New soil information for the MARS Crop Yield Forecasting System[1]

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1 Introduction

The report is about the development of a framework for incorporating version 4.0 of the Soil Geographical Database of Europe (SGDBE) in the Crop Growth Monitoring System (CGMS) which is a part of the **Mars Crop Yield Forecasting System** (MCYFS).

The work is subdivided into different activities which are discussed in the following chapters:

- generation of soil parameters with FAO (Food and Agriculture Organisation) soil map (see chapter 2)
- check and update of WRB soil names (see chapter 3)
- rewriting the Pedotransfer Rules (PTR) for salinity, alkalinity and drainage class according to the new nomenclature (see chapter 4)
- redefinition of new Soil Physical Groups and their parameters (see chapter 5)
- redefinition of new Rooting Depth classes (see chapter 6)
- re-evaluation of CGMS Suitability Criteria (see chapter 7)
- new evaluation of Soil Suitability Criteria (see chapter 7)

1.1 Background and policy context

The MARS (Monitoring Agriculture with Remote Sensing) STAT Sector of the Agriculture and Fisheries Unit of the Joint Research Centre (DG-JRC EC) is part of the Institute for the Protection and Security of the Citizen of the European Commission.

The need of early European figures on harvests allowed the development of the MARS-STAT activities (Meyer-Roux, Vossen, 1993). Among these, a crop yield forecasting system was put into place to supply early information to the DG-Agriculture Outlook group on the **development and growth conditions of crops during the campaign.**

The MARS STAT action is running in an operational context what is called the Mars Crop Yield Forecasting System (MCYFS) according to the Council/Parliament Decision 1445/2000/EC on the application of area frame survey and remote sensing techniques to the agricultural statistics for 1999 to 2003. The legal basis had a Renewal of the Decision for the period 2004-2007 (Ref. PE/CONS 3661/1/03 OJ L 309 of 26.11.2003). Research actions related to the system find currently a legal basis on the JRC multi annual working programme (FP6 2003-2006 action 1121 MARS STAT).

1.2 The Soil Geographical Database of Europe

This database forms the core of European Soil Information System (EUSIS) developed by the action 'Monitoring the State of European Soils' (MOSES) of the Land Management and Natural Hazards Unit (LMNH) of the Institute for Environment and Sustainability (IES) of the JRC. Its history dates back to the mid 80's:

In 1985, the Commission of the European Communities published a soil map of the EC at 1:1,000,000 scale. In 1986, this map was digitised to build a soil database to be included in the

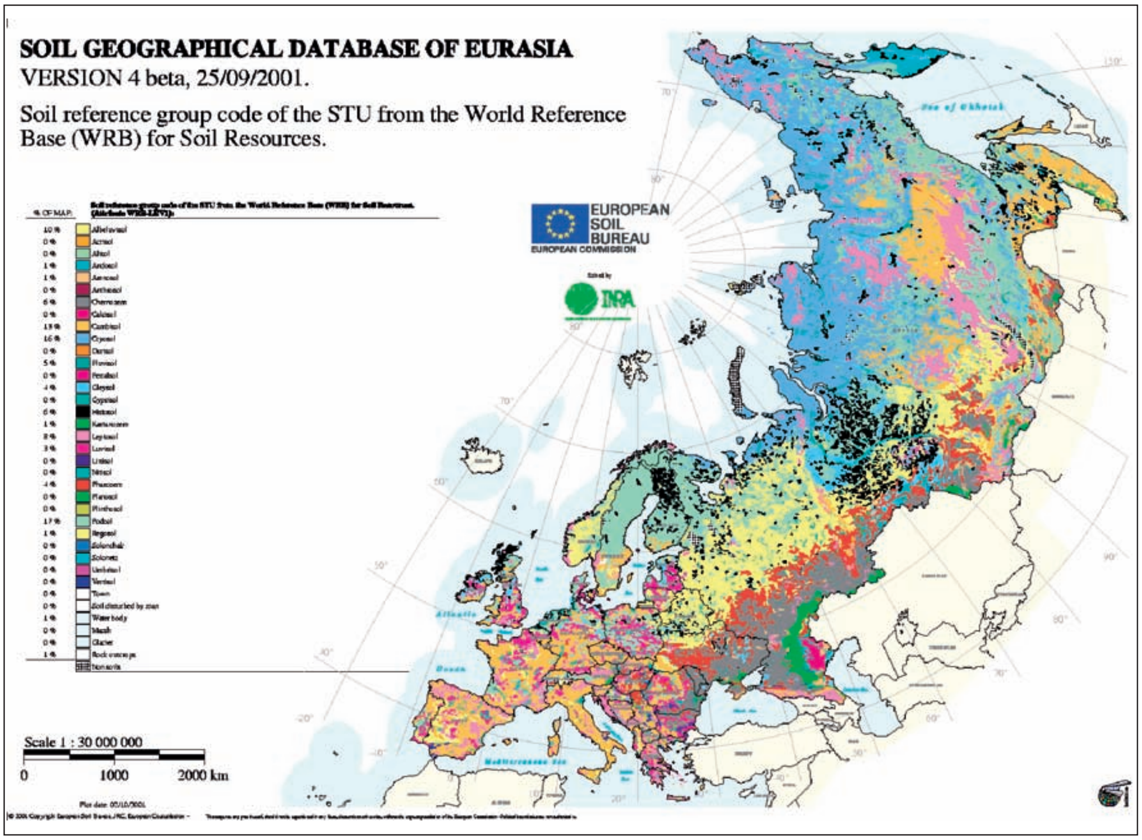
CORINE project (Co-ordination of Information on the Environment). This database was called the Soil Geographical Database of the EC, version 1. The database was enriched in 1990-1991 from the archive documents of the original EC Soil Map and became version 2. The JRC then formed the Soil and GIS Support Group with experts to give some advice concerning this database. These experts recommended that new information should be added and each participating country should make updates, leading to the current version 4.0 of the database.

The aim of the Soil Geographical Database at scale 1:1,000,000 is to provide a harmonised set of soil parameters covering Europe and the Mediterranean countries to be used in agro-meteorological and environmental modelling at regional, state, or continental levels. Its elaboration focuses on these objectives.

Originally covering countries of the European Union, the database has recently been extended to Central European and Scandinavian countries (fig. 1). It currently covers Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, FYROM (Former Yugoslav Republic of Macedonia), Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Serbia and Montenegro, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom. The extension is completed for Iceland and the New Independent States (NIS) covering Belarus, Moldova, Russia and Ukraine. Finally, work is on-going to further extend it to other Mediterranean countries: Algeria, Cyprus, Egypt, Jordan, Lebanon, Malta, Morocco, Palestine, Syria, Tunisia and Turkey.

Beside these geographical extensions, the database has also experienced important changes during its lifetime. The latest major changes concern the introduction of a new extended list for parent materials, and, for coding soil types, the use of the new World Reference Base (WRB) for Soil Resources in association with the 1990 FAO-UNESCO revised legend.

Figure 1-1: **Provisional soil map extracted from the Euroasian Geographical Soil Databases ver. 4.0.**



The database is currently managed using the ArcInfo® Geographical Information System (GIS) software package.

The database contains a list of Soil Typological Units (STU), characterizing distinct soil types that have been identified and described. The STU are described by attributes (variables) specifying the nature and properties of the soils, for example the texture, the moisture regime, the stoniness, etc. The scale selected for the geographical representation is the 1:1,000,000. At that scale, it is not technically feasible to delineate each STU. Therefore STUs are grouped into Soil Mapping Units (SMU) to form soil associations. The criteria for soil groupings and SMU delineation have taken into account the functioning of pedological systems within the landscape.

The detailed instruction guide (doc. EUR 20422 EN) of this inventory as well as the full data and documentation are available from the EU Soil Portal: http://eusoils.jrc.it/index.html.

