions:

- the regression coefficient is significant at 95% confidence level;
- a minimum of 6 valid values over the period;
- for a distance of 3 years or less to valid data.

Where possible data should only be interpolated between years with valid data. Extrapolating data beyond the limits of years with data was found to be lead to misleading values when there was a discontinuation of trends, such as the changes to the agricultural sector before and after the early 1990s in Eastern Europe.

- **Change analysis**

The complete time series is subjected to a statistical analysis analogous to the analysis applied to the fused data. When values are found to be outside the accepted range these values are replaced by a distance-weighted average.

- **Adjust items to thematic group**

Individual data items are adjusted to the thematic group they belong to. The adjustments are based on the assumption that data available for groups of items are more frequently and consistently available than for the individual members.

There are two types of data adjustments carried out:

a) Proportional adjustment to group area or production

When data are available for all items of a group the sum of the group / category items should correspond to the area or production of the total group / category. Deviations of the sum are adjusted by proportionally distributing the difference to the individual items. This is the case for example for land use categories. Due to their prevalence in agricultural production systems a group of cereals is used to adjust individual cereal crops.

b) Limit to group area or production

When the items are inadequate to define a group the sum of the items should not exceed the area or production of a more general entity. If it does the item values are limited to the general entity. An example is the area of manure application, which should not exceed the area of cropland and managed grassland.

At the end of the processing stage a complete time-series of statistical data without instances of missing data should be available. This data forms the input to the spatial analysis part of the data processing procedure.

5.2 Processing Spatial Data

The purpose of processing spatial data is to process all aspects of CM and GM activities with spatially explicit information on location and occurrence of change. This demand for a spatially explicit change analysis somewhat differs from Reporting Method 2. In reporting method 2 the spatial units are defined by the activity as a whole. This practice is suitable to report changes at the level of activities, but not to estimate the effect of changes in management and input within an activity. According to Approach 3 land use changes should be spatially explicit. This approach should be broadened to encompass all elements of a land uses system, i.e. land use category, management practice and input level. Such information is generally not available as spatial explicit data. The task of processing of spatial data is, therefore, to generate spatially explicit data layers of all elements that affect changes in soil C-stocks for CM and GM.

The principle of the spatial analysis of changes to soil organic C-stocks is presented in Figure 32.

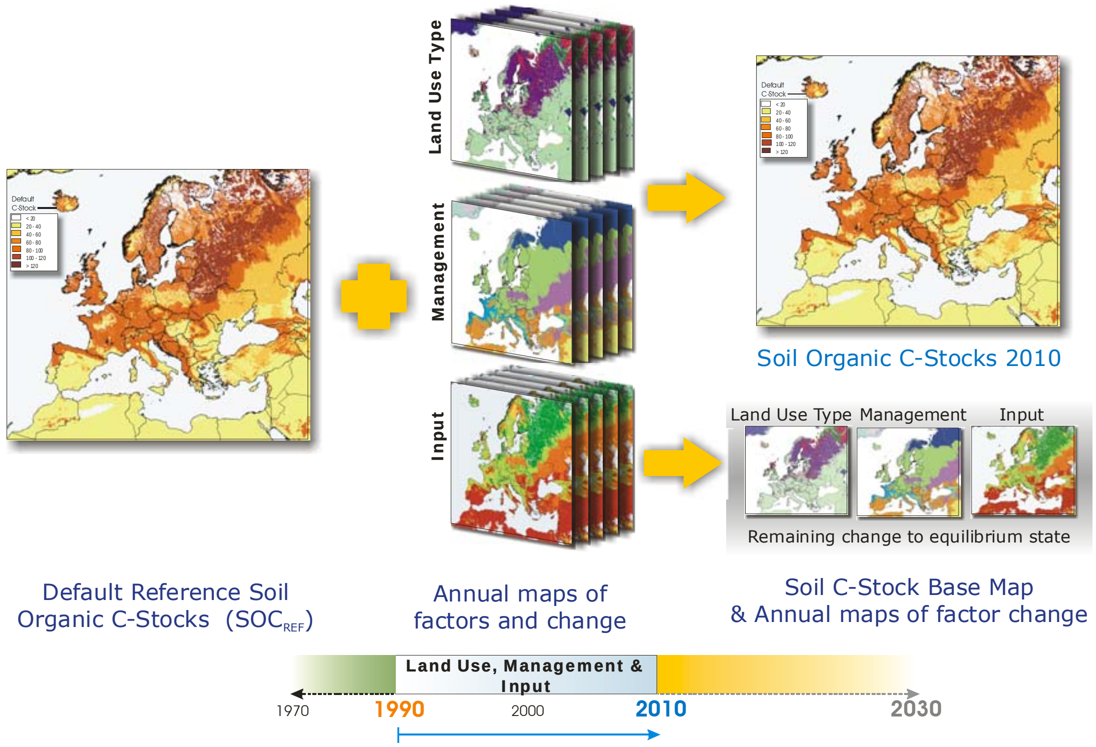

Figure 32: Principle of processing spatial base layer for soil organic C-stocks

The initial element of processing changes in soil organic C-stocks is a map of Default Reference Soil Organic C-Stocks. To this map changes in land use category, management practice and input level are applied on an annual basis. With a transition period of 20 years for changes to C-stocks the annual changes to the C-stocks are 5% of the potential change.

The starting year for a base map of soil organic C-stocks for 2010 is thus the year 1990. Changes are processed annually. Because status and change of C-stocks for a given year depend on the status and change of C-stocks plus influencing factors in previous years such data layers need to be maintained.

5.2.1 Common Characteristics of Spatial Data

All spatial data are in raster format and conform to common specifications with the following parameters:

Data format:	Raster
No. of columns:	5900
No. of rows:	4600
Reference system:	ETRS 89 LAEA
Reference unit:	meter
Min. X:	1500000.0
Max. X:	7400000.0
Min. Y:	900000.0

Max. Y:	5500000.0
Resolution:	1000.0

The area covered by the spatial frame is depicted in Figure 33.

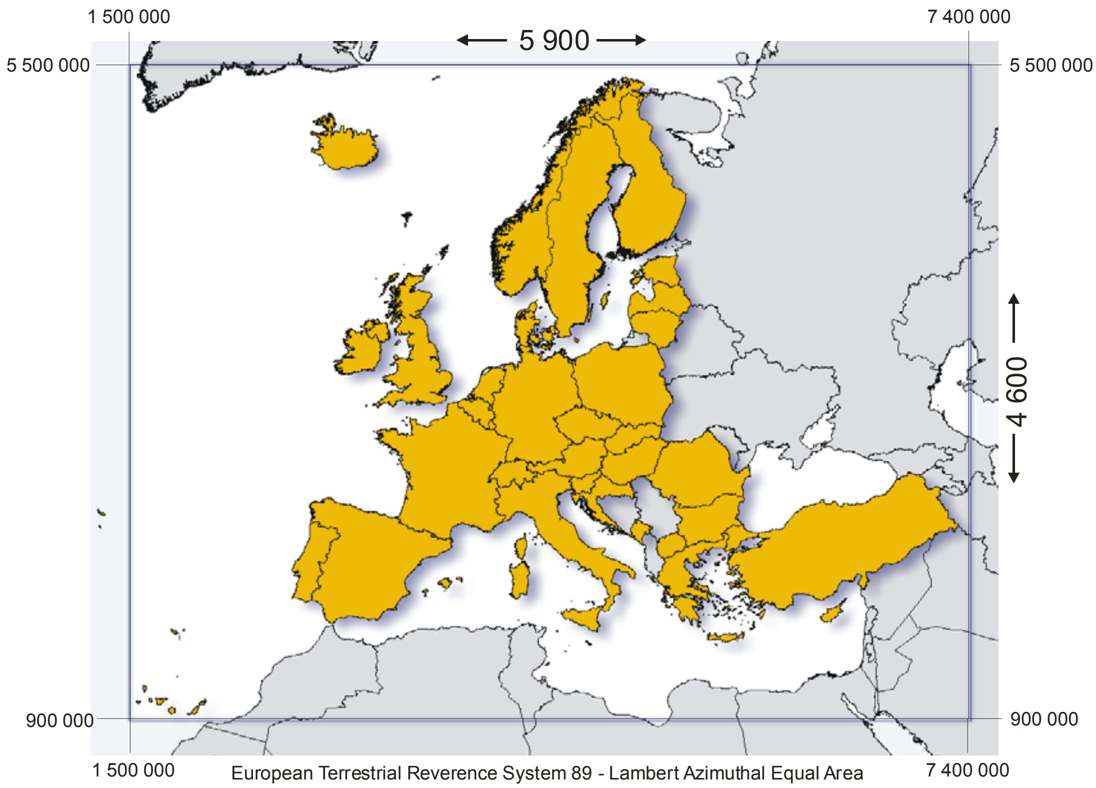

Figure 33: Coverage of Frame for processing spatial data

The spatial frame of the data was adjusted to the extent of the *European Environment Agency* (EEA) CLC2000 layer [28]. The grid spacing is 1 km and the projection is compatible with the specifications of the INSPIRE Directive (*European Terrestrial Reference System 1989* (ETRS89) *Lambert Azimuthal Equal Area* (LAEA) Coordinate Reference System; [6]). The frame covers, candidate countries, but not all overseas areas.

All spatial data, also ancillary data, are processed to comply with these specifications. To avoid any border effects of some spatial procedures the size of the working frame is slightly larger. From the processing frame the area of interest is then extracted.

5.2.2 Principles of Spatial Allocation

For the spatial allocation a multi-criteria analysis within the framework of a *spatial decision support system* (sDSS) was used. The method is based on a multi-objective/multi-criteria evaluation decision support analysis [29]. In a DSS a decision is made following a set of rules, which are structured by one or several objectives ([30]; [31]).

The area of spatial allocation is the NUTS 2 unit. Each NUTS 2 unit is processed separately for each year of the data period. The objectives are the given by the set of items (attributes) that are allocated within a NUTS unit. Hence, the number of objectives ranges from one, for farm yard manure, to 20, for the allocation of crops.

For each attribute the level of association with the properties of each location within a NUTS 2 unit is determined. The association between attributes and locations is determined by a set of defined criteria. The choice is made through the evaluation of these criteria. The objectives are in competition for a location, because the extent of the NUTS element is limited. Conflicts in the choice of allocation between attributes are resolved by ranking the level of association of an objective with a location.

The level of association is determined by sets of constraints and factors. Constraints are conditions that negatively affect to allocation of an attribute to the location. Factors are conditions that favour the allocation. In the GIS used for this study constraints are of data type Boolean and factors may be expressed on a continuous scale. Criteria constrains, therefore, act as geographic masks on which the criterion factors take effect or which completely exclude areas from the allocating process.

Where factors are concerned there is rarely a particular or precise value that defines a location as either meeting the requirements or not. An example is the suitability of slope for arable use. To process imprecise and uncertain conditions of factors fuzzy set theory is used to define the membership. Applying fuzzy set theory to mapping soil properties is not new. An overview of uses of the approach is given by [32]. Fuzzy sets and logic were also applied to land evaluation to estimate the suitability of an area for a specific land use ([33]; [34]; [35]). Fuzzy logic to define a membership function (MF) can be of different types. A graphical presentation of a sigmoidal and J-shaped MS function is given in Figure 34.

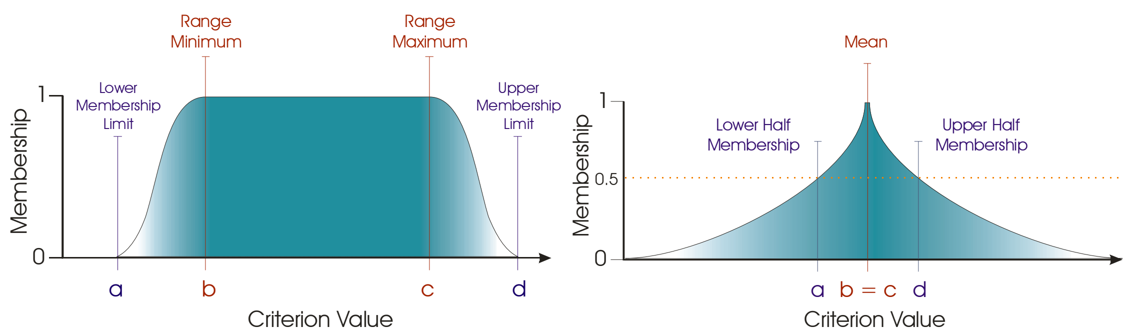

Figure 34: Sigmoidal and J-Shaped fuzzy logic Membership Functions

A sigmoidal MF with four control points is used where a criterion covers a range of values with the same magnitude for membership. Full membership is defined for the range of values between the inner inflection points. Values for the start and end control points need to be set to cover the possible range of values. For values beyond the outer control points the membership becomes 0. The symmetrical J-shaped function defines a single point to full membership and all other factors to a membership value that varies with the criterion values in the spatial units. In contrast to the sigmoidal function under practical conditions the J-shaped function only approaches a membership value of 0, but does not reach it. Thus, the J-shaped MF can be applied where the outer control points are not well defined. The fuzzy set membership functions shown in the graph are symmetrical, but applied in the MCE were also non-symmetrical functions and monotonically increasing / decreasing functions.

In this work fuzzy set logic was used more generally to define the membership of objects in a multi-criteria decision process not just for bio-physical suitability of crops and land uses, but also for modelling temporal processes, such as crop rotation systems.