1.3 The Mars Crop Yield Forecasting System

Within the MCYFS several elements and independent modules are integrated to monitor crop behaviour and produce crop yield forecasts. The MCYFS is run operationally on an area covering the whole European Continent, Maghreb and Turkey. The crops covered by system simulation models currently are spring barley, grain maize, rape seed, sunflower, potato, sugar beet, field beans, pastures and rice. However, the crop parameters simulated can be extended to other crops or varieties belonging to the same class such as winter barley, durum wheat, and field peas. An extended documentation of the MCYFS can be found under the **METAMP report**, 2004 (http://agrifish.jrc.it/marsstat/Crop%5FYield%5FForecasting/METAMP/).

The main pillars of the system are:

- Observed meteorological data collection, processing and analysis
- Simulation of agro-meteorological crop growth parameters
- Low resolution satellite data analysis
- Statistical analysis and forecasts

The MCYFS can be ideally divided into three levels:

1. At the first level the meteorological data are collected, quality checked, processed and analysed as own source of information.

2. At the second level a simulation engine (a crop growth simulation system) is run to transform the meteorological data into an effect on crop biomass production. The engines used are the **Crop Growth Monitoring System** (WOFOST model adapted to the European Scale) and LINGRA (used for pastures). At this stage auxiliary information like **soil parameters**, crop calendars, crop practices, crop parameters (the last three form the core of the crop knowledge base) are injected as fundamental information for an acceptable simulation. Many crop specific indicators and predictors are produced and transferred to the statistical analysis to support the production of a quantitative yield forecast. The second level of the system includes as well the processing of remote sensing data to produce measured vegetation indicators which can be compared with the agro-meteorological indicators and used as well as predictors. Results from the first two levels are accessible for external users via the MARSOP-portal (*http://www.marsop.info/*).

3. At the third level, the indicators obtained from meteo, agro-meteo and remote sensing are related to the time series of the official yields and analysed through scenarios. The final re-

sults are quantitative yield forecasts that together with the analysis of the previous output are published into the MARS bulletins (*http://agrifish.jrc.it/marsstat/Bulletins/2006.htm*).

1.4 Current use of soil data in CGMS

For the second level of the MCYFS where the CGMS is running to produce decadal crop growth indicators **soil data is needed as a static input variable**.

In the current CGMS the Soil Geographical Data Base of Europe (SGDBE) at 1:1,000,000 version 3.1 (INRA, 1995; Le Bas, 1996; Jones and Buckley, 1996) is used. The MAGHREB countries, Turkey, Russia, Moldova, Ukraine and Belarus are not covered in this version of the SGDBE implemented in the CGMS. For these countries, data from the Digitised World Soil Map at 1:5,000,000 (FAO, 1995) are used.

The soil data is used to determine soil input variables to the agrometeorological model giving information about the **soil type's geographical location** and the **soil properties** which are needed to simulate the crop growth during the year. The main soil properties are soil depth aiming at defining the **potential rooting depth**, and water retention properties giving through **soil physical groups**. The description of the soil characteristics for the crop simulation model in CGMS only relies on these two parameters. They fully describe the soil for simulation purposes. Each STU is attributed to a soil physical group defining the available water capacity (AWC). The AWC is a static soil characteristic and gives the amount of water between field capacity (wet soil) and wilting point (no water available for plants anymore) per unit length rooting depth. Multiplication of AWC and rooting depth gives the maximum available water which a soil can supply to a plant. It should be noted that the rain fed crop yields of the CGMS are more sensitive to the rooting depth than to the soil physical group (van der Goot, 1998).

Further, the soil map is used as a 'land use probability map' to define which crops have to be included in the **simulation for a given soil unit**. Ideally, this decision would be taken on the basis of actual land-use information, but a European-wide detailed classification of land cover is not available. Hence, within the CGMS the decision is simply based on the **soil suitability** of the different crops: if at least part of the soil mapping unit (one or more STU's) is deemed appropriate then the simulation will be performed. The result of this strategy is that the yield figures produced by the CGMS are assessed for suitable soils only.

Suitable soils are determined per crop group on the basis of **crop growth limiting properties** of these soils. The limiting soil properties are for instance slope, texture, agricultural limiting phase, rooting depth, drainage, salinity and alkalinity. The slope, texture and phase data can be obtained directly from the soil database, while others like rooting depth, drainage conditions, salinity and alkalinity have to be derived from basic soil properties using pedotransfer rules.

2 Generation of soil parameters with FAO soil map

For countries listed in Annex 1 which are not covered in the SGDBE, the attributes of SOIL, SLOPE, TEXT and PHASE/AGLIM are generated using additional databases such as the 1:5,000,000 Soil Map of the World (FAO).

2.1 Data available from the SGDBE at 1:1,000,000 scale

In the latest version of the Soil Geographical Database of Europe (SGDBE), the countries can be grouped in 5 categories following the available data (see Table 2-1). For the categories 1, 2 and 3, the data available is used directly in the project. For category 4, an attempt to link the available data with the Digital Soil Map of the World was foreseen to try to complete the data for STU organisation within SMU, texture and phases. As this could not be realised the Soil Digital Map of the World is used. For category 5, as no data is available, the Digital Soil Map of the World must be used. The countries are also listed in Annex 1. For each country, the origin of the soil data is indicated together with the basic soil name reference. For the latter see chapter 4 for more information on the several soil classifications.

Table 2-1: **Categories of countries following the available information**

Category	SMU delineation	STU.ORG	STU	Countries
1	available at a resolution of 1:1,000,000	available	available for all attributes	Albania, Algeria (Northern part), Austria, Belgium, Bulgaria, Czech Republic, Denmark, Egypt, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lebanon, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom
2	available at a resolution of 1:1,000,000	available	available for some attributes	Bosnia and Herzegovina, Croatia, FYROM (Former Yugoslav Republic of Macedonia), Yugoslavia, Palestine
3	available at a resolution of 1:2,500,000	available	available for some attributes	Belarus, Moldova, Russia, Ukraine
4	available at a resolution of 1:1,000,000 with a soil name or a soil association	not available	not available	Cyprus, Iceland, Morocco, Tunisia, Turkey
5	not available	not available	not available	Algeria (Southern part), Armenia, Azerbaijan, Georgia, Jordan, Libya, Malta, Syria, Israel, Canary Islands

2.2 Data available from the DSMW at 1:5,000,000 scale

The Digital Soil Map of the World (DSMW) corresponds to the digitisation of the Soil Map of the World at 1:5,000,000 scale and its legend. Soils are described through soil associations for which we have the list of soil types in the FAO-UNESCO 1974 legend, texture in three classes, slope in three classes and phases. A percentage of area for each soil type within each soil association was also computed.

2.3 Use of the DSMW

For the countries in categories 4 and 5 (see Table 2-1), the DSMW was used. The following steps were applied:

1. importing the data available in the ArcInfo® export format into ArcInfo®. They are in geographical co-ordinates (not projected). The data was divided into three different categories:
   - afscntll: for Africa
   - euscntll: for Europe
   - nescntll: for Asia
2. eliminating the countries situated outside the area of interest;
3. harmonising the structure of the three categories for having the same naming and structure for all the attributes;
4. projecting the categories into the projection used for the SGDBE;
5. harmonising the structure of the categories to be compatible with the structure of the SGDBE;
6. realising a geometrical fitting following the procedure elaborated for the SGDBE, and using data from the Digital Chart of the World on the basis of:
   - country borders,
   - river patterns compared to the extent of Fluvisols,
   - lakes,
   - temporary hydrological patterns compared with saline soils for Northern African countries,
7. applying geometrical conformity rules to the fitted categories;
8. adding the fitted categories to that of the SGDBE following the procedure elaborated for the SGDBE.

For the semantic data, i.e. the description of soil associations, they are available in one file named worldexp.dat, in ASCII format. The structure of the file is described in Table 2-2.