The raster layer uses as processing entities not the areas of CM and GM. Instead, each grid of the spatial layers is treated as a distinct and exclusive unit of land use, management and input. One grid cell can only contain a single value for each factor. For a spatial resolution of 1 km this is a noteworthy generalisation. Also the temporal dimension can only be approximated, for example the crop in a given year in a crop rotating system. The spatial data should therefore be aggregated as statistical data to represent a larger spatial unit for a period of time, such as a NUTS 2 unit for 20 years.

5.2.3 Factor and Constraints Data

All data that are used to set factor and constraints for the multi-criteria evaluation are spatial in character and conform to the specifications of spatial layers. For a condition that influence changes in soil organic C-stocks the data indicate the degree of suitability for the condition to occur at each grid cell. The data are thus part of the procedure of spatially allocating conditions, not of the method for estimate changes in soil C-stocks.

The factor and constraints data can be grouped into the following categories:

- **Climatic data**

  The source of the climatic data is the WorldClim set of global climate data at 30 arc sec. grid spacing [57] ([36]). From the data the data on potential evapotranspiration (PET) and the Aridity Index (AI) were derived. PET and AI data following the same computations ([37]) are available from the Consultative Group for International Agricultural Research - Consortium for Spatial Information (CGIAR-CIS)[58].

  An additional meteorological indicators is:

  - Potential Soil Moisture Deficit (PSMD);

    PSMD [38] is computed for the period March - May for spring planting and for September - November for autumn planting.

- **Soil properties**

  Soil properties were developed from a raster version of a merge of the European Soil Database (ESDB) and the Harmonized World Soil Database (HWSD) [7]. The soil data contains a spatial attribution of all the soil typological units to a 1 km raster layer[59]. From this all properties of the soil database can be mapped, not just the properties of the dominant typological unit of a soil mapping unit. This includes data on derived properties, such as water regime or limitations to agricultural use.

  Additional ancillary soil data is:

  - Packing Density (PD)

    PD [39] is computed as:

[57] Download site: http://www.worldclim.org/current

[58] Project site: http://www.cgiar-csi.org/
Download site: http://www.cgiar-csi.org/data/global-aridity-and-pet-database

[59] Download site: http://esdac.jrc.ec.europa.eu/content/european-soil-database-derived-data

$$PD = DB + 0.009 \div CLAY\ (\%)\ [g\ cm^{-3}]$$

Together with soil moisture the parameter is an indicator of the energy needed to work the soil.

- **Topography**

  Topographic and geomorphological features were derive from the 30 arc sec. set of the *Global Multi-resolution Terrain Elevation Data 2010* (GMTED2010)[60].

For most factors and constraints the properties from the categories were combined to form additional supplementary data, from example to indicate crop suitability. The data of these categories generally are invariable with time. Some factors are dynamic and change over time, such as the distance of a location to a land use category.

5.3 Implementation of Spatial Allocation

The principles of the spatial allocation are described by [40]. Since the publication of the paper the technical capabilities of the tools used have expanded considerably, but the concept remains valid. The general course followed for spatially allocating statistical data is:

1. express change as annual demand in areas for items of a group;
2. define suitability for group items;
3. set rules for temporal development;
4. procure land use change matrix;
5. detail membership function, factors and constraints for multi-criteria evaluation;
6. specify objective weights and rank data for multi-objective land allocation.

The demand for area of a land use category is the increase in area from one year to the next. Hence, only the changes in land use are spatially assigned, not the whole area. Not assigned is the decrease in area of a land use category. This implies that land use change is driven by the areas that expand, not by the lack of suitability of the areas than shrink. Conversely, for individual crops inside the sub-category "long-term cultivated" the demand for areas is the crop area of the statistical data, not the annual change in crop area.

Suitability for a land use category or crop is not only the appropriateness of the environmental conditions for grassland or cropland, but also includes a probability of change to occur. Distance to areas of previous changes is therefore a suitability factor.

The temporal development takes into account that land use does not oscillate from ear to year. Once a location changed land use category it becomes less likely to change again. In this aspect land use categories differ from crops which may be grown in annual alteration at a location. However, for rice, perennial crops and set-aside the changes are restricted to occur only once the sub-category was assigned to the same location for a number of years.

[60] Project site: https://lta.cr.usgs.gov/GMTED2010
Download site: http://earthexplorer.usgs.gov/

A spatially explicit land use change matrix is the main aspect of Approach 3. The changes between land use categories are guided by the change matrix. For the period 1990 to 2000 the change matrix is extracted from the CLC90 and CLC2000 data, for the period 2000 to 2010 from CLC2000 and CLC2006. The change matrix is based on land transitions between categories. These transitions are the potential of each category changing to each other category. The transition potentials are evaluated using a Multi-Layer Perceptron.

During the multi-criteria evaluation the constraints are defined first. Constraints come in different types. One type are limits the conversion of land use categories. This type prevents for example changes from rock outcrops to cropland. A second type is a restriction to change land use category more than once over a number of years. The period depends on the land use category: for artificial areas this is less than 20 years, for grassland less than 5 years. The parameters for factors are in most cases set by a fuzzy set membership function. Where factors are of type Boolean, for example for irrigation, a continuous membership function is generated from the number of years of irrigation at a location. The output of the multi-criteria evaluation are rank layers which in which the grid cells are ordered according to their suitability for the factor.

Items are assigned to a location using a multi-objective land allocation procedure. The procedure combines the rank data with a weight factor to allocate all items of a group.

5.4 Land Use

The principal element for the spatial allocation of CM and GM is the factor land use. The initial spatial distribution of land use is derived from Corine Land Cover 2000 data. The translation of land cover to land use is relatively straightforward (see Table 4). Less evident is the transfer of the statistical data on the distribution of land use by NUTS unit to the spatial layer. For some categories and regions the differences in areas are not negligible. One option of resolve the matter is to disaggregate all land use categories to NUTS 2 units based on the areas of the statistical data. An advantage of this approach is that the land use areas of the spatial data layer correspond to those of the statistical data. A shortcoming is that a new land use layer has to be generated. The initial layer should be generated for the start year of the processing period, here 1990. For this year Corine data (CLC90) is to a certain degree erratic in temporal and spatial coverage. Other spatial land cover is not very useful since spatially explicit changes in land use categories are derived from the temporal sequence of land cover in the spatial data.

As an alternative the CLC2000 data was used as the basis for the spatial land use for the year 2000 without adjustment to the areas of the statistical data. Land use areas for other years are processed as changes in the statistical data and are allocated to the spatial layer starting from the year 2000. The procedure is graphically presented in Figure 35.

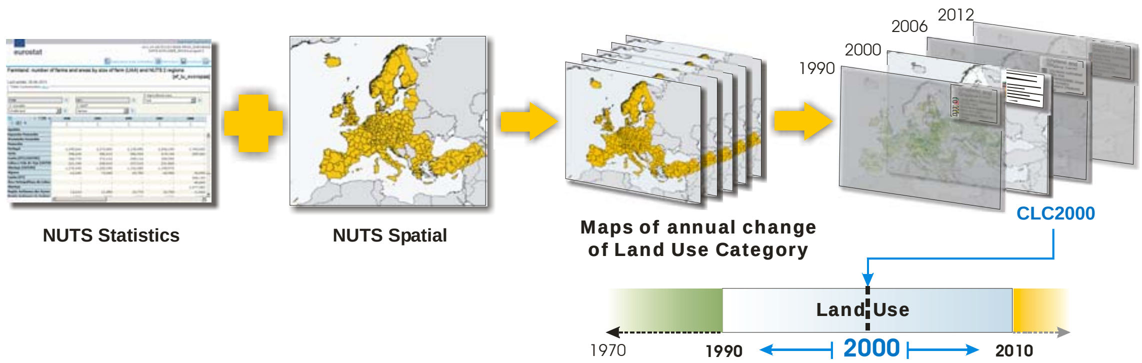

Figure 35: Processing spatial layers for Land Use Categories

The allocation of land use categories is predisposed towards the situations as found in the 1990 and 2006 Corine land cover data. In general, locations that were the same land use in CLC90, CLC2000 and CLC2006 receive low weights for the probability of changing land use between those years. It was considered unlikely that artificial or natural areas would change land use more than once in the intervening years. On locations where land use differs between the two bounding years the suitability to change is set to increase as the processing year approaches the final year. The changes in land use categories are not forced to lead to the Corine data in either year, but respect the changes derived from the statistical data for NUTS units.

An advantage of the approach is that a generally available spatial data set forms the basis for allocating land use changes. The approach also simplifies the computation of spatially explicit land use changes. A disadvantage is that the spatial layers are not fully representative of the land use areas, only for the annual changes.

The allocation of the changes in land use categories are made on the basis of drivers for change and allocation of land use categories deducted from relating land use with environmental and physical parameters.

The drivers used to support the spatial allocation of changes between land use categories are:

- Temperature (*ºC*)
- Precipitation (*mm*)
- Topsoil pH (*pH* H_2O)
- Soil Depth (*cm*)
- Soil Texture (*class*)
- Topsoil Salinity ($dS\ m^{-1}$)
- Limit to Agriculture (Cultivation)
- Slope (*%*)
- Distance (*m*) to land use category

These drivers are those used to define the suitability for crops and are only loosely related to land use and the settings differ between the various categories. More to the point, they are applied to support the allocation of changes in land use rather than land use as such. It should be underlined that the drivers are not the factors driving land use change and that they are not sufficiently comprehensive to be used to extrapolate changes in land use categories outside beyond the statistical data.

The statistical data provides data on the level of change, but not on particular changes between land use categories. The allocation of changes in land use categories is therefore guided by a land transition model. The model is derived from Corine Land cover data for 1990, 2000 and 2006 which are combined with the driver data. Changes and drivers are analysed by a *multi-layer perceptron* (MLP) neural network. The flow is presented in Figure 36.

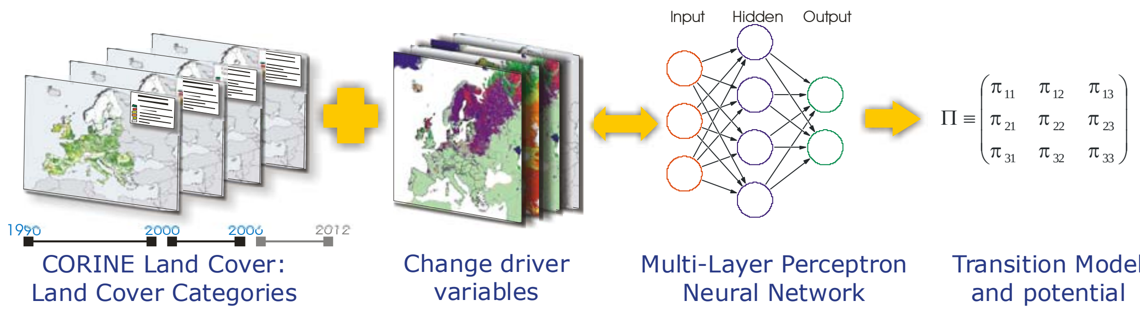

Figure 36: Transition potential model and potential for the allocation of changes in land use category

The output of the procedure is a transition matrix with the potential of any category changing to another category. The potential is then used in the MCE to allocate changes in land use categories.

The controlling spatial elements for all other processing are these layers of land use categories. To assess the effect of changes in land use categories on soil organic C-stocks status and changes in land use at a given spatial location are recalculated, starting in 1990.

5.4.1 Cropland

The area demand for crops is the area under a crop as available from the statistical data. The suitability of a location for a crop is estimated using the FAO Ecocrop database[61]. The parameters used for crop suitability are:

- Temperature (*ºC*)
- Precipitation (*mm*)
- Topsoil pH (*pH* H_2O)
- Soil Depth (*cm*)
- Soil Texture (*class*)
- Topsoil Salinity ($dS\ m^{-1}$)
- Limit to Agriculture (Cultivation)
- Slope (%)
- Elevation (m)

[61] Project site: http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2114

Some of the parameters of the Ecocrop database were not used either because they were problematic to assess (soil fertility) or because they were overly general (latitude, longitude). As fuzzy set membership function a symmetric sigmoidal function is applied. The function inflection points where the membership is above zero are set by the Ecocrop absolute minimum and maximum values. Membership reaches 1 between the values specified to represent optimal conditions.

In addition to the Ecocrop suitability constraints were defined to moderate the suitability of crops. The limiting factors are:

- Mean of monthly mean minimum for period April to. September
- Mean of monthly mean maximum for period April to September
- Total precipitation for October to December

There is no land use change matrix for crops as for land use. In its place a set of rules is applied that specify the likelihood of a crop being grown consecutively at a location. The method simulates standard crop rotation systems for the culture types cereals, maize, rice, root crops and temporary grass. The actual sequence of crops is then modified by the distribution of crop areas within the NUTS 2 unit.

A special case is the allocation of set-aside areas. Under CM set-aside is a sub-category and located at the same level as long-term-cultivated, rice or perennial crops. In statistical data it may be included under arable land. In Corine data, and most other spatial land use data, the set-aside areas are not identified as a separate item. These areas are thus assumed to be part of the non-irrigated arable land class. As a consequence, set-aside areas are not in competition with other CM sub-categories but with other crops within the area of arable land. Set-aside areas are also not tied to geo-morphological or environmental conditions. The initial spatial allocation of set-aside areas was therefore based on a stratified-random allocation. The allocation in subsequent years was governed by the regulations for set-aside areas under the Common Agricultural Policy.