The data was imported into ArcInfo® as an INFO file. Then, the structure was changed to have two separate files for the SGDBE:

– one file giving the organisation of soil types within SMU,

– the other giving the description of the soil types with the same structure as those of the SGDBE:

– the attributes FAO85-FULL, TEXT-SRF-DOM, TEXT-SRF-SEC, SLOPE-DOM, SLOPE-SEC, AGLIM1 and AGLIM2 are entered

– the other attributes have no information.

Table 2-2: **Structure of the ASCII file worldexp.dat giving the description of soil associations (SMU).**

Attribute name	Signification	Main characteristics
SNUM	SMU number	integer type with 4 digits
FAOSOIL	soil code of the SMU	character type This code is composed by the dominant soil type followed by a number (showed on the legend), the dominant texture class and the dominant slope class. For non soil units, the code is constituted by 2 characters only.
PHASE1 PHASE2	dominant and secondary phases	character type
MISCLU1 MISCLU2	dominant and secondary miscellaneous units (non soil units)	integer type
PERMAFROST	permafrost zone code	integer type
A set of attributes that is repeated for each soil type of the SMU		
SOIL UNIT	soil name	character type
PERCENT	percentage of area of the soil type within the SMU	integer type
1A	percentage of area that corresponds to the values '1' for texture and 'a' for slope for the soil type	real type
1B	percentage of area that corresponds to the values '1' for texture and 'b' for slope for the soil type	real type
1C	percentage of area that corresponds to the values '1' for texture and 'c' for slope for the soil type	real type
2A	percentage of area that corresponds to the values '2' for texture and 'a' for slope for the soil type	real type
2B	percentage of area that corresponds to the values '2' for texture and 'b' for slope for the soil type	real type
2C	percentage of area that corresponds to the values '2' for texture and 'c' for slope for the soil type	real type
3A	percentage of area that corresponds to the values '3' for texture and 'a' for slope for the soil type	real type
3B	percentage of area that corresponds to the values '3' for texture and 'b' for slope for the soil type	real type
3C	percentage of area that corresponds to the values '3' for texture and 'c' for slope for the soil type	real type
NO TEXTURE NO SLOPE	percentage of area that corresponds to the values ' ' for texture and ' ' for slope for the soil type	real type

The minimum value of the texture class was given to the dominant texture class. The same approach was used to determine the dominant slope class (Table 2-3 and Table 2-4). That means if the texture classes are 1 and 2, then the dominant texture class is 1 (the minimum value) and the secondary texture class is 2. It is not the minimum value in the sense of percentage of area. Both classes have the same percentage of area in the DSMW file. An adaptation of the coding used within the SGDBE was necessary because in the DSMW, texture and slope are only in 3 classes (Table 2-5 and Table 2-6).

The values for the phases where copied from those of the soil association to all the STUs that are within the soil association. An adaptation of the codes was made to maintain the particularity of the DSMW codes (Table 2-7). For some countries, parent material information was available in the booklets of the Soil Map of the World. This information has been added to the STU description using the codes for the attributes of the SGDBE MAT1 and MAT2, and PAR-MAT-DOM and PAR-MAT-SEC.

Only soil associations and soil types from the area of interest were kept and the two files obtained were added to those of the SGDBE.

Table 2-3: **Correspondence for texture class values between the DSMW and the SGDBE**

Texture classes from the DSMW	Dominant texture class for TEXT-SRF-DOM from the SGDBE	Secondary texture class for TEXT-SRF-SEC from the SGDBE
1	1	0
2	6	0
3	7	0
1/2	1	6
1/3	1	7
2/3	6	7
‘ ’ and soil name ≠ ND[1]	9	0
‘ ’ and soil name = ND	0	0

Table 2-4: **Correspondence for slope class values between the DSMW and the SGDBE**

Slope classes from the DSMW	Dominant slope class for SLOPE-DOM from the SGDBE	Secondary slope class for SLOPE-SEC from the SGDBE
a	1	0
b	5	0
c	6	0
a/b	1	5
a/c	1	6
b/c	5	6
‘ ’	0	0

Table 2-5: **Definition of texture classes**

Code	Description
0	no information
9	no texture (Histosols, etc.)
1	coarse (clay < 18% and sand > 65%)
2	medium (18% < clay < 35% and sand > 15%, or clay < 18% and 15% < sand < 65%)
3	medium fine (clay < 35% and sand < 15%)
4	fine (35% < clay < 60%)
5	very fine (clay > 60%)
6	medium (18% < clay < 35%, or clay < 18% and 15% < sand < 65%) (for use with the Digital Soil Map of the World only)
7	very fine (clay > 35%) (for use with the Digital Soil Map of the World only)

[1] ND signifies Not Determined, that means no information about the soil association.

Table 2-6: **Definition of slope classes**

Code	Description
0	no information
1	level (dominant slope ranging from 0 to 8%)
2	sloping (dominant slope ranging from 8 to 15%)
3	moderately steep (dominant slope ranging from 15 to 25%)
4	steep (dominant slope over 25%)
5	sloping to moderately steep (dominant slope from 8 to 30%) (for use with the Digital Soil Map of the World only)
6	steep to mountainous (dominant slope more often greater than 30%) (for use with the Digital Soil Map of the World only)

Table 2-7: **Definition of the agricultural limiting constraints classes**

Code	Description
0	no information
1	no limitation to agricultural use
2	gravelly (over 35% gravel diameter < 7.5 cm)
3	stony (presence of stones diameter > 7.5 cm, impracticable mechanisation)
4	lithic (coherent and hard rock within 50 cm)
5	concretionary (over 35% concretions diameter < 7.5 cm near the surface)
6	petrocalcic (cemented or indurated calcic horizon within 100 cm)
7	saline (electric conductivity > 4 mS.cm-1 within 100 cm)
8	sodic (Na/T > 6% within 100 cm)
9	glaciers and snow caps
10	soils disturbed by man (i.e. landfills, paved surfaces, mine spoils)
11	fragipan
12	excessively drained
13	almost always flooded
14	eroded phase, erosion
15	phreatic phase (shallow water table)
16	duripan (silica and iron cemented subsoil horizon)
17	petroferric horizon
18	permafrost
20	stony (for use with the Digital Soil Map of the World only. The stony phase in the Digital Soil Map of the World corresponds to the gravelly and the stony phases of the SGDBE
21	petric (for use with the Digital Soil Map of the World only)
22	petrogypsic (for use with the Digital Soil Map of the World only)
23	cerrado (for use with the Digital Soil Map of the World only)

2.4 Geometric correction

Some countries in the Mediterranean area do not have the final geometry. The final introduction of these countries into the SGDBE version 4.0 has been made by INRA following the procedure elaborated for the SGDBE. This means the following for each country (Algeria (Northern part), Egypt, Palestine, and Lebanon):

1. harmonising the structure of country coverage for having the same naming and structure for all the attributes;
2. projecting the country coverage into the projection used for the SGDBE;
3. realising a geometrical fitting following the procedure elaborated for the SGDBE, and using data from the Digital Chart of the World (eventually updated using Arc World data from ESRI web site for country borders) on the basis of:
   - country borders,
   - river patterns compared to the extent of Fluvisols,
   - lakes,
   - towns,
   - temporary hydrological patterns compared with saline soils.
4. applying geometrical conformity rules to the fitted coverage;
5. adding the fitted coverage to that of the SGDBE following the procedure elaborated for the SGDBE.

2.5 Determining the original soil classification of the STU used

The SGDBE version 4.0 represents a synthesis of the knowledge of the spatial pattern of soils at a resolution of 1:1,000,000 in each country it is covering. To make such synthesis, each country expert needed to make a correlation between his national classification and the classification of reference used for the SGDBE. Historically, three different classifications have been used as reference in the SGDBE:

- the FAO-UNESCO 1974 legend, with new subdivisions added by country experts, which is given by the attribute FAO85-FULL in the STU file;
- the FAO-UNESCO 1990 revised legend, which is given by the attribute FAO90-FULL in the STU file;
- and recently, the World Reference Base for soil resources (WRB), which is given by the attribute WRB-FULL in the STU file.