5.4.2 Grazing Land

Defining the area grazed from the statistical data is not without some convolution. Pastures are grassland that are grazed by animals while meadows are used for fodder. Grazing is considered to occur when animals graze for >= 2 hours. Eurostat table [ef_pm_grazecs] contains the total area grazed on the holding (M_4_1_1_HA). This area includes temporary grassland. This is not the area reported as "Permanent grassland and meadow" (B_3_1_HA). In some cases the grazed area exceeds the area of permanent grassland. To remain consistent with the PERMANENT_GRAZED_AREA the grazed area is derived from the sum of areas which refer to a grazing period (M1-2, M3-4, M5-6, M7-9 and M_GE10).

The area grazed on common land is not available, not even from table [ef_pmcomlecs]. Grazed common land areas in the SAPM of the FSS relate to land owned or rented by the farmer, not to all land. The field B_3_HA (Total: Permanent grassland and meadow) only covers the grazing land belonging to a holding. As an approximation grazing is distributed by the fodder area. Even so, using the fodder area to proportionally extend the grazed area is only valid where fodder crops are used as LVS fodder. The relationship is distorted where fodder crops, such as maize, are used for other purposes, e.g. as biofuel.

The form used to process the statistical data on grazed areas and grazing livestock is presented in Figure 37.

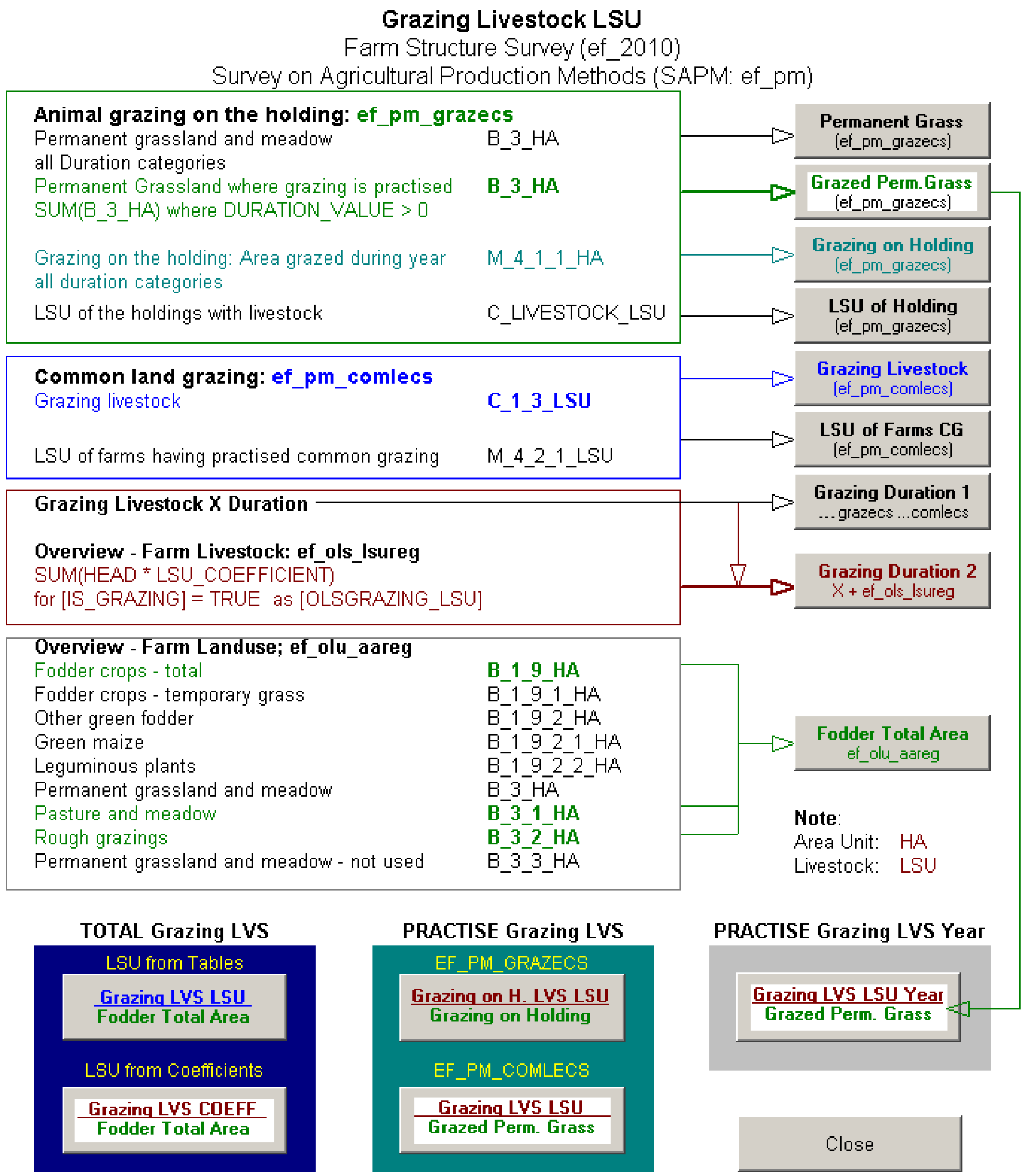

Figure 37: Form to process the statistical data on grazed areas and grazing livestock

The table [ef_pm_grazecs] offers data only for the year 2010. With the changes in grassland and grazing livestock over time it may be imprudent to consider the area permanent pastures and meadows as invariable. To provide some measure of changes in permanent pasture the changes in grazing livestock are used to adapt permanent grassland.

For grazing land the suitability parameters of the land use categories were extended to include an estimate of the growing season of grassland vegetation ([41]; [42]). The distance parameter includes the distance between the CLC classes "Pastures" to

"Natural grassland". Changes in the areas of CM are expected to primarily affect such classes.

Once the land use category is allocated it is subdivided into:

- Permanent Pasture
- Permanent Meadow
- Rough Grazings

The separation supports the characterisation of the CM management and input level. Areas of "rough grazings" are included in CM instead of the category "Natural grassland" because the statistical data provides such areas for the holding, not all grassland.

It was assumed that areas of "rough grazings" would encompass regions of lower suitability for grassland than areas of permanent pasture and meadows. The suitability settings were therefore set to cover a wider range of values.

5.5 Management

The application of management practices was treated as one group and without distinction between CM and GM. Some practices are clearly tied to a management category, such as tillage practice, while others may apply to either category, such as irrigation. The proper assignment to CM and GM is determined by the spatial location of the practice.

5.5.1 Irrigation

Areas under irrigation were allocated for the following crop types:

- Permanent Grass (km^2)
- Cereals
- Maize (grain and green)
- Pulses
- Potatoes
- Sugar beet
- Rape and turnip
- Sunflower
- Soya
- Cotton

Eurostat table [ef_poirrig] contains as indicator for irrigated grassland the combined area of permanent and temporary grassland (Code: M_8_1_2_11_HA). The irrigated area is distributed between the items proportionally to area statistics.

Where the practise is not of relevance to estimating changes in soil organic C-stocks irrigated areas are not considered. As a consequence, the irrigated areas of rice or permanent crops are not processed.

The criteria defining the suitability for irrigation are:

- Limit to agricultural use (class)
- Soil Texture (class)
- Water Regime (class)
- Presence of impermeable layer
- Packing Density [*g cm*$^{-3}$]
- FAO85 Gleyic Property (class)
- Water Management (class)
- Distance to surface water (*m*)
- Slope (%)

The temporal criterion for allocating irrigation are set to continue with the practice at the site or in the vicinity of the location to which irrigation was previously allocated.

5.5.2 Crop Yield

The harvested yield of crops is used to assist in the allocation of input levels and forms an input parameter for estimating the amount of dry matter in crop residues. Yield differs in character from area. As opposed to area and data, which is of type Boolean at a location, yield is a ratio type and an attribute to a combination of crop and location. As a consequence, the method of allocating yield to locations inevitably deviates from the allocation of areas. Annual yield is allocated to an area rather than changes between years, as for areas. Variations from the mean value for yield in a NUTS unit are simulated by defining a relationship between yield and crop suitability. As model a saturated growth function is applied.

The function used to estimate yield for a given crop and year within a NUTS unit for relative yield and suitability (0 ... 1) is:

$$YLD\_FNCT_C^{NUTS} = \frac{SUIT_c}{b + SUIT_c} \times YLD\_MAX_c \quad [dt\ ha^{-1}]$$

where

$$b = \frac{SUIT\_AVG_c^{NUTS}}{YLD\_AVG\_REL_c^{NUTS}} - \left(SUIT\_AVG_c^{NUTS}\right)^2$$

and

$$YLD\_AVG\_REL_c = \frac{YLD\_AVG_c}{YLD\_MAX_c}$$

with

YLD_FNCT:	yield from saturated growth [*dt ha*$^{-1}$]
SUIT:	relative suitability for crop (0 – 1)
YLD_MAX:	maximum crop yield from external data [*dt ha*$^{-1}$]
SUIT_AVG:	average relative suitability within NUTS unit (0 – 1)

YLD_AVG: average yield for NUTS unit [$dt\ ha^{-1}$]

YLD_AVG_REL: average relative yield for NUTS unit (0 – 1)

c: crop

NUTS: NUTS Level 2 unit

As defined the function leads to a non-proportional distribution of yield within the NUTS unit. To avoid inconsistencies with the statistical data the crop yields thus distributed are pondered by the statistical value for crop production of the NUTS Level 2 unit:

$$\sum YLD\_FNCT_c \times AREA_c = k \times PROD\_STAT_c$$

$$=> YLD\_EST = YLD\_FNCT_c \times \frac{\sum YLD\_FNCT_c \times AREA_c}{PROD\_STAT_c^{NUTS}} \quad [dt\ ha^{-1}]$$

with

YLD_EST: adjusted estimated yield [$dt\ ha^{-1}$]

AREA: relative suitability for crop (0 – 1)

YLD_FNCT: yield from saturated growth [$dt\ ha^{-1}$]

PROD_STAT: crop production for NUTS unit

NUTS: NUTS Level 2 unit

For the allocation of yield a temporal persistence at a location is not defined. Instead, persistence is afforded by the crop suitability layer.

5.5.3 Tillage Practice

The level of soil disturbance is expressed in three levels of tillage:

- Conservation Tillage
- Zero Tillage
- Conventional Tillage

Inconsistencies between the extent of arable land and the sum of the land recorded under a tillage practice are reduced by calculating the area under conventional tillage as:

$$TILL\_CONV = \sum CULT\_TYPE + LU\_RICE - (TILL\_CONS + TILL\_ZERO) \quad [km^2]$$

with

TILL_CONV: area under conventional tillage [km^2]

TILL_CONS: area under conservation tillage [km^2]

TILL_ZERO: area under zero tillage [km^2]

CULT_TYPE: area under a culture type [km^2]

LU_RICE: area under land use type “rice” [km^2]

To cover all arable land potentially subjected to a reduced tillage practice the area of all crops belonging to the land use category of long-term cultivated are combined with the area under rice (LU Type). The application of a tillage practice at a location depends on the combination of suitability for reduced tillage and the crop type in a given year. Temporal persistence of a reduced tillage practice at a location is further governed by the probability of continuous conservation or zero tillage.

Conventional tillage is assumed when the land use changes from any type to cultivated land. It is also assumed for the first year after conversion when the crop type changes from temporary grassland or energy crops to an arable crop type as well as from set-aside. This is not the case when areas with crops change to these types.

5.5.4 Fertilised Grass

Data on the area of grassland that receives applications of mineral fertiliser are not directly available from a statistical or spatial database and are therefore deducted from other available data.

The area of fertilised grass is estimated from the area of fertilised fodder crops and the areas of permanent grass and grazing. The area of fodder crops is composed of:

- green maize,
- other roots,
- fodder legumes,
- temporary grass and grazing.

The area of managed grassland is sub-divided as:

$$\textit{Permanent Grassland} = \textit{Fertilised Grassland} + \textit{Non-Fertilised Grassland}$$

Thus, the following relation can be defined:

$$\textit{Fertilised Grassland} = \textit{Total Fodder Area} - \textit{Fertilised Fodder Area}$$

Data on fertilised fodder areas are only available for the year 2000. To estimate the area of fertilised grassland for other years during the period the area is adjusted to the number of grazing livestock. For this the area of fertilised permanent grassland and the share of the area of fertilised grassland in GM is calculated for the year 2000 as:

$$FERT\_GRASS\_SHARE = \frac{FERT\_GRASS\_AREA}{GM\_AREA} \quad [\textit{unitless}]$$

The area of fertilized grassland may be grazed by livestock or provide forage for grazing livestock on the holding. In the computations no distinction is made between the uses.

The area of fertilized grassland is estimated at country level. To provide a measure of the area at NUTS Level 2 and to account for changes in grazing livestock over time the area of fertilized grassland is modified by the number of grazing livestock at NUTS Level 2. "Grazing livestock" is not the number of animals actually grazing on grassland, but refers to the type of livestock (cattle, sheep, goats and equidae). The head count of grazing livestock is converted to LSU to reduce the effect of differences in the consumption of fodder between grazing livestock and age groups.