Depending on the date of introduction and his own knowledge, each country expert used only one of the three reference classifications for soil naming of STUs. In the present SGDBE, the nature of the reference soil classification used by each country expert to make the correlation with the national classification is not available. This information was added in the STU file using the following three 'confidence level' attributes:

- FAO85-FULL.CL: for the FAO-UNESCO 1974 legend,

– FAO90-FULL.CL: for the FAO-UNESCO 1990 revised legend,

– WRB-FULL.CL: for the WRB.

These attributes were already present in the SGDBE and were used to distinguish the soil names that were given by the national expert on one hand (code 'o' for original) from those estimated through a taxotransfer rule (the codes used here were then an information about the accuracy of the estimation, with the codes 'h' for high, 'm' for medium and 'l' for low). When a national expert gave a soil name for several soil classifications, then all the concerned 'confidence level' attributes were given the value 'o'. But, in fact, only one of these soil classifications was used for the correlation with the national classification. Using the archives of the SGDBE, it was determined which soil classification was used as reference and then the corresponding 'confidence level' attribute is given the value 'o' for original reference classification. If another soil name was given by the national expert using one of the other soil classifications, then the corresponding 'confidence level' attribute is given the value 'i' for estimation by the national expert. For example, if the national expert used the FAO-UNESCO 1974 legend as reference soil classification, then the attribute FAO85-FULL.CL is given the value 'o'. If the national expert gave also a soil name using the FAO-UNESCO 1990 revised legend, then the attribute FAO90-FULL.CL is given the value 'i' (instead of 'o' as it was previously).

The reference classification used by the national expert is called hereafter 'the original soil name' and is shown in Annex 1.

In the following chapters, the term SGDBE will correspond to the SGDBE version 4.0 completed with the DSMW extracted through the activity described in this chapter.

3 Verification and update of WRB-codes

The World Reference Base for soil resources (WRB) is the international reference base for soil classification (FAO et al., 1998) adopted by the International Union of Soil Sciences (IUSS) in 1998. WRB was elaborated to be a reference system that can be used world-wide. It is a two-tier system of soil classification, with 30 Major Soil Groups (the 'Reference Base') and 121 uniquely defined qualifiers for specific soil characteristics (the 'WRB Classification System'). A set of prefixes is also established which may be added to the qualifier to indicate the depth of occurrence or the degree of expression of certain soil features. Several qualifiers and prefixes could be used depending on the degree of precision required for soil naming. It is the reason why WRB was chosen as reference system for the extension of the SGDBE to European New Independent States (Russia, Belarus, Moldova and Ukraine) and to Mediterranean countries.

3.1 Activities

First, ISRIC has checked the WRB-classification which has been estimated for western, northern and central Europe. Where there was no estimation (only FAO-UNESCO 1974 legend), ISRIC has made an estimation. The latter includes all the countries that are taken from the Digital Soil Map of the World (1 to 5 million scale). Then some modifications to take into account other information like 'Depth of an obstacle to roots' and its knowledge about the precision of the phases were added.

The following legends or classifications are taken into account:

- WRB98: World Reference Base for Soil Resources, 1998 (World Soil Resources Reports 84. FAO, Rome)
- FAO85: Classification used on the Soil Map of the European Communities and the Soil Map of Central Europe at 1:1,000,000 scale, which is an extension of the FAO-UNESCO 1974 legend (Soil Map of Middle Europe 1:1,000,000. ISSS and CEC. CEC, Luxembourg).
- FAO90: Revised Legend of the Soil Map of the World 1:5,000,000 (World Soil Resources Report 60. FAO, Rome)

As a first step, all blank fields of the WRB coding in the STU table were completed with the best possible match between FAO85 and WRB, or between FAO90 and WRB. Besides filling blank fields, ISRIC has checked estimated WRB codes, derived from FAO85 and FAO90. Sometimes an error has been found. In such a case the WRB code has been changed. ISRIC didn't take into account that some WRB codes were given by the country as original soil name. Then the estimation by ISRIC of the WRB code only for the STU where the original soil name was not in WRB was used.

In the conversion, the phases, as indicated in the AGLIM1 and AGLIM2 attributes of the STU table, have been taken into account by ISRIC, in particular the gravelly, stony, lithic, saline, sodic, petrocalcic and petrogypsic phases. Where possible and relevant, the topsoil and subsoil textures have been taken into account as well. For European soils, it appears that the phases gravelly and stony don't correspond to a high amount of gravel or stones (when looking at the profile database); it was proposed not to take these phases into account when ISRIC proposed to use them to qualify the soil as skeletic (more than 40% of gravel or stones). But the ISRIC proposal for skeletic soils has been kept for the STU coming from the Digital Soil Map of the World (phase 20). The list of WRB estimation is given in Annex 2.

4 Rewriting PTR salinity, alkalinity, chemical toxicity and drainage based on the wrb-standard

To estimate the derived attributes SALINITY, ALKALINITY and DRAINAGE, pedotransfer rules (PTR) will be rewritten to accept the new standard nomenclature system of the World Reference Base (WRB) of Soil Resources (FAO et al., 1998). These PTR will be applicable to the countries listed in Annex 1.

4.1 Remarks about the use of soil names in pedotransfer rules

4.1.1 Original soil names

The soil name has a great importance in defining pedotransfer rules from the SGDBE because it summarises a great amount of information on soil properties that are not directly available from the database. So it is important to know which classification system has been used by the national expert to make the correlation with the national classification system (see paragraph 2.5). Using another soil name instead of the 'original one' when applying PTR can introduce new errors because this soil name is generally an estimation derived from the 'original soil name' and not directly from the national soil name. Thus, when the use of soil names is needed in a pedotransfer rule, it is proposed to use the soil name that was originally given by the national expert and not another one. This can be done using the 'confidence level' attribute attached to each soil name attribute.

4.1.2 Limits in using the soil name for estimating soil properties

The first important limit in using the soil name for estimating soil properties is due to the 'accuracy' of the soil classification system used. In the SGDBE, three reference classifications are used which do not have the same 'accuracy'. The first one is the FAO-UNESCO 1974 legend from the Soil Map of the World (FAO-UNESCO, 1974). It is not a classification but a legend defined for a soil map at a scale of 1:5,000,000. Consequently, there are very few subdivisions available and the legend is not detailed enough for a soil map at 1:1,000,000 scale. The main limits in using the FAO-UNESCO 1974 legend are thus linked with:

- the difficulty encountered by national experts to find the more accurate and the more correlated soil name in that legend;
- the introduction of new subdivisions by national experts to have more possibilities for naming soils but for many of which no precise definition is available, making the interpretation of the soil properties of these new subdivisions difficult.

When the SGDBE was extended to Eastern and Northern Europe, the FAO-UNESCO 1990 revised legend was proposed to be used as reference classification. This legend is a revision of the FAO-UNESCO 1974 legend with introduction of new soil names (Leptosols for example). But it remains a legend for the soil map of the world and it is not a classification. The main limits in using the FAO-UNESCO 1990 revised legend are thus the same as those for the FAO-UNESCO 1974 revised legend.

The World Reference Base for soil resources (WRB) is the international reference base for soil classification (FAO et al., 1998) adopted by the International Union of Soil Sciences (IUSS) in 1998. WRB was elaborated to be a reference system that can be used world-wide. It is a two-tier system of soil classification, with 30 Major Soil Groups (the 'Reference Base') and 121 uniquely defined qualifiers for specific soil characteristics (the 'WRB Classification System'). A set of prefixes is also established which may be added to the qualifier to indicate the depth of occurrence or the degree of expression of certain soil features. Several qualifiers and prefixes could be used depending on the degree of precision required for soil naming. It is the reason why WRB was chosen as reference system for the extension of the SGDBE to European New Independent States (Russia, Belarus, Moldova and Ukraine) and to Mediterranean countries.