The area of fertilised grassland for NUTS level 2 units is estimated from NUTS Level 0 units by a proportional distribution as:

$$FERT\_GRASS^{NUTS\_L2} = \frac{FERT\_GRASS^{NUTS\_L0}}{GRAZING\_LVS^{NUTS\_L0}} \times GRAZING\_LVS^{NUTS\_L2} \quad [km^2]$$

with

GRAZING_LVS: grazing livestock [*LSU*]

NUTS_L0: country

NUTS_L2: NUTS Level 2 unit

For fertilised grassland the estimated area is spatially allocated rather than changes between years. Temporal persistence at locations is supported by defining a coefficient depending on the number of years of fertilized grassland at a location.

5.5.5 GM Management Level

The areas of GM cover the items "*permanent meadow*", "*permanent pasture*" and "*rough grazings*" of the statistical data. Permanent pastures and meadows can be in any category, but areas of "*rough grazings*" cannot have the status "*improved*".

The MCE factors used to evaluate the GM management condition are:

- Mean NPP by climate region
- Livestock stocking rate
- Livestock grazing intensity
- Slope
- Aridity Index
- Soil retention

The assignment of the GM management condition follows the decision tree of IPCC, 2006. The process identifies first a level of degradation and then improvements. The nominal status is used as a default where neither degradation nor improvements are present and is not specifically identified.

- **GM Degradation**

  Grassland is considered degraded when the C-input to the soil is less than under native grassland. An indicator of GM degradation is estimated from comparing the mean NPP of native grassland with the GM area "permanent pasture" and "rough grazing". Areas of "permanent meadows" are considered to be not grazed and not degraded and are, therefore, not included when computing the mean NPP for permanent grassland.

  Grazing intensity is estimated from grazing livestock stocking rate. The stocking rate is defined as:

$$GRAZING\_LVS\_SR = \frac{GRAZING\_LVS}{GRAZED\_AREA} \quad [LSU\ km^{-2}]$$

with

GRAZING_LVS_SR:	grazing livestock stocking rate [$LSU\ km^{-2}$]
GRAZING_LVS:	grazing livestock [*LSU*]
GRAZED_AREA:	area grazed by grazing livestock [km^2]

A measure of the intensity of grazing is given by modifying the stocking rate by the growing period of grassland vegetation and the duration of grazing on pastures as:

$$GRAZING\_INT = GRAZING\_PART \times GRAZING\_LVS\_SR \quad [LSU\ km^{-2}\ month^{-1}]$$

where

$$GRAZING\_PART = \frac{GRAZING\_DURATION}{GROWING\_PERIOD} \quad [unitless]$$

with

GRAZING_INT:	grazing intensity [$LSU\ km^{-2}\ month^{-1}$]
GRAZING_PART:	part of growing period with grazing [*unitless*]
GRAZING_DURATION:	duration of grazing on pasture [*month*]
GROWING_PERIOD:	growing period of grassland [*month*]

Grazing duration varies between grazing livestock categories and age and gender for cattle. Data are taken from Eurostat FSS data in table [ef_pmgrazecs]. In the FSS no distinction is made between the various grazing livestock categories. Some information on grazing for types of cattle can be obtained from the IPCC default values for the manure management system "Pasture, range or paddock", but only for broad regions (Eastern and Western Europe). Therefore, estimates of grazing livestock stocking rates and intensity should to be treated with caution.

In the MCE the fuzzy membership function for livestock intensity is set to reach saturation at 4.5 $LSU\ km^{-2}\ month^{-1}$. At this point some notable degradation of grassland compared to a native condition is expected.

- **GM Improved**

  The status of grassland is improved where the productivity of the vegetation is higher than under native conditions. The factors indicating an improvements are:

  - irrigation,
  - fertilization and
  - where the NPP of GM areas is higher than for native grassland.

  The average NPP of potentially improved GM areas is computed for the combined area of "permanent pasture" and "permanent meadows" by climate region within the national boundaries. For the difference to the mean NPP for native grassland a sigmoidal fuzzy set membership function is used in the MCE with a saturation point set to a value of 1.0 for the ratio of the average NPP for native grassland to the average NPP for permanent pastures and meadows.

- **GM Nominal or Native**

  Nominal GM management is assigned to areas that are not allocated to areas that are either degraded or improved.

5.6 Input

The input factor for changes in soil organic C-stocks differentiates two (GM) or four (CM) levels. For GM input levels only apply to areas where grassland are improved over the natural conditions. The level is based on the number of management practices applied at a location which were already used to identify areas of grassland improvements. For CM the input level is defined by a more complex combination of practices that affect removals and additions of organic material to the soil. These practices are not part of the management factors and need to be computed. Although CM and GM are generally processed separately, in areas of mixed farming systems the parameters defining the CM input level are strongly related to GM management practices, in particular in areas with grazing livestock. The main effects are the removal of crop residues as animal bedding material and the application of farm yard manure.

It should be noted that practices that increase C-input for CM should only be considered when used in at least 1/3 of the crop rotation[62].

5.6.1 Crop Residues

The first criteria in the classification scheme of the CM input level regards the abstraction, or not, of crop residues from the field. Only in case that crop residues remain on the field are practices influencing C-input of relevance. The practices that influence C-input distinguish between those applied where

a) low-yielding crops are grown and

b) residue production of other crops can be enhanced.

Some of the practices influencing C-input are common to both conditions, but not all.

The CM input level is defined by the practices influencing C-input, not directly by the level of crop residues produces. The quantity of crop residues produces is, however, required to estimate the areas from which crop residues are removed, such as for animal bedding.

- **Residue Dry Matter Production**

  The amount of above-ground crop residues is computed for all cultivated crop types and rice based on the equation and default parameters of Table 11.2 of IPCC, 2006:

$$AG\_DM_c = m\_DM_c \times \frac{YLD\_harvested_c}{10} \times FRAC\_DM_c + c\_DM_c \quad [t\ ha^{-1}]$$

[62] IPCC, 2006: Note under Figure 5.1

with

AG_DM_c:	above-ground residue dry matter yield for crop *c* [*t ha-*^{1}]
$YLD\_harvested_c$:	annual fresh matter harvested crop yield for crop *c* [*dt ha*$^{-1}$]
$FRAC\_DM_c$:	dry matter fraction of harvested crop *c* [*kg d.m. (kg harvested weight)*$^{-1}$]
m_DM_c:	residue function slope for crop *c* [*unitless*]
c_DM_c:	residue function intercept for crop *c* [*t ha-*^{1}]
c:	crop type

The equation implemented has been adapted to allow for the difference in units used by IPCC and this implementation of the method. The slope (*m_DM*) and intercept (*c_DM*) coefficients of the linear relationship between crop yield and residue dry matter production are taken from Table 11.2 [1]. As crop yields the annual estimates of the statistical data are used.

For cereals, including rice and grain maize, the above-ground residue yield is then converted from dry matter to the residue harvested yield and production by using the dry matter fraction of the harvested product following Equation 11.7 and the dry matter default values of Table 11.2 [1]:

$$PROD\_AG\_harvested_{Cereals} = \sum AG\_harvested_c \times \frac{AREA\_NUTS_c}{1000} \quad [t\ NUTS^{-1}]$$

where

$$AG\_harvested_c = \frac{AG\_DM_c}{FRAC\_DM_c} \quad [t\ ha^{-1}]$$

with

PROD_AG_harvested:	above-ground fresh matter residue production for cereals *c* [*t NUTS*$^{-1}$]
$AG\_harvested_{cer}$:	above-ground residue harvested yield for cereal crop *cer* [*t ha*$^{-1}$]
AG_DM_{cer}:	above-ground residue dry matter yield for cereal crop *cer* [*t d.m. ha-*^{1}]
$FRAC\_DM_{cer}$:	dry matter fraction of harvested cereal crop *cer* [*kg d.m. (kg harvested weight)*$^{-1}$]
cer:	cereal crop type

It is assumed that the moisture content of the crop residues are comparable to the harvested product. This may be valid for cereals and dried pulses, but less so for crops such as sunflower seed. It is not valid for root crops. However, the harvested yield of residues are only computed for crops that are used as animal bedding where the assumption can be applied.

- **Residue Burning**

Cropland areas potentially burnt are restricted to cereals, including rice, but excluding maize. Factors used to define the suitability for residue burning are:

- Precipitation
- Soil depth
- Soil texture class
- MODIS burnt area

Given the legislation on burning crop residues in Europe the default value for the fraction of the area burnt is linearly reduced from 10% in 1990 to 0% in 2010.

For the years 2000 and later data from the MODIS Burnt Area Products[63] are used. Any direct use of the data to signify burning of crop residues should consider the low level of confidence assigned to burnt agricultural areas in the QA data (Class 5). Instead of using the spatial data directly the frequency of an area burning from 2000 to 2009 was calculated. The area of cultivated land burnt is then estimated for each year of the period by spatially allocating the burnt area which is aggregated to NUTS Level 2. This procedure allows using the same computations for all years, including years without MODIS data, and aligning the burnt areas to the locations of crops for which residues would burn. These are mainly cereals, but excluded are root crops.

- **Residue Removal**

The demand for crop residues is expressed as the fraction of residues removed from the field ($Frac_{removed}$). The specified uses of residues are feed, bedding and construction. In Europe the use of crop residues as livestock feed and as construction material was considered minor compared to the use as bedding material and only the latter was processed. The use of crop residues as biofuel, packing material or for growing mushrooms can be considerable, but very limited data are available for theses uses. For the removal of residuals it is not enough to obtain data on the area concerned, but also needed is the rate of removal. For the removal of crop residuals as animal bedding the vicinity to areas where animals are housed is one factor for the spatial allocation. One may also assume that crop residues are either removed completely or not at all. For the removal of crop residues to be used as biofuel or packing material information on the location of the industrial consumers should be accompanied by their capacity of processing the residues. In particular for the use of crop residues as biofuels the aspect of sustainable removal is given much attention. Based on an expert assessment approximately 25 to 30% of crop residues could be removed when sustainability issues are taken into account [43]. However, the sustainable rate of removal was found to depend very much on specific site conditions [44]. Consequently, removals of crop residues below that level should thus be considered as not negatively affecting soil organic carbon. Under this provision the rate of residue removal from a field becomes a decicive criterion in the decision of the management factor for cropland. However, the removal rate is highly variable, usually linked to estimates of crop yield, as are data on the rate ([45]; [46]). A proxy to estimate the removal of crop residues for biofuel could be the development of the area of dedicated biofuel crops [47]. In the statistical data the use of a crop is not specified, only the area under a crop. The annual increase in the use of biofuel was prominent between 2000 and 2010, but it has levelled off after

[63] Project site: http://modis-fire.umd.edu/pages/BurnedArea.php

2010 [48]. The strength of the relationship between the area under dedicated biofuels and the use of crop residues depends on the preference given to the type of biofule produced, for example ethanol or diesel. The whole theme of biofuels is driven by policy matters and therefore difficult to characterise from the use of proxies. The removal of crop residues for biofuels has not been estimated and it is not used as a criterion in the classification of the input level on cropland.

To remain consistent with application rates of farm yard manure the estimates of crop residues removed for animal bedding makes use of the IPCC procedure of estimating managed manure nitrogen available for application to managed soils, feed, fuel, or construction purposes (Equation 10.34 of [1]). The demand of crop residues for bedding material utilises Equation 10.34 of [1], which contains a parameter of the amount of nitrogen form bedding (*NbeddingMS*).

Demand for bedding material is processed for manure management systems "solid storage" and "deep bedding". The data available from IPCC on the share of MMSs is spatially and temporally indistinct statistics from the Eurostat FSS were used to obtain more detailed estimates. The associations between FSS data on animal housing and the IPCC classification for manure management is available from the form used to process the statistical data, which is presented in Figure 38.

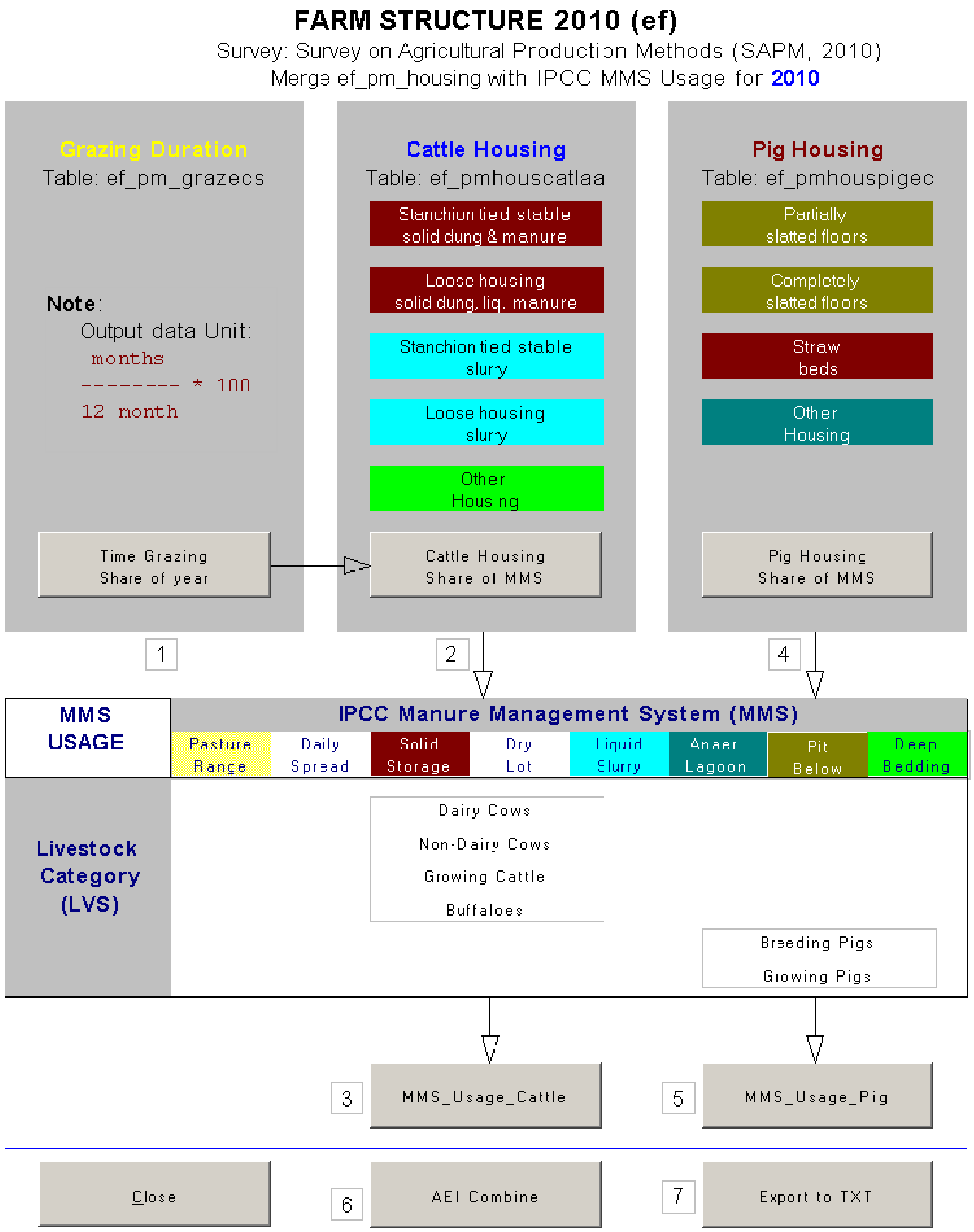

Figure 38: Form to align Eurostat FSS statistics on animal housing to IPCC Manure Management System

The time of grazing is equivalent to the IPCC category of "Pasture / range / paddock". It is applied to cattle, but not pigs. The associations between animal housing and IPCC MMS is colour-coded. For estimates of animal bedding material only the MMSs "Solid storage" and "Deep bedding" are relevant.

The total demand for animal bedding material is estimated in two stages:

a) Default amount of bedding material for livestock category *LVS* and manure management system *MMS*:

$$BED\_DEF_{LVS}^{MMS} = \frac{N\_BED_{LVS}^{mms}}{N\_AG_c \times FRAC\_DM_c} \text{ [kg straw head}^{-1}\text{ yr}^{-1}\text{]}$$

with

$BED\_DEF_{LVS}^{MMS}$: demand for animal bedding material from harvested crop residues for livestock category *LVS* and manure management system *MMS* [*kg straw head*$^{-1}$ *yr*$^{-1}$]

$N\_BED_{LVS}^{MMS}$: amount of nitrogen from bedding material for livestock category *LVS* and manure management system *MMS* [(*kg N animal*$^{-1}$ *yr*$^{-1}$]

N_AG_c: N content of above-ground residues in crop *c* used as bedding material [*kg N yr*$^{-1}$]

$FRAC\_DM_c$: dry matter fraction of harvested crop *c* [*kg d.m. (kg harvested weight)*$^{-1}$]

The default values used to estimate the amount of nitrogen from bedding material are listed in Table 7.

Table 7: Default values used to estimate the amount of nitrogen from bedding material

Manure Management System	**Livestock Category**	**N from bedding material** $N\_BED_{LVS}^{MMS}$	**Demand for Bedding Material*** $BED\_DEF_{LVS}^{MMS}$
MMS	*LVS*	*kg N head^{-1} yr^{-1}*	*kg straw head^{-1} yr^{-1}*
Solid Storage	Dairy cow	7.0	1326
	Growing cattle	5.5	1042
	Other cattle	4.0	758
	Buffaloes	4.0	758
	Mature pigs	5.5	1042
	Growing pigs	0.8	152
	Sheep	0.7	133
	Goats	0.45	85
	Equidae	5.0	947
Deep bedding	Dairy cow	14.0	2652
	Growing cattle	11.0	2083
	Other cattle	8.0	1515
	Buffaloes	8.0	1515
	Mature pigs	11.0	2083
	Growing pigs	1.6	303
	Sheep	1.4	265
	Goats	0.9	170
	Equidae	10.0	1894

* N content of above-ground residues: 0.006
dry matter fraction of straw: 0.88

The values for nitrogen from bedding material are taken from Chapter 10.5.4 of IPCC. 2006. For the computations it is assumed that the fraction of nitrogen lost in the manure management system (Table 10.23 of [1]) area from animal excretion and not from the bedding material.

The N contents of the above-ground crop residues N_AG_c are taken from Table 11.2 (N_{AG}). For cereals the factor for “Grains” is used, which is 0.006.

The conversion of dry matter to harvested fresh matter is computed using the default value (0.87) for the dry matter fraction of harvested products (*FRAC_DM*) for cereals as specified in Table 11.2 (column *DRY*) of [1].

b) Total annual demand for bedding material from all livestock categories *LVS* and manure management systems *MMS* is computed as:

$$BED_{demand} = \sum_{LVS} \sum_{MMS} BED\_DEF_{LVS}^{MMS} \times HEAD_{LVS} \times FRAC\_USE_{LVS}^{MMS}$$

[*t straw yr*$^{-1}$]

where

$$FRAC\_USE_{LVS}^{MMS} = \frac{\sum_{1}^{12} \left(HEAD_{LVS}^{MMS} \right)_{Month}}{12 \times HEAD_{LVS}} \text{ [unitless]}$$

with

BED_{demand}:	total demand for bedding material from all livestock categories and manure management systems [*t straw year*$^{-1}$]
$BED\_DEF_{LVS}^{MMS}$:	default demand of animal bedding material from crop residues for livestock category *LVS* and manure management system *MMS* [*kg straw head*$^{-1}$ *yr*$^{-1}$]
HEAD:	number of livestock for species/category *LVS* [*1000 Head*]
FRAC _USE :	fraction of time of livestock category *LVS* spent in manure management system *MMS* spent during year [*month* (12 *month*)$^{-1}$]
MMS:	manure management system "solid storage" or "deep bedding"
LVS:	livestock species/category

The area of crops with residues for animal bedding needed to satisfy the demand is then estimated from the ratio of the animal bedding demand to the amount of residues produced. This ratio is proportionally applied to the total crop area from which residues could be removed for animal bedding, as expressed in the equation:

$$BED\_AREA_{Cereals} = \frac{BEDdemand}{AGharvested\_PROD_{Cereals}} * AREA_{Cereals} \ (km^2)$$

with

BED_AREA:	crop area from which residues are removed for animal bedding [km^2]
BEDdemand:	total demand for bedding material from all livestock categories and manure management systems [*t bedding yr-1*]
AGharvested_PROD:	above-ground residue fresh matter production [*t yr-1*]
AREA:	total crop area from which residues could be removed for animal bedding [km^2]

Cereals:	total of crop type cereals, incl. grain maize and rice

The area thus calculated very much simplifies estimating the area required to satisfy the demand for animal bedding. It is assumed that residues for animal bedding are either completely removed at a location (grid cell in spatial layer) or remain. No preference is given to residues from any crop type to provide animal bedding. The demand for crop residue area translates directly into a demand for area for the multi-object land allocation process.

Up to this point the computations are performed for statistical data of the NUTS units, in the GIS. A conceptual reason for not processing grid layer data is the spatial separation of the demand for crop residues and the location of the source. The demand for animal bedding material is at the location of the holding, where animals are kept, but the source of the material is the arable land, where residues become available. The locations of demand and source are mutually exclusive, i.e. livestock is never allocated to arable land, only the demands. Subsequent processing proceeds in the spatial domain.

The factors defined for the suitability of a location for removing crop residues for animal bedding are:

- suitability for cereal crops
- distance to areas of fertilised grass
- distance to a fodder crop
- FAO gridded livestock for cattle

The factors do not include the distance to MMS types "solid storage" and "deep bedding". The MMS are not spatially allocated other than at NUTS Level 2. Including the FAO gridded livestock layer as a factor introduces a susceptibility of the allocation process to remove residues depending on local cattle density. This does not signify that the share of these MMSs is higher in areas of high cattle density than in areas with lower cattle density.

- **N from Crop Residues**

For an evaluation of the amount of N from crop residues and forage or pasture renewal as specified in Equation 11.6 [1].

Above-ground residue dry matter production AG_DM_c has already been computed in the previous step. The ratio of below-ground residues to harvested yield used in Equation 11.6 is found by first calculating below-ground residue dry matter and then computing the ratio.

Below-ground residue dry matter is computed as:

$$BG\_DM_c = RATIO\_BG\_BIO_c \times \left(AG\_DM_c + \frac{YLDharvested_c}{10} \right) \; [t\ ha^{-1}]$$

with

BG_DM_c:	below-ground residue dry matter for crop *c* [$t\ ha^{-1}$]

AG_DM_c:	above-ground residue dry matter for crop *c* [$t\ ha^{-1}$]
$RATIO\_BG\_BIO_c$:	Ratio of belowground residues to above-ground biomass [*unitless*]
$YLDharvested_c$:	harvested annual fresh yield for crop *c* [$dt\ ha^{-1}$]

All other parameters used in Equation 11.6 have been processed at this stage and can be employed as specified in the equation when using statistical data by NUTS unit. In the implementation of processing spatial data the parameters for total annual area harvested and the area burnt are binary layers. For the harvested area a binary layer exists for each crop (spatial allocation of crop) while for the area burnt a single binary layer is computed.

- **Managed Manure N**

The estimates for crop residues removed from the field for animal bedding are closely linked to the computations of the "amount of managed manure nitrogen available for application to managed soils or for feed, fuel, or construction" (Equation 10.34 in IPCC, 2006) is computed. Although not strictly needed for estimating changes in soil organic C-stocks for CM and GM managed manure N is computed to allow an evaluation of overall N application rates.

Following the computations of the demands for animal bedding material from crop residues Equation 10.34 is rearranged as follows:

$$N_{MM}\_AVB = \sum_{LVS}\sum_{MMS} HEAD_{LVS} \times \frac{USAGE_{LVS}^{MMS}}{100} \times \left(Nex_{LVS} \times \left(1 - \frac{FRAC\_LOSS^{MMS}}{100} \right) + N\_BED^{MMS} \right)$$

[$t\ N\ yr^{-1}$]

with

N_{MM}_AVB:	managed manure nitrogen available for application [$t\ N\ yr^{-1}$]
$HEAD_{LVS}$:	number of head of livestock species/category *LVS* [*1000 Head*]
$USAGE_{LVS}^{MMS}$:	fraction of total annual nitrogen excretion for each livestock species/category *LVS* that is managed in manure management system *MMS* [%]
Nex_{LVS}:	annual average N excretion per animal of species/category *LVS* ($kg\ N\ animal^{-1}\ yr^{-1}$)
$FRAC\_LOSS^{MMS}$:	fraction of managed manure nitrogen for livestock category *LVS* that is lost in the manure management system *MMS* (%)
N_BED^{MMS}:	amount of nitrogen from bedding ($kg\ N\ animal^{-1}\ yr^{-1}$)
MMS:	manure management system
LVS:	livestock category

The equation used is equivalent to Equation 10.34, but units of the parameters differ to comply with the units used for processing.

5.6.2 Soil Conservation Practices

Soil conservation practices are measures that either increase residues or soil organic C-stocks above those of low residue crops (Note: 3, Figure 5.1) or enhance residue production (Note: 4, Figure 5.1).

In the SAPM survey data the following practices are recorded:

- Normal winter crop
- Cover or intermediate crop (Note: 3, 4)
- Plant residues (Note: 1)
- Bare soil

The presence of "Normal winter crop" is treated as absence of a crop with low residue yields. The use of "cover or intermediate crops" is treated as a practice that enhances residue production. "Plant residues" remaining on the field can be understood as a practice that increases C-input. However, the criterion is already used to indicate that crop residues were not removed (Note: 1) at a higher position in the classification scheme and is therefore not applied for a second time.

Since the data are only available for a limited number of years the results from the MOLA crop allocation procedure are used to supplement the data.

The following rules for allocating the areas apply:

a) Winter wheat and winter barley are treated as "normal winter crop". To allow for spring varieties the crop types the areas for "Common wheat" and "Barley" are distributed according to the statistical data into winter and spring varieties. "Rye" is always treated as a winter crop, but "Oats" are treated as a non-winter crop. "Durum wheat" is split into half winter and half spring crop, as are "Other cereals". "Rape and turnip" are allocated to the winter crop category. All other crops are treated as spring or summer crops.

b) The practices "Normal winter crop" and "Bare soil" are mutually exclusive. "Cover or intermediate crops", "Plant residues" and "Bare soil" are allocated with preference to areas with non-winter crops.

c) The use of "Plant residues" is allocated only to areas from which residues were not removed for animal bedding.

d) Areas not subjected to these conservation practices are temporary grassland, energy crops and fodder legumes.

The factors defining the general suitability of the practices are initially aligned to the suitability of the crops. The practices "Cover or intermediate crop" and "Plant residues" are given higher ratings in areas where conservation or zero tillage is used. For the practice "Bare soil" areas are given preference where summer crops with late harvests (root crops) were grown. To provide some consistent allocation of the practices a factor using the number of years a practice has been applied is added.