The use of the WRB is an improvement for the SGDBE because it is a reference system independent from any scale of soil maps. Nevertheless, the correlation between WRB and national soil classifications is not always simple as the concepts used can be very different, or because the soil types occurring in a country can be too specific and were not taken into account for a world-wide reference system (for example, Icelandic volcanic soils). Another limitation in using the soil name for estimating soil properties is the relation between soil names and soil properties. The soil classifications used are mainly based on pedogenesis criteria. In some cases, a direct link can be made between the soil name and a soil property, but, often this direct link is not possible. For example, if we can consider that a Lithosol has a soil depth of less than 10 cm, such a link with soil depth is not possible for Cambisols or Luvisols, which represent the main soil types in Europe

We can illustrate these two main limitations with two examples. The first one corresponds to the Lithosols which are, by definition in the FAO-UNESCO 1974 legend, soils less than 10 cm deep and limited in depth by a hard and coherent rock. In the SGDBE, Lithosols are mainly defined (77%) with an obstacle to roots that can be interpreted as soils having a shallow depth (i.e. depth of an obstacle to roots between 20 to 40 cm). But some Lithosols (23%) are defined as deeper soils. When looking at the other attributes defining these Lithosols, we can see that they are mainly developed on soft parent materials. In this case, the national expert encountered difficulty in making a correlation between the national classification and the FAO-UNESCO 1974 legend. He chose the best correlated soil name, depending on the criteria he wanted to emphasis (here probably the lack of soil differentiation), but the correlation was in fact very bad (Figure 4-1).

Figure 4-1: **Number of STUs (in %) by class of a depth of an obstacle to roots for Lithosols, Cambisols and Luvisols.**

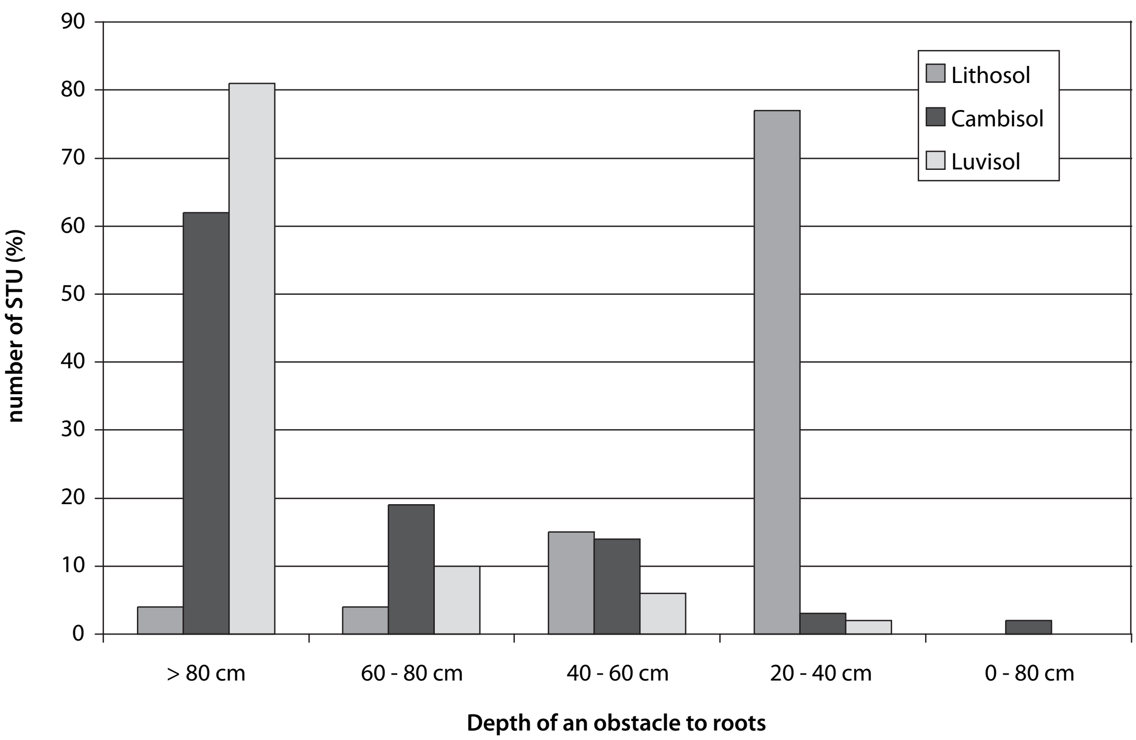
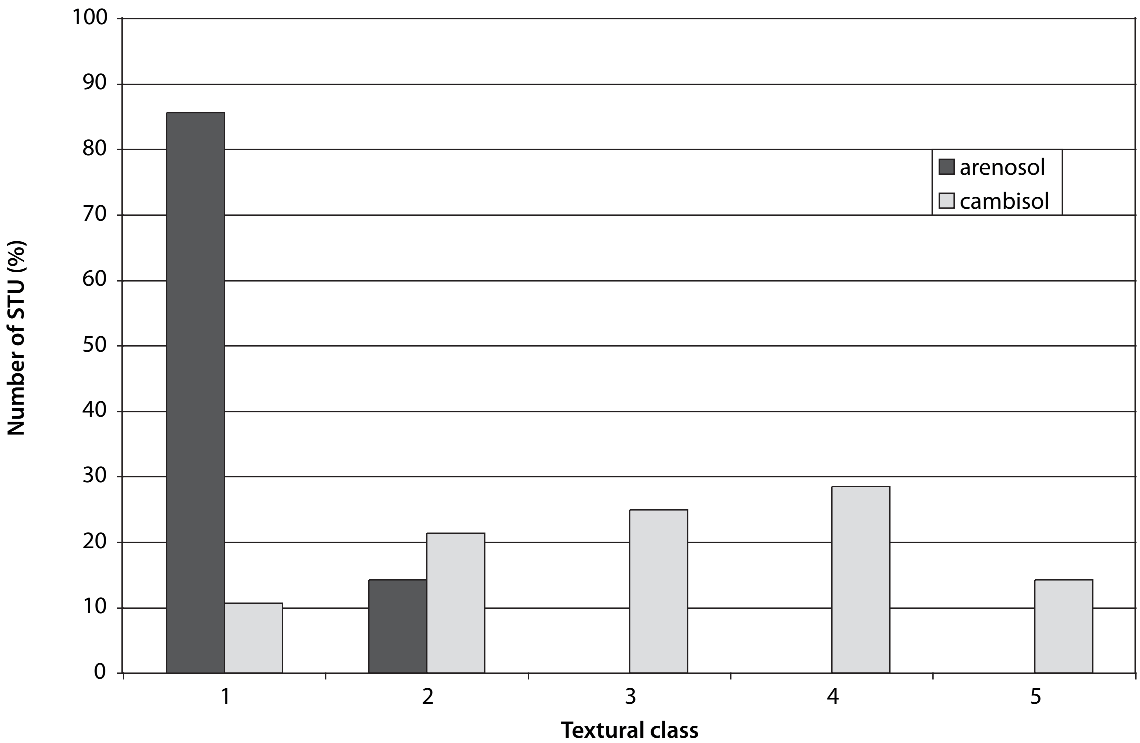


Figure 4-2: **Number of STUs (in %) by topsoil textural class for Arenosols and Cambisols in the SGDBE.**



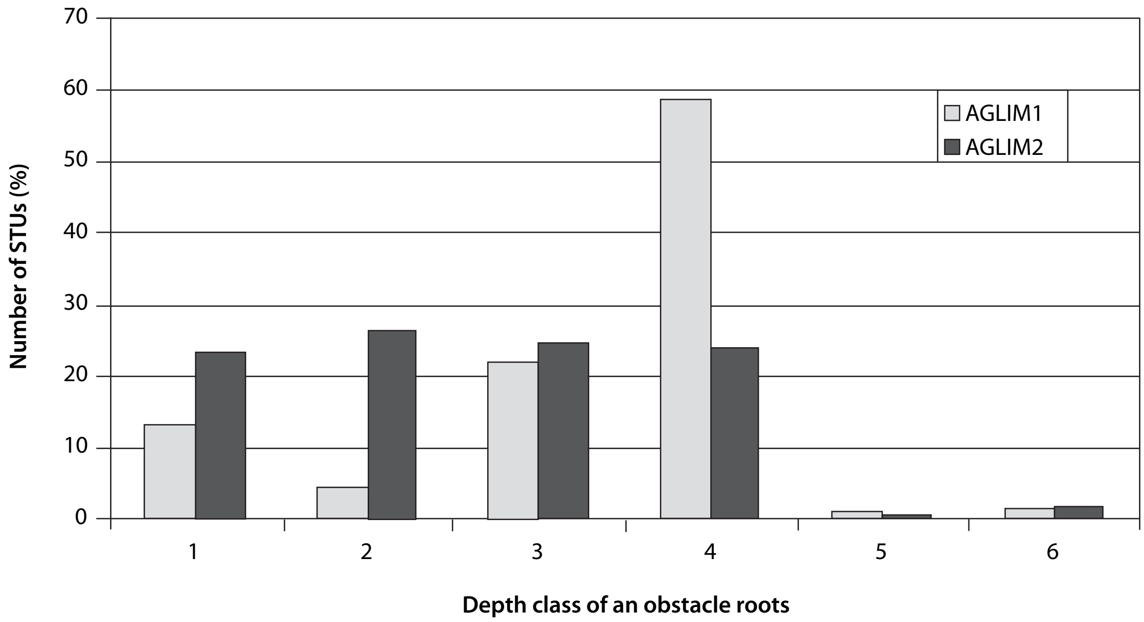
A second example is the link between topsoil texture and soil name. In the SGDBE, Arenosol (in WRB) are mainly with a coarse topsoil texture (86%). But a link between topsoil texture classes and soil name is not so easy for Cambisols (Figure 4-2) where nearly all the topsoil textural classes are represented. Due to these limitations, some attributes were added to improve the knowledge about soil properties in the database (for example, depth of an obstacle to roots). It is thus recommended to use preferentially attributes about soil properties and to use the soil name only when no attributes about the requested soil property are available or when there is missing data.

4.1.3 Limits in using the phases for estimating soil properties

The phases (attributes AGLIM1 and AGLIM2 in the data base) were defined for the soil map of the world and for the soil map of the EC as characteristics of soil types that are significant to the use or management of the land but that are not diagnostic for the separation of soil units themselves. These phases were presented on the maps as overprints. They generally refer to agricultural limitations like appearance of a hard rock at shallow depth (lithic phase), or stoniness (stony, gravelly phases), etc. As they give information about agricultural limitations, they were mainly used to determine some soil properties. But their definition is often not very precise and results in misinterpretation. It appears that the phases are not very accurate. One example is the relation between the lithic phase and the depth of an obstacle to roots (see Figure 4-3).

Considering these limitations, it is recommended, as for the soil name, to give priority to the attributes that give direct information about the soil properties and to use the phases only when no other information is available.

Figure 4-3: **Number of STUs (in %) by depth class of an obstacle to roots for STUs having a lithic phase (dominant: AGLIM1, or secondary: AGLIM2) in the SGDBE.**



4.2 Salinity rule

4.2.1 Description of the current salinity rule

The current rule used for estimating salinity in CGMS is described in Table 4-1.

Table 4-1: **Current salinity rule used in CGMS**

Soil name in FAO 1985	Salinity
*** (all soil names)	weak
Z** (Solonchaks)	strong
y (Gypsic soils)	strong
Jt (Thionic Fluvisols)	strong

When analysing this rule, it appears that the rule considers four categories of soils:

- soils having a low amount of salt;
- soils having a high amount of salt (Solonchaks (FAO-UNESCO 1974 legend));
- soils having a high amount of gypsum which can be toxic for plants (Gypsic soils (FAO-UNESCO 1974 legend));
- soils having a high amount of sulphur which can be toxic for plants (Thionic Fluvisols (FAO-UNESCO 1974 legend)).

The last two categories can lead to confusion when using the PTR salinity for other purposes than CGMS. So we propose to create two distinct rules, one for salinity, the other for toxicity to plants, in the knowledge base of the SGDBE version 4.0. For CGMS only (in its present state), the results of these two rules will be merged into a unique variable in respect to the present structure of CGMS.

Salinity of soil can prevent plants to take water from soil. It is measured by the electrical conductivity of the saturation extract in dS/m at 25°C (ECse). The tolerance to salt is different from one crop to another. The threshold for salinity tolerance (mean of salinity within rooting depth) varies from 1.3 dS/m for the more sensitive crops to 10 dS/m for the more tolerant ones.

4.2.2 Review of available information in the SGDBE for salinity estimation

In the SGDBE, the information concerning salinity is available in the soil name attributes (FAO85-FULL, FAO90-FULL, WRB-FULL) and in the agricultural limitation attributes (AGLIM1, AGLIM2).

4.2.2.1 Attribute FAO85-FULL

The attribute FAO85-FULL describes the soil name of the STU following the FAO-UNESCO 1974 legend, modified for the Soil Map of the European Communities in 1985. Several subdivisions, for which no definition is available, have been introduced by contributors to the SGDBE. In the FAO-UNESCO 1974 legend, soil names that give information about salinity are the Solonchaks. In the definition of Solonchaks, the reference to salinity is given by the presence of a high salinity which is defined as soils having, at some time of the year:

- an EC_{se} of more than 15 mmhos/cm at 25°C (1 mmhos/cm = 1 dS/m),
  - within 125 cm depth if the topsoil texture class (weighted mean) is coarse, or
  - within 90 cm depth if the topsoil texture class (weighted mean) is medium, or
  - within 75 cm depth if the topsoil texture class (weighted mean) is fine.

- or an EC_{se} of more than 4 mmhos/cm at 25°C, within 25 cm depth if the pH (H_2O, 1:1) is more than 8.5.

All soils having a high salinity must be named as Solonchaks except if they have the characteristics of Histosols, Lithosols, Vertisols and Fluvisols when referring to the key for determining soil names. There is no subdivision defined in the FAO-UNESCO 1974 legend considering salinity for these soil groups.

In the SGDBE, STUs that have in their name a reference to salinity are Solonchaks and a Salo-thionic Gleysol (Table 4-2). For Solonchaks, referring to their definition, they can be considered as having a high salinity. For the Salo-thionic Gleysol, as Gleysols appear after Solonchaks in the key of the FAO-UNESCO 1974 legend, we can consider that this soil does not have a high salinity but a medium one.

Table 4-2: **Values of the FAO85-FULL attribute that give information about salinity**

FAO85-FULL code	Signification	Number of STUs	Area in SGDBE (km^2)
Z	Solonchak	41	67528
Zg	Gleyic Solonchak	30	15261
Zgf	Fluvi-Gleyic Solonchak	1	87
Zm	Mollic Solonchak	1	11
Zo	Orthic Solonchak	40	28282
Zt	Takyric Solonchak	4	4463
Gtz	Salo-thionic Gleysol	1	2738

4.2.2.2 Attribute FAO90-FULL

The attribute FAO90-FULL describes the soil name of the STU following the FAO-UNESCO 1990 legend which is a revision of the FAO-UNESCO 1974 legend. In the FAO-UNESCO 1990 legend, soil names that give information about salinity are Solonchaks and salic soils. Solonchaks are soils having salic properties. In the other soil groups, the salinity is used as a criterion for subdivision only for Fluvisols. The Salic Fluvisols are soils presenting salic properties. The salic properties refer to an EC_{se} of more than 15 dS/m at 25°C, at some time of the year, within 30 cm from the soil surface, or more than 4 dS/m within 30 cm from the soil surface if the pH (H_2O, 1:1) exceeds 8.5.