5.6.3 Mineral Fertiliser Application

Data on fertiliser consumption are only available by country. The use of mineral N fertiliser at NUTS Level 2 is therefore estimated from N application rates by crop for each year. Application rates of mineral N fertiliser are available from the FAO FertiStat database[64] for a number of crops for the year 2000. Estimates of N application rates for individual crops and years were processed for statistical data in two stages:

1. The first task is to complete the table of application rates for all crops and countries for the year 2000. This is achieved by proportionally distributing application rates from crops with common data in at least two countries to missing entries. The task has to be performed only once and was performed using a spreadsheet rather than a programme.
2. The second task is to provide estimates of N application rates for all years. This was achieved by transferring changes in the overall N application rate to application rates for crops using data for the year 2000 as reference. The computations are implemented following the equation:

$$APP\_N\_RATE_c^{year} = F\_USE\_N\_RATE^{year} * APP\_N\_RATE_c^{2000} \text{ [kg N ha}^{-1}\text{]}$$

where

$$F\_USE\_N\_RATE^{year} = \frac{USE\_N^{year}}{APP\_AREA^{year}} * \frac{APP\_AREA^{2000}}{USE\_N^{2000}}$$

with

APP_N_RATE:	N application rate for crop *c* in year *year* [*kg N ha-1*]
USE_N:	use of mineral N fertilizer in year *year* [$t\ N\ year^{-1}$]
APP_AREA:	area where N is applied in year *year* [$1000\ ha\ year^{-1}$]

The application rates of mineral N fertilizer for crops are national estimates. Estimates of application rates for grid locations are obtained from relating N application rates to crop yield.

The relationship is defined as:

$$YIELD_c = m * (N\_RATE_c)^{0.5} + c_c \text{ [dt N ha}^{-1}\text{]}$$

with

YIELD:	crop yield [*dt ha-1*]
N_RATE:	mineral N application rate [$kg\ N\ ha^{-1}$]
c:	crop type

The data on crop yield is a function of local crop suitability. It comprises the elements defining crop suitability, such as climate and soil conditions.

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[64] Project page: http://www.fao.org/ag/agp/fertistat/

The yield data is the average yield of a crop *c* for the area covered by the data of crop N application rates. For each crop the estimates are then adjusted to the N application rates of the NUTS unit with data.

5.6.4 Farm Yard Manure

Farm yard manure processed is the combination of manure and slurry from livestock of agricultural holdings. As data source mainly the Eurostat data from the SAPM survey are used. The data are only available for the year 2010 and at national level. Reported is not the amount of manure or slurry applied, but the percentage of the utilised agriculture area (UAA) of the agricultural holdings within the ranges of 5 classes.

To find an estimate of the area over which farm yard manure was applied the percentage of the UAA was applied to the UAA. As percentage the central value of the class range was used. Potentially, farm yard manure can be applied to all crops on arable land plus meadows (temporary and permanent). Areas excluded from applying farm yard manure where grazed grassland and areas of set-aside.

The temporal range of data was extended by applying the changes in livestock of the Eurostat tables [ef_ls_ovaareg] and [ef_olsaareg] relative to the year 2010. The merged data is then processed as other statistical data of unit type "Area".

In the spatial domain a FYM-livestock coefficient is computed as:

$$COEFF\_FYM\_LVS_{2010} = \frac{FYM\_AREA_{2010}}{HOUSING\_LVS_{2010}} \quad [km^2\ LSU^{-1}]$$

with

COEFF_FYM_LVS:	ration of FYM applied area to livestock for year 2010 [km^2 LSU^{-1}]
FYM_AREA:	area where FYM is applied for year 2010 [km^2]
HOUSING_LVS:	number of livestock in housing for year 2010 [LSU]

The coefficient is then applied to the annual statistics of the number of livestock in housing to obtain annual estimates of the area where FYM is applied, as given in the equation:

$$FYM\_AREA_{year} = COEFF\_FYM\_LVS_{2010} * HOUSING\_LVS_{year} \quad [km^2]$$

with

FYM_AREA:	area where FYM is applied for year *year* [km^2]
COEFF_FYM_LVS:	FYM to livestock coefficient for year 2010 [km^2 LSU^{-1}]
HOUSING_LVS:	number of livestock in housing for year *year* [LSU]

The area potentially receiving FYM is composed of all CROP types, LU type rice and perennial crops and permanent meadows. The difference to processing the statistical data in the database application is the use of spatially allocated areas instead of NUTS units, which also separates grazing areas from meadows. To avoid undue demands for

FYM area in the MOLA process the annual area for applied FYM is limited to the potential area as present in the spatial layers.

The spatial allocation is constrained to the areas where FYM is potentially applied. The application is further limited to slopes < 15%. Within the potential area for FYM the suitability factor is set highest for cereals and at half the suitability for grassland and perennial crops.

6 Conclusions

IPCC proposes the Tier 1 method as the most basic form of accounting and reporting GHG from CM and GM. The decision schema for separating land use types, management practices and input levels are detailed in the reports as are the equations and parameters used in the equations. Implementing the Tier 1 method as an application on a computer was not particularly demanding. Difficulties arise when trying to populate the database with national data. The main source of national data originates from statistical surveys. The type of data available from the surveys frequently only approximates the information used in the Tier 1 decision schema and equations. Other than thematic equivalence the data often lack a complete time-series of annual data that covers a period of at least 20 years. This lack of a consistent and complete time-series of data is occasionally unavoidable, for example as a consequence of the changes in national borders during the 1990s or modifications to sub-national administrative boundaries. The political changes in the 1990s were followed by significant changes in land use, in particular in the agricultural sector in Eastern European countries. Extrapolating trends for CM and GM from the 1990s backwards in time is therefore hazardous and unwarranted. Hence, a starting year of 1990 was the considered a practical compromise between data availability and an early start of the processing period.

While statistical data at national level are available from several source, such as FAO, World Bank and Eurostat, the availability of data at sub-national level, such as administrative regions, is scarcer. Eurostat data were used as the sole source of sub-national statistical data. For spatially explicit data, as required by Approach 3, the situation of data availability is quite unpromising. To satisfy the data needs of the Tier 1 method heavy use of proxies was made. Statistical data were processed to complete missing data at regional administrative level and to cover years without data. The output of the statistical data processing stage is a complete time-series of data covering 1990 to 2010 for all regional administrative units.

The shortcomings in the availability of spatially explicit data were addressed by implementing a spatial allocation procedure. The procedure distributes demands in area to specific locations within a larger spatial unit. The demands for area are varied, such as for a land use types, management practises or input levels. The area demands are derived from the annual statistical data. The procedure structures the various and competing demands for area into factors and constraints. Factors define the suitability of a spatial location to accommodate a specific demand for area while constraints limit the allocation. The allocation is aided by a land use change matrix that has been developed from multi-annual Corine Land cover data using a multi-layer perceptron classifier. The output of the process are annual spatial layers of soil organic C-stocks, but also spatially explicit annual data of all parameters defining changes in soil organic C-stocks. This allows evaluating the effect of any changes over the 20-year period from 1990 to 2010 and includes a complete history to account for residual effects in the annual assessment.

All thematic layers of the data set produced are spatially specific, but do not necessarily reflect the conditions at each location. Rather, the data are consistent between layers for a location and over the period. The data are valid within the framework of their production, which may limit the use outside this context. Changes in soil organic C-stocks should be aggregated to a larger spatial unit, such as NUTS Level 2.

The main challenge in estimating GHG emissions and removals for CM and GM is the availability of suitable data. Some aspects of data availability and processing need further deliberation.

- **Land Use Factor**

For the categories that define the land use factor Corine land cover data provides a broad correspondence. The method implemented requires that any areas of mixed classes of the CLC classification (*Complex cultivation patterns* (2.4.2) and *Land principally occupied by agriculture with significant areas of natural vegetation* (2.4.3)) be consigned to a single land use category. Assigning the classes to land use categories can be guided by agricultural statistics. For GM the class *Pasture* (2.3.1) is used to signify managed grassland. For CLC90 the class will not cover all managed grassland, but was defined to include only those areas of grassland that are close to inhabited and cultivated land and more than occasional grazing can occur also in areas designated as *Natural Grassland* (3.2.1). For CLC2000 the guidelines for separating pastures from natural grassland seem to emphasise biomass production [8] and thus is closer to the GM land use category. Nonetheless, classifying areas to either type is frequently uncertain and allocating changes in GM land use should not be exclusively relate to CLC class *Pastures*.

- **Management Factor**

  The availability of consistent, complete and transparent data on management practices is quite scarce. The main source of statistical data on CM and GM management practices are the Eurostat Farm Structure Survey. A full census is carried out every 10 years, while data for other years are collected from samples. Also using data from the sample surveys a complete time-series can only be established by interpolating data between years.

  The data provided by the Survey on Agricultural Production Methods is a prominent source for information on management practices and input levels. So far the data are only available for the year 2010. Some aspects of the data or their presentation in the database can be confounding, such as linking animal housing with manure storage and treatment facilities to estimate the amount of manure applied on cropland. A repetition of the survey and at more detail than national level, for example at NUTS level 2, would be immensely useful to the evaluation of management practices.

- **Input Factor**

  In the IPCC Tier 1 method the level of input for CM, and management and input for GM, are defined in decision schema, but the criteria are rather qualitative and at times vague. No distinction is made between mineral fertiliser application rates, only if mineral N is applied or not. One may assume that if used mineral fertiliser is generally applied in quantities that will have a notable effect on crop yields and biomass production. Less evident and therefore more open to interpretation is the status of GM. The effect of uncertainty in the initial identification of the GM status is to some degree moderated by applying only changes in management and input, provided they are based on a consistent evaluation.

The use of a GIS for accounting of GHG emissions and removals from CM and GM from changes in soil organic C-stocks as a result of changes in land use and management is probably the only viable option. This conclusion is independent of the IPCC tier used, including a modelling approach under Tier 3. Common to all Tiers is further the matter of the availability of suitable data. Models may provide more detail of the changes in the soil organic C-stocks, but do not substitute for the lack of data on changes in land use, management practice or input level. While extending the temporal range of spatially explicit data into the past may prove taxing and rely on even more assumptions there is reasonable prospect for increasing the amount and scope of contemporary data.

Annex I: Data Sources

This Annex contains the sources of the data used for processing the Tier 1 method. Any data listed are freely available for download from web-pages available on the internet. For accessing the data a user may have to register.

The type of data are separated into statistical (tables) and spatial (maps). The statistical data refer to conditions within an administrative unit. For statistical data other than Eurostat this unit is generally a country. For Eurostat statistical data the level of detail of administrative units varies. As a general rule more data are available for larger units, although this is not always the case. Mainly, but not necessarily, the data from larger units are aggregated from the data of the composing smaller units.

For Eurostat statistical data the data name corresponds to the name of the table in the database, given in [] in the main text. Due to the organisation of the web-page a link to specific tables as an URL is not available. With few exceptions the data are located under the theme "Agriculture, forestry and fisheries: Agriculture (t_agri)". A few tables are located under "Agri-environmental indicators (t_aei)". Data from FAOSTAT are referenced to the new web-page. As for Eurostat data, the FAOSTAT web-design allows selecting specific data items for download. In contrast to Eurostat, for downloading data the option for bulk downloads is used. Where "System" is given as source the data were processed from other sources, as specified in the main text.

Not included in the list of source data are default values g by IPCC documents for a Tier 1 method. These values are generally not spatially diverse or at most defined for large regions comprising several countries.