In the SGDBE, STUs that have in their name a reference to salinity are Solonchaks only (Table 4-3). We can consider them having a high salinity.

Table 4-3: **Values of the FAO90-FULL attribute that give information about salinity**

FAO90-FULL code	Signification	Number of STUs	Area in SGDBE (km^2)
SC	Solonchak	1	53
SCg	Gleyic Solonchak	1	595
SCh	Haplic Solonchak	5	761
SCn	Sodic Solonchak	7	148

4.2.2.3 Attribute WRB-FULL

The attribute WRB-FULL describes the soil name of the STU following the WRB (FAO-ISRIC-ISSS, 1998). In the WRB, soil names that give information about salinity are Solonchaks, 'salic' soils, or 'petrosalic' soils. In the definition of Solonchaks, the reference to salinity is given by the presence of a salic horizon within a depth of 50 cm. The 'salic' soils are soils other than Solonchaks that have a salic horizon within 100 cm from the soil surface. The use of several specifiers modifies the definition as follows:

- endosalic: the salic horizon is between 50 to 100 cm from the soil surface.
- episalic: the salic horizon is between 25 to 50 cm from the soil surface.
- hyposalic: the EC_{se} is more than 4 dS/m in at least one sub-horizon within 100 cm from the soil surface.
- hypersalic: the EC_{se} is more than 30 dS/m in at least one sub-horizon within 100 cm from the soil surface.

The salic horizon is a surface or a shallow subsurface horizon which contains a secondary enrichment of readily soluble salts, i.e. salts more soluble than gypsum. The diagnostic criteria for a salic horizon is precisely that this type of horizon must have an EC_{se} of more than 15 dS/m at some time of the year, or an EC_{se} of more than 8 dS/m if the pH (H_2O) of the saturation extract exceeds 8.5 (for alkaline carbonate soils) or is less than 3.5 (for acid sulphate soils). Petrosalic soils are soils having within 100 cm from the soil surface a horizon of 10 cm or thicker which is cemented by salts more soluble than gypsum. There is no precision about the EC_{se} value of this horizon.

In the SGDBE, soil names in WRB-FULL that give information about salinity are Solonchaks and salic soils (Table 4-4). There are no petrosalic soils. We can consider Solonchaks as having a high salinity. For salic soils, the salinity is also high except for hyposalic soils which have a medium salinity. The difference between the different salic soils will be on the depth of the salic horizon which could be precised using the specifiers Endo (from 50 to 100 cm) or Epi (from 25 to 50 cm). Without specifiers, the salic horizon is present from 0 to 50 cm for a Solonchak (by definition), and from 0 to 100 cm for the other possible soil groups.

Table 4-4: **Values of the WRB-FULL attribute that give information about salinity**

WRB-FULL code	Signification	Number of STUs	Area in SGDBE (km^2)
SCgl	Gleyic Solonchak	2	11303
SCha	Haplic Solonchak	5	24148
SCgy	Gypsic Solonchak	1	150
SCso	Sodic Solonchak	2	974
SCcc	Calcic Solonchak	2	7712
SCgyw	Hypogypsic Solonchak	2	52
FLsz	Salic Fluvisols	4	20580
HSsz	Salic Histosols	1	2782
CLszn	Endosalic Calcisol	3	44208
VRsz	Salic Vertisols	1	903

4.2.2.4 Attribute AGLIM1

This attribute gives information about the dominant agricultural limitation. It was named a phase in the Soil Map of the World and in the Soil Map of the European Communities. The phase represented, on these maps, subdivisions within soil units based on important characteristics for land use but that cannot be used as diagnostic criteria for the soil units designation. It covered different limitations to agricultural use like high amount of stones, presence of hard rock or cemented horizon, etc.

The saline phase characterises soils having a horizon within 100 cm from the soil surface, which have an EC_{se} of more than 4 mmhos/cm (FAO-UNESCO, 1974). The Solonchaks (FAO-UNESCO 1974 or 1990) generally have no saline phase indicated because the salinity limitation is obvious for these soils. The saline phase was thus used only for soils that were not classified as Solonchaks. Nevertheless, in the SGDBE, the saline phase was used also to characterise some Solonchaks. Thus, we considered this information as redundant with the soil name. For these soils only, the saline phase was not considered.

Considering the soil types that are not Solonchaks, the presence of a saline phase can be interpreted in different ways considering the soil name:

- For FAO-UNESCO 1974 soil names, two categories can be defined:
    - soil groups where a high salinity is excluded from their definition: Gleysols, Regosols, Arenosols, Andosols, Rendzinas, Chernozems, Kastanozems, Phaeozems, Xerosols, Yermosols, Greyzems and Cambisols. For these soils, when a saline phase is present, that means that these soils have a medium salinity, because if a high salinity is present then they must be classified as Solonchaks.
    - the other soil groups where a high salinity is allowed: Histosols, Lithosols, Vertisols, Fluvisols, Podzols, Ferralsols, Planosols, Solonetz, Rankers, Podzoluvisols, Nitosols, Acrisols, Luvisols. For these soils, when a saline phase is present, the salinity can be medium or high.

- For FAO-UNESCO 1990 soil names, two categories can be defined as well:
  - soil groups where a high salinity is excluded from their definition: Gleysols, Regosols, Andosols, Chernozems, Kastanozems, Phaeozems, Cambisols, Calcisols and Gypsisols. For these soils, when a saline phase is present, that means that these soils have a medium salinity, because if a high salinity is present then they must be classified as Solonchaks.
  - the other soil groups where a high salinity is allowed: Histosols, Anthrosols, Leptosols, Vertisols, Fluvisols, Arenosols, Podzols, Plinthosols, Ferralsols, Planosols, Solonetz, Greyzems, Podzoluvisols, Nitisols, Alisols, Acrisols, Luvisols and Lixisols. For these soils, when a saline phase is present, the salinity can be medium or high.
- In WRB, the concept of phase does not exist anymore. But, as the attribute AGLIM1 exists in the database, countries give information about phases. WRB, contrary to the two FAO-UNESCO legends, is not limited to a fixed list of soil types. Several adjectives can be used to describe the main characteristics of the soil. Concerning salinity, the use of the adjective salic, with or without specifiers, is thus not limited. So, we can consider that all the soil types having a saline phase and that are not Solonchaks, neither salic or petrosalic soils, have a medium salinity (in fact, these soils should be named also hyposalic).

Concerning the FAO-UNESCO 1974 soil names, if we look at the dominant land use USE-DOM and the dominant parent material MAT1, we can see that there are some correlations between some soil types, their parent material and their land use (Table 4-5). For STUs having a dominant saline phase, halophile grasslands as dominant land use represent about 25% (for only the STUs with USE-DOM $\neq 0$). But, this land use type represents about 60% of the STUs if we consider only some particular parent materials:

- 120: estuarine or marine alluvium
- 440: coastal sands (dunes)
- 441: shelly coastal sands
- 442: non calcareous coastal sands

The corresponding soil types, except Solonchaks or Gtz, are Fluvisols or Gleysols. Unfortunately, the land use is not known everywhere and particularly for some Mediterranean countries

***Table 4-5:* List of dominant land use for STUs having a dominant phase saline and an original soil name in FAO-UNESCO 1974 legend**

USE-DOM		Number of STUs			
Code	Signification	all soil types all materials	without Z** and Gtz all materials	all soil types mat1 = 120, 440, 441, 442	without Z** and Gtz; mat1 = 120, 440, 441, 442
0	no information	64	51	1	0
1	pasture	12	10	1	1
3	arable land	15	11	1	1
4	wasteland	1	0	0	0
10	moor	1	1	1	1
11	halophile grassland	12	8	7	7
14	rice	1	1	1	1
19	extensive pasture	6	3	0	0
	Total	112	85	12	11

where salinity problems are crucial. We thus propose to use only the parent material information considering that the Fluvisols developed on parent materials 120, 440, 441 and 442 have a high salinity. The Gleysols are maintained to a medium salinity with a low confidence level.