Table 8: Statistical Data Sources

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
Conservation_ Agriculture_Area	Aquastat	Conservation agriculture area	statistical	NUTS 0	1974 … irregular	
Total_Harvested_ Irrigated_Crop_Area	Aquastat	Total harvested irrigated crop area	statistical	NUTS 0	1990 … irregular	
FERT_CARD	CARD	Fertilizer Use by Crop at the Country Level (1990–2010)	statistical	NUTS 0	1990 … 2010	
ECAF_Tillage	ECAF	Areas under conservation tillage	statistical	NUTS 0	2005	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
aei_fm_manfert	Eurostat, Fertilizers Europe	Consumption estimate of manufactured fertilizers, N fertiliser (t N)	statistical	NUTS 0	1985 …	
aei_fm_usefert	Eurostat	Use of inorganic fertilizers, N fertiliser (t N)	statistical	NUTS 0, 2	2000 …	
aei_fm_manfert	Eurostat	Consumption estimate of manufactured fertilizers (t N)	statistical	NUTS 0	1985 …	
aei_ps_inp	Eurostat, FADN	Farm input consumption areas, 3 classes (ha)	statistical	NUTS 0	1995 … 2007	
aei_fm_ms	Eurostat	Manure storage facilities	statistical	NUTS 0, 1, 2, 3	2000, 2003, 2010	
agr_r_landuse[65]	Eurostat	Land use area	statistical	NUTS 0, 1, 2	1974 …	
agr_r_acs agr_r_crop[66]	Eurostat	Crop area, production, yield	statistical	NUTS 0, 1, 2	2000 …	
agr_r_animal	Eurostat	Livestock number (1000 head)	statistical	NUTS 0, 1, 2	1977 …	
Apro_acs apro_cpp_crop[67]	Eurostat	Crops products - annual data, area, production, yield	statistical	NUTS 0	1955 …	
apro_cpp_luse[68]	Eurostat	Land use - annual data (1000 ha)	statistical	NUTS 0	1950 …	
apro_mt_lscatl	Eurostat	Cattle population - annual data (1000 head)	statistical	NUTS 0	1959 …	

[65] no longer available in Eurostat database (last check: October, 2016)

[66] replaces previous [agr_r_crops], but data records only start with year 2000, nomenclature changed

[67] no longer available in Eurostat database (last check: October, 2016); replaced by a [apro_acs_h] for 1955 – 199 and [apro_acs_a] for 2000 onwards

[68] no longer available in Eurostat database (last check: October, 2016)

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
apro_mt_lsequi	Eurostat	Equidae - annual data (1000 head)	statistical	NUTS 0	1960 … 1997	
apro_mt_lsgoat	Eurostat	Goats population - annual data (1000 head)	statistical	NUTS 0	1960 …	
apro_mt_lspig	Eurostat	Pig population - annual data (1000 head)	statistical	NUTS 0	1969 …	
apro_mt_lssheep	Eurostat	Sheep population - annual data (1000 head)	statistical	NUTS 0	1960 …	
ef_ls_ovlsureg	Eurostat	Livestock (number)	statistical	NUTS 0, 2	1990 … irregular	
ef_lsfodderaa	Eurostat	Fodder crops	statistical	NUTS 0	2005 … irregular	
ef_lu_ofirrig	Eurostat	Irrigation (ha)	statistical	NUTS 0, 1, 2	1990 … irregular	
ef_lu_ofsetasid	Eurostat	Fallow land and set-aside land (ha)	statistical	NUTS 0	1990 … irregular	
ef_lu_ovcropaa	Eurostat	Farmland (ha)	statistical	NUTS 0, 1, 2	1990 … irregular	
ef_olsaareg	Eurostat	Livestock (heads)	statistical	NUTS 0, 1, 2	2005, 2007, 2010	
ef_oluaareg	Eurostat	Land use (ha)	statistical	NUTS 0, 1, 2	2005, 2007, 2010	
ef_pmcomlecs	Eurostat	Common land grazing (ha)	statistical	NUTS 0	2010	
ef_pmgrazecs	Eurostat	Animal grazing on the holding (ha, LSU, period)	statistical	NUTS 0, 1, 2	2010	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
ef_pmhouscatlec	Eurostat	Animal housing – cattle (places, head)	statistical	NUTS 0, 1, 2	2010	
ef_pmhouslhenec	Eurostat	Animal housing - laying hens (places, 1000 head)	statistical	NUTS 0, 1, 2	2010	
ef_pmhouspigec	Eurostat	Animal housing – pigs (places, head)	statistical	NUTS 0, 1, 2	2010	
ef_pmmanapaa	Eurostat	Solid manure application as % of the UAA (area, LSU)	statistical	NUTS 0	2010	
ef_pmmanstolsu	Eurostat	Manure storage and treatment facilities (area, LSU)	statistical	NUTS 0, 1, 2	2010	
ef_pmslurapaa	Eurostat	Slurry application as % of the UAA (area, LSU)	statistical	NUTS 0	2010	
ef_pmsoilaa	Eurostat	Soil conservation (ha)	statistical	NUTS 0, 1, 2	2010	
ef_pmtilaa	Eurostat	Tillage methods (ha)	statistical	NUTS 0, 1, 2	2010	
ef_pograss	Eurostat	Permanent grassland (ha)	statistical	NUTS 0	2005, 2007, 2010	
ef_poirri	Eurostat	Irrigation (ha)	statistical	NUTS 0, 1, 2	2005, 2007, 2010, 2013	
ef_pomengmo	Eurostat	Mushrooms, energy crops, GMO (ha)	statistical	NUTS 0	2005, 2007, 2010	
ef_r_nuts	Eurostat	Structure of agricultural holdings by NUTS 3 regions - main indicators (ha)	statistical	NUTS 0, 1, 2, 3	2000, 2003, 2005, 2007	
Production_Crops_ E_Europe	FAOSTAT	Production of crops (area, yield, production)	statistical	NUTS 0	1962 …	
Production_Livestock_ LVS	FAOSTAT	Livestock (head, 1000 head)	statistical	NUTS 0	1962.	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
FAO_Input_Fertilizers_ N_Archive	FAOSTAT	Fertiliser input archive (t N)	statistical	NUTS 0	1961 … 2002	
FAO_Input_Fertilizers_ N_Consumption	FAOSTAT	Fertiliser consumption (t N)	statistical	NUTS 0	2002 …	
FERTISTAT	FAO	Fertiliser use by crop (kg N ha^{-1})	spatial	NUTS 0	2000	
IFA_N_Consumption	IFA	Fertiliser consumption (1000 t N)	spatial	NUTS 0	1962 …	

Table 9: Spatial Data: System Input

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
DIST00_CLC_Water	CLC2000	Distance to inland water surface, 100m resolution	spatial	grid	2000	V. 17
CLC90_IPCC	Corine LC 1990	Corine LC 1990 classified to IPC Land Use categories	spatial	grid	1990	V. 17
CLC00_IPCC	Corine LC 2000	Corine LC 2000 classified to IPC Land Use categories	spatial	grid	2000	V. 17
CLC06_IPCC	Corine LC 2006	Corine LC 2006 classified to IPC Land Use categories	spatial	grid	2006	V. 17
CLC90_IRRIG_ CNTY_MSQ	Corine LC 1990	Corine LC 1990 permanently irrigated areas	spatial	grid	1990	V. 17
CLC00_IRRIG_ CNTY_MSQ	Corine LC 2000	Corine LC 2000 permanently irrigated areas	spatial	grid	2000	V. 17
CLC06_IRRIG_ CNTY_MSQ	Corine LC 2006	Corine LC 2006 permanently irrigated areas	spatial	grid	2006	V. 17
CLC90_INLAND _WATER_MSQ	Corine LC 1990	Corine LC 1990 inland water areas	spatial	grid	1990	V. 17
CLC00_INLAND _WATER_MSQ	Corine LC 2000	Corine LC 2006 inland water areas	spatial	grid	2000	V. 17
CLC06_INLAND _WATER_MSQ	Corine LC 2006	Corine LC 2006 inland water areas	spatial	grid	2006	V. 17
CLC90_OTHER _AREAS_MSQ	Corine LC 1990	Corine LC 1990 other areas	spatial	grid	1990	V. 17
CLC00_OTHER _AREAS_MSQ	Corine LC 2000	Corine LC 2000 other areas	spatial	grid	2000	V. 17

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
CLC06_OTHER _AREAS_MSQ	Corine LC 2006	Corine LC 2006 other areas	spatial	grid	2006	V. 17
ESACCI_LC2000_ V161_ETRS_LAEA_BOX	ESA CCI LC	ESA CCI land cover 2000 classified to IPCC	spatial	grid	2000	V.1.6.1
ESACCI_LC2010_ V161_ETRS_LAEA_BOX	ESA CCI LC	ESA CCI land cover 2010 classified to IPCC	spatial	grid	2010	V.1.6.1
ESACCI_LC00_ IRRIG_CNTY_MSQ	ESA CCI LC	ESA CCI land cover 2000 irrigated areas	spatial	grid	2000	V.1.6.1
ESACCI_LC10_ IRRIG_CNTY_MSQ	ESA CCI LC	ESA CCI land cover 2010 irrigated areas	spatial	grid	2010	V.1.6.1
ESACCI_LC00_ SPARSE_CNTY_MSQ	ESA CCI LC	ESA CCI land cover 2000 sparsely vegetated areas	spatial	grid	2000	V.1.6.1
ESACCI_LC10_ SPARSE_CNTY_MSQ	ESA CCI LC	ESA CCI land cover 2010 sparsely vegetated areas	spatial	grid	2010	V.1.6.1
STU_AOIEU_ T_PH_H2O	ESDB STU raster	Topsoil pH (ph H_2O)	spatial	grid	static	V. 2.0
STU_AOIEU_ DEPTH_ROOTS	ESDB STU raster	Soil depth for roots (cm)	spatial	grid	static	V. 2.0
STU_AOIEU_ T_TEXT_CLS	ESDB STU raster	Topsoil texture class (cm)	spatial	grid	static	V. 2.0
STU_AOIEU_ T_ECE	ESDB STU raster	Topsoil Salinity (dS/m)	spatial	grid	static	V. 2.0
STU_AOIEU_AGLIM1	ESDB STU raster	Limit to Agriculture (Cultivation)	spatial	grid	static	V. 2.0
STU_AOIEU_ T_BD_LOG	ESDB STU raster	Topsoil bulk density (g/cm^3)	spatial	grid	static	V. 2.0

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
STU_ESDB_ T_TEXT_DOM	ESDB STU raster	Topsoil dominant texture class	spatial	grid	static	V. 2.0
STU_ESDB_ S_TEXT_DOM	ESDB STU raster	Subsoil dominant texture class	spatial	grid	static	V. 2.0
STU_ESDB_WR	ESDB STU raster	Water regime	spatial	grid	static	V. 2.0
STU_ESDB_IL	ESDB STU raster	Presence of impermeable layer	spatial	grid	static	V. 2.0
STU_AOIEU_T_PD	ESDB STU raster	Topsoil packing density	spatial	grid	static	V. 2.0
STU_ESDB_FAO85 _IS_Gleyic	ESDB STU raster	Gleyic property of soil	spatial	grid	static	V. 2.0
STU_ESDB_WM1	ESDB STU raster	Water regime applied	spatial	grid	static	V. 2.0
GISCO-NUTS	Eurostat GISCO	Downloaded via direct access to database	spatial	NUTS	static	2010
SUIT_LU_*category*	FAO Ecocrop	Bio-physical suitability for each Land Use category; based on FAO Ecocrop	spatial group	grid	static	
SUIT_CULT_ *type*	FAO Ecocrop	Bio-physical suitability for each crop type; based on FAO Ecocrop	spatial group	grid	static	
GRIDDED_LIVESTOCK_ CATTLE_2010_ ETRSLAEA_BOX	GLW	FAO gridded livestock for cattle	spatial	grid	2007	V 2

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
GRIDDED_LIVESTOCK_ PIGS_2010_ ETRSLAEA_BOX	GLW	FAO gridded livestock for pigs	spatial	grid	2007	V 2
GRIDDED_LIVESTOCK_ SHEEP_2010_ ETRSLAEA_BOX	GLW	FAO gridded livestock for sheep	spatial	grid	2007	V 2
GRIDDED_LIVESTOCK_ GOATS_2010_ ETRSLAEA_BOX	GLW	FAO gridded livestock for goats	spatial	grid	2007	V 2
GRIDDED_LIVESTOCK_ CHICKEN_2010_ ETRSLAEA_BOX	GLW	FAO gridded livestock for chicken	spatial	grid	2007	V 2
IRRIGATION_AOIEU	GMIA	Global Map of Irrigation Areas	spatial	grid	static	V. 5
GMTED2010_SLOPE_P	GMTED2010 derived	Terrain slope (%)	spatial	grid	static	29.07.2015
GMTED2010_HEIGHT	GMTED2010 derived	Terrain elevation (m)	spatial	grid	static	29.07.2015
LADA_V11_LUS_ ETRSLAEA_BOX	LADA	LADA land use classes	spatial	grid	static	V. 1.1
SOIL_RETENTION	LUISA	Soil retention	spatial	grid	static	
MOD17A3_AVG_ NPP_ETRS_LAEA_BOX	MODIS NPP	MODIS Net Primary Productivity	spatial	grid	2000 … 2010	
IPCC_CLIM_REGION_ ETRS_LAEA	RED	Climate regions according to IPCC classification	spatial	grid	period 1960 - 1990	
IPCC_CLIM_C_DEF_ MINERAL	RED	Default reference value for soil organic C-stocks	spatial	grid	static	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
MODIS_BURNT_ FRQ_2000_2009	UMD	MODIS frequency of burnt area 2000 – 2009	spatial	grid	2000 …	V. 5.1
TMIN_AVG_AMJJAS	WorldClim derived	Mean of monthly mean minimum Temperature for April - September	spatial	grid	Mean month 1960 - 1990	V. 1.4
TMAX_AVG_AMJJAS	WorldClim derived	Mean of monthly mean maximum Temperature for April - September	spatial	grid	Mean month 1960 - 1990	V. 1.4
TMAX_MAX_AMJ	WorldClim derived	Maximum of monthly mean maximum Temperature for April - June	spatial	grid	Mean month 1960 - 1990	V. 1.4
TMAX_MAX_JAS	WorldClim derived	Maximum of monthly mean maximum Temperature for July - September	spatial	grid	Mean month 1960 - 1990	V. 1.4
TMEAN_MEAN_YEAR_ ETRS_LAEA	WorldClim	Mean annual temperature	spatial	grid	Mean month 1960 … 1990	V. 1.4
PREC_SUM_YEAR_ ETRS_LAEA	WorldClim	Mean annual precipitation sum	spatial	grid	Sum month 1960 … 1990	V. 1.4
PREC_SUM_MAM	WorldClim derived	Total precipitation for March - May	spatial	grid	1960 - 1990	V. 1.4
PREC_SUM_OND	WorldClim derived	Total precipitation for October - December	spatial	grid	1960 - 1990	V. 1.4
AI_YEAR_ETRS_LAEA	WorldClim derived	Aridity Index also available from	spatial	grid	1960 - 1990	V. 1.4
GROWING_PERIOD _GRASS_TMEAN[1]	System	Growing period grassland	spatial	grid	1960 - 1990	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
FACTOR_NPP_LU-*category*	System	NPP fuzzy set membership function for a Land Use category	spatial group	grid	Period mean 2000 – 2010	
PSMD_MAM[2]	System	Potential soil moisture deficit March - May	spatial	grid	1960 - 1990	
PSMD_SON[2]	System	Potential soil moisture deficit September – November	spatial	grid	1960 - 1990	

[1] Schaumberger, A., E. Pötsch, H. Formayer (2012) GIS-based analysis of spatio-temporal variation of climatological growing season for Austria. Grassland Science in Europe, Vol. 7, edited by P. Golinski, M. Warda and P. Stypinski, ISBN 978-83-89250-77-3, p634-636.

[2] Rickard, D. S. (1960) The estimation of seasonal soil moisture deficits and irrigation requirements for Ashburton, New Zealand, New Zealand Journal of Agricultural Research, 3:5, 820-828, DOI: 10.1080/00288233.1960.10419881. URL: http://dx.doi.org/10.1080/00288233.1960.10419881

Table 10: Data Sources

Source	Name	URL
Aquastat	FAO Aquastat	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
CARD	Center for Agricultural and Rural Development, Iowa State University	http://www.card.iastate.edu/products/publications/synopsis/?p=1178
CGIAR PET	Consultative Group on International Agricultural Research, Global Aridity and PET Database	http://www.cgiar-csi.org/data/global-aridity-and-pet-database
CLC	CORINE Land Cover	http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-1990-raster-3 http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-raster-3 http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-3 http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012
ECAF	European Conservation Agriculture Federation	http://www.ecaf.org/downloads
ESA CCI LC	ESA CCI Land Cover dataset	http://maps.elie.ucl.ac.be/CCI/viewer/
ESDB STU raster	European Soil Database derived data	http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDB_Data_Distribution/derived_data.html
ESTAT_SAPM	Survey on Agricultural Production Methods	http://ec.europa.eu/eurostat/data/database
Eurostat	Eurostat Database by Themes: Agriculture, forestry and fisheries	http://ec.europa.eu/eurostat/data/database
Eurostat GISCO	Geographical information system of the Commission, Nomenclature of territorial unites for statistics	http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts#nuts10

Source	Name	URL
FAO Ecocorop	FAO Ecocrop Database	http://ecocrop.fao.org/ecocrop/srv/en/dataSheet?id=2114
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics Division	http://faostat3.fao.org/browse/Q/*/E
GlobalPET	Global Potential Evapo-Transpiration dataset	http://www.cgiar-csi.org/data/global-aridity-and-pet-database http://www.cgiar-csi.org/data/global-aridity-and-pet-database
GLW	Gridded Livestock of the World	http://www.livestock.geo-wiki.org/
GMIA	Global Map of Irrigation Areas	http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm
GMTED2010	Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010)	https://lta.cr.usgs.gov/GMTED2010 http://topotools.cr.usgs.gov/gmted_viewer/gmted2010_global_grids.php
IFA	International Fertilizer Association	http://www.fertilizer.org//En/Statistics/Agriculture_Committee_Databases.aspx
LADA	Land Degradation in Drylands Land Use System	http://www.fao.org/geonetwork/srv/en/resources.get?id=37139&fname=irrit.zip&access=private
MODIS NPP	Terra/MODIS Net Primary Production Yearly L4 Global 1km	https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod17a3
UMD	University of Maryland	http://modis-fire.umd.edu/
RED	Renewable Energy Directive Reference Data	http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy/
FAOSTAT	Food and Agricultural organization of the United Nations - Statistics Division	http://faostat3.fao.org/download/Q/QC/E
WorldClim	WorldClim Global Climate Data	http://www.worldclim.org/ http://www.worldclim.org/current

Annex II: System Output

The method for processing a soil organic C-stock baseline is based on building a stack of data for 20 consecutive years. The 21st year (2010) is the first year where all previous changes have been fully accounted for. All data outputs are spatially specific and temporally dependent, i.e. the allocation of changes in a current year depends on the conditions over the previous years. As a consequence, the layers should not be used without the temporal context.

To all land use, management and input layers a history file is attached during processing. The portion of occupation of a management practice or input level over time is not only an aspect in the spatial allocation, but can be of importance when deciding whether a factor modifies soil organic C-stocks. Such information can be re-created form the layer stack information and is not included in the list of outputs.

Table 11: Spatial Data: System Processed

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
LU_CATEGORY	System	Location of Land Use categories (1 to 9)	spatial	grid	1990 … 2010	
LU_CULT	System	Location of culture types within long-term cultivated	spatial	grid	1990 … 2010	
PERMANET_GRAZE	System	Permanent Grassland areas grazed by livestock	spatial	grid	1990 … 2010	
ROUGH_GRAZING	System	Areas of rough grazing	spatial	grid	1990 … 2010	
IRRIG_ *type*	System	Irrigated area for permanent grassland, cereals, cotton, grain maize, potatoes, pulses, rape and turnip, soya, sugar beet and sunflower	spatial	grid	1990 … 2010	
YIELD_HARV_ *type*	System	Yield of harvested crop for all culture types	spatial	grid	1990 … 2010	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
TILL_PRACTICE	System	Tillage practice applied: conventional, conservation or zero	spatial	grid	1990 … 2010	
FERT_GRASS	System	Fertilised permanent grassland	spatial	grid	1990 … 2010	
GrazingLVS_Density_ Index	System	Grazing livestock density index	spatial	grid	1990 … 2010	
GrazingLVS_Stocking_ Rate	System	Grazing livestock density index	spatial	grid	1990 … 2010	
GrazingLVS_Stock_ Density_Month	System	Grazing livestock density-month index	spatial	grid	1990 … 2010	
Grazing_Degraded	System	Areas of degradation (moderately, severely) on permanent grassland	spatial	grid	1990 … 2010	
Grazing_Improved	System	Areas of improved (moderately, considerably) on permanent grassland	spatial	grid	1990 … 2010	
LVS_Bedding_ Removed	System	Crop residues removed for bedding material of livestock under MMS	spatial	grid	1990 … 2010	
BURNT_AREA	System	Burnt areas on cropland	spatial	grid	1990 … 2010	
N_Residues	System	Amount of N in crop residues (above and below ground)	spatial	grid	1990 … 2010	
SOIL_CONSERVATION	System	Practice of soil conservation: Normal winter crop Cover or intermediate crop Plant residues Bare soil	spatial	grid	1990 … 2010	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
N_RATE_ *type*	System	Mineral N fertiliser application rate (dt N ha^{-1}) for crop type	spatial	grid	1990 … 2010	
FYM_APPLIED	System	Areas where farm yard manure is applied (km^2)	spatial	grid	1990 … 2010	

Annex III: Spatial Layers for Tier 1

This Annex summarises the spatial layers used to estimate changes in soil organic C-stocks for CM and GM. The layers are arranged according to the items presented in the decision schema of IPCC.

Table 12: Spatial Data: Tier 1

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
Climate Region						
FROST_DAYS		occurrence of frost days in year (not used)	spatial	grid		
MAT	WorldClim	annual mean of daily temperature (MAT)	spatial	grid	Mean 1960 … 1990	
MMT	WorldClim	monthly mean of daily temperature (MMT)	spatial	grid	Mean 1960 … 1990	
MAP	WorldClim	mean of total annual precipitation (MAP)	spatial	grid	Mean 1960 … 1990	
PET	WorldClim	mean of total annual potential evapo-transpiration (PET)	spatial	grid	Mean 1960 … 1990	
HEIGHT	GMTED2010	Elevation	spatial	grid	static	
Soil Type						
ORG_DEPTH	ESDB STU raster	Thickness of organic horizon	spatial	grid	static	
SOC_CONTENT	ESDB STU raster	OC by weight	spatial	grid	static	
CLAY_CONTENT	ESDB STU raster	Clay content	spatial	grid	static	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
SAND_CONTENT	ESDB STU raster	Sand content	spatial	grid	static	
WR	ESDB STU raster	Subject to water saturation episodes	spatial	grid	static	
WRB_CLASS	ESDB STU raster	WRB Classification	spatial	grid	static	
Default Reference Soil Organic C-Stock						
SOIL_TYPE	System	Soil Type	spatial	grid	static	
CLIMATE_REGION	System	Climate regions	spatial	grid	static	
DEF_SOC	System	Default Reference Soil Organic C-Stock	spatial	grid	static	
Land Use Category (F_{LU})						
LU_CATEGORY	System	Permanent Grassland	spatial	grid	1990 … 2010	
LU_CATEGORY	System	Annual crop[1]	spatial	grid	1990 … 2010	
LU_CATEGORY	System	Rice, paddy rice[1]	spatial	grid	1990 … 2010	
LU_CATEGORY	System	Perennial/tree crops[1]	spatial	grid	1990 … 2010	
LU_CATEGORY	System	Set-aside (<20 years)[1]	spatial	grid	1990 … 2010	
LU_CATEGORY	System	Natural Vegetation	spatial	grid	1990 … 2010	
LU_CATEGORY	System	Wetlands	spatial	grid	1990 … 2010	
LU_CATEGORY	System	Artificial	spatial	grid	1990 … 2010	
LU_CATEGORY	System	Other	spatial	grid	1990 … 2010	

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
Cropland Management (*F_{MG}*)						
TILL_PRACTICE	System	No primary tillage, minimal soil disturbance				
TILL_PRACTICE	System	Primary and/or secondary tillage with reduced soil disturbance				
TILL_PRACTICE	System	Full tillage				
Cropland Input (*F_I*)						
		Residue Management				
LVS_Bedding_ Removed	System	Crop residues removed				
BURNT_AREA	System	Crop residues burnt				
		Practice reducing C-input				
LU_CATEGORY	System	Rotation with bare fallow				
LU_CULT	System	Low residue crops				
		Practice increasing C-input				
SOIL_CONSERVATION	System	Green manure				
SOIL_CONSERVATION	System	Cover crops				
LU_CATEGORY	System	Vegetated fallow				
IRRRIG	System	Irrigation				
LU_CULT	System	Grass in crop rotation				
		Additions				
N_RATE_ *type*	System	N-mineral fertiliser				

Data Name	Source	Comment	Data Type	Spatial Reference	Temporal Coverage	Version
FYM_APPLIED	System	Organic amendments (manure)				
LU_CULT	System	N-fixing crop				
Grazing Land Category (F_{LU})						
LU_CATEGORY	System	Permanent Grassland				
Grazing Land Management (F_{MG})						
Grazing_Degraded	System	Degraded relative to native				
Grazing_Improved	System	Higher productivity relative to native				
Grazing Land Input (F_I)						
FERT_GRASS	System	Fertilised grassland				
IRRRIG	System	Irrigated grassland				
FACTOR_NPP_LU-*category*	System	Higher productivity				

[1] Part of Cropland, long-term cultivated

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List of Acronyms

Acronym	Label
AFOLU	Agriculture, Forestry and Other Land Use
AI	Aridity Index
AOI	Area of Interest
AR	Afforestation/reforestation
ASCII	American Standard Code for Information Interchange
AVHRR	Advanced Very High Resolution Radiometer
CARD	Center for Agricultural and Rural Development, Iowa State University
CGIAR-CIS	Consultative Group for International Agricultural Research – Consortium for Spatial Information
CLC	CORINE Land Cover
CORINE	Coordinate Information on the Environment
CM	Cropland Management
CR	Control-Return (ASCII code)
CSV	Comma-separated values
D	Deforestation
ECAF	European Conservation Agriculture Federation
EEA	European Environment Agency
EF	Emission factor (organic soils)
ESDB	European Soil Database
ETRS89	European Terrestrial Reference System 1989
EU	European Union
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics Division
FM	Forest Management
FYM	Farm yard manure
FSS	Eurostat Farm Structure Survey
GHG	Greenhouse gas
GIS	Geographic Information System
GloPEM	Global Production Efficiency Model
GLW	Gridded Livestock of the World
GM	Grazing Land Management
GMIA	Global Map of Irrigation Areas

Acronym	Label
GMTED	Global Multi-resolution Terrain Elevation Data
HAC	High activity clay soil
HS	Histosols
HWSD	Harmonized World Soil Database
IFA	International Fertilizer Industry Associations
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
LADA	Land Degradation in Drylands
LAEA	Lambert Azimuthal Equal Area
LF	Line-feed (ASCII code)
LOC	Low activity clay soil
LSU	Livestock Unit
LUC	Land use change
LUISA	Land-Use-based Integrated Sustainability Assessment modelling platform
LULUCF	Land use, land use change and forestry
LUS	Land use system
MAP	Mean Annual Precipitation
MCE	Multi-criteria evaluation
MODIS	Moderate Resolution Imaging Spectroradiometer
MOLA	Multi-object land allocation
MF	Membership Function
MMS	Manure Management System
NASA	National Aeronautics and Space Administration
NPP	Net Primary Productivity
NUTS	Nomenclature des Unités territoriales statistiques
PD	Packing Density
PET	Potential evapo-transpiration
PSDM	Potential Soil Moisture Deficit
RDBMS	Relational Database Management System
RV	Re-vegetation
SAPM	Survey on Agricultural Production Methods
sDSS	Spatial Decision support System
SOC	Soil organic carbon
SOCREF	Default reference value for the soil organic carbon stock
UAA	Utilised agricultural area
UNEP	United Nations Environment Programme

Acronym	Label
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
WDR	Wetland Drainage and Rewetting
WRB	World Reference Base for Soil Resources

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