For FAO-UNESCO 1990 soil names, the relation between saline phase, land use and parent material is simpler. The parent material 120 is always used with Solonchaks. The soil types that are not Solonchaks and that have a dominant saline phase are Solonetz or Gleysols and the dominant land use is always pasture (Table 4-6). It is proposed to consider them as having a medium salinity.

Table 4-6: **List of dominant land use for STUs having a dominant phase saline and an original soil name in FAO-UNESCO 1990 legend**

USE-DOM		Number of STUs		
Code	Signification	all soil types all materials	without SC* and FLs	all soil types mat1 = 120
1	pasture	8	8	0
11	halophile grassland	11	0	6
13	industrial crops	2	0	2
total		21	8	8

4.2.2.5 Attribute AGLIM2

This attribute gives information about the secondary agricultural limitation the same way as for AGLIM1 attribute. The saline phase in AGLIM2 has the same definition as for AGLIM1.

A problem is encountered when using the secondary phase. If we accept the Solonchaks, when AGLIM2 is saline, 76% of the STUs with an original soil name in the FAO-UNESCO 1974 legend have no dominant phase (77% for the STUs having an original soil name following the FAO-UNESCO 1990 legend). In these cases, only a part of the STU can have saline constraints, not all the area of the STU. If we consider that the value of the salinity rule should correspond to the dominant salinity of the STU, we must then consider these STUs as having a low salinity. This is partially confirmed by the dominant land use that is generally arable land or pasture for these STUs. When there is a dominant phase, we can consider the salinity as medium.

4.2.3 Adapt the PTR with the information available in the SGDBE

The analysis of the available information shows that the information from the soil name can be used to characterise the presence of a horizon having saline properties at a maximum depth of 125 cm. Three classes of salinity are proposed to be estimated:

- low: $EC_{se} < 4$ dS/m
- medium: $4 < EC_{se} < 15$ dS/m
- high: $EC_{se} > 15$ dS/m

The proposed salinity rule is described in Table 4-7. For some soil types, the threshold can be less than 15 dS/m (4 dS/m for a Solonchak (FAO90) having a pH > 8.5, or 8 dS/m for a Solonchak or a salic soil (WRB) having a pH > 8.5 or a pH < 3.5). But, the Ec_{se} can be higher than 15 dS/m. It is considered that these soil types have a high salinity in order to avoid having classes that overlap (these soils have generally other limitations like alkalinity or sulphur toxicity).

Table 4-7: **New rule for salinity**

FAO85-FULL	FAO85-FULL.CL	FAO90-FULL	FAO90-FULL.CL	WRB-FULL	WRB-FULL.CL	AGLIM1	AGLIM2	MAT1	SALI-NITY	CL
*	*	*	*	*	*	*	*	*	low	high
*	*	*	*	*	*	7	*	*	medium	medium
*	*	*	*	*	*	*	7	*	medium	medium
*	*	*	*	*	*	1	7	*	low	low
8	0	*	*	*	*	*	*	*	high	high
J**	0	*	*	*	*	7	*	120	high	medium
J**	0	*	*	*	*	7	*	44*	high	medium
G**	0	*	*	*	*	7	*	120	medium	low
G**	0	*	*	*	*	7	*	44*	medium	low
Gtz	0	*	*	*	*	*	*	*	medium	medium
Z**	0	*	*	*	*	*	*	*	high	high
*	*	SC*	0	*	*	*	*	*	high	high
*	*	FLs	0	*	*	*	*	*	high	high
*	*	*	*	SC**	0	*	*	*	high	high
*	*	*	*	**sz	0	*	*	*	high	high
*	*	*	*	**szn	0	*	*	*	high	high
*	*	*	*	**szp	0	*	*	*	high	high
*	*	*	*	**szh	0	*	*	*	high	high
*	*	*	*	**szw	0	*	*	*	medium	medium
*	*	*	*	**ps	0	*	*	*	high	medium

4.3 Alkalinity rule

4.3.1 Description of the current PTR used to derive alkalinity

The current rule used for estimating alkalinity in CGMS is described in Table 4-8.

Table 4-8: **Current alkalinity rule used in CGMS**

Soil name in FAO 1985	Salinity
*** (all soil names)	weak
S** (Solonetz)	strong

In the current rule, alkalinity is estimated as strong only if the soil is a Solonetz (FAO-UNESCO 1974 legend).

Alkalinity of soil has two effects on crops. The first one is a toxicity effect due to the Sodium ions. The second effect is an indirect one due to a massive or columnar structure and a lower permeability of the soil which are unfavourable conditions for rooting and ploughing. It is measured by the ratio between the exchangeable sodium and the exchange capacity, called ESP.

4.3.2 Review of available information in the SGDBE for alkalinity estimation

In the SGDBE, the information concerning alkalinity is available in the soil name attributes (FAO85-FULL, FAO90-FULL, WRB-FULL) and in the agricultural limitation attributes (AGLIM1, AGLIM2).

4.3.2.1 Attribute FAO85-FULL

In the FAO-UNESCO 1974 legend, soil names that give information about alkalinity are the Solonetz and Solodic Planosols. In the definition of Solonetz, the reference to alkalinity is given by the presence of a natric B horizon.

A natric B horizon is an argillic B horizon which has in its upper 40 cm:

- a saturation with exchangeable sodium of more than 15%,
- or more exchangeable magnesium plus sodium than calcium plus exchange acidity (at pH 8.2) if the saturation with exchangeable sodium is more than 15% in some subhorizon within 200 cm from the soil surface.

The Solodic Planosols are Planosols having more than 6% sodium in the exchange complex of the slowly permeable horizon. The classification of a soil in the Solonetz group is not only due to a high saturation with exchangeable sodium but also to the presence of other characteristics: the natric B horizon must have the characteristics of an argillic B horizon and must have also a columnar or prismatic structure. There is no criteria 'high alkalinity' as it exists for salinity. So, all soils having a high alkalinity are not always classified as Solonetz. On the other hand, there is no subdivision defined in the FAO-UNESCO 1974 legend considering alkalinity for other groups than Solonetz, except for Solodic Planosols.

In the SGDBE, STUs that have in their name a reference to alkalinity are Solonetz and a Sodi-pellic Vertisol (Table 4-9). For Solonetz, referring to their definition, they can be considered as having a high alkalinity. For Sodi-pellic Vertisols, as Vertisols appears before Solonetz in the key of the FAO-UNESCO 1974 legend, this soil could have potentially a high alkalinity. But we have no information in the database that could confirm it. This STU has a dominant land-use arable land and is drained. It is proposed to estimate its alkalinity to medium.

Table 4-9: **Values of the FAO85-FULL attribute that give information about alkalinity**

FAO85-FULL code	Signification	Number of STUs	Area in SGDBE (km^2)
S	Solonetz	2	354
Sg	Gleyic Solonetz	6	2791
Sof	Fluvi-Orthic Solonetz	1	325
Sm	Mollic Solonetz	1	189
So	Orthic Solonetz	10	3507
Vpn	Sodi-pellic Vertisol	1	127

4.3.2.2 Attribute FAO90-FULL

In the FAO-UNESCO 1990 legend, soil names that give information about alkalinity are Solonetz and sodic soils. Solonetz are soils having a natric B horizon. A natric B horizon is an argic B horizon which has in its upper 40 cm:

- a saturation with exchangeable sodium of more than 15%,

- or more exchangeable magnesium plus sodium than calcium plus exchange acidity (at pH 8.2) if the saturation with exchangeable sodium is more than 15% in some subhorizon within 200 cm from the soil surface.

In the other soil groups than Solonetz, the alkalinity is used as a criterion for subdivision only for Solonchaks. Sodic Solonchaks are Solonchaks that present sodic properties at least between 20 and 50 cm from the soil surface. The sodic properties refer to saturation in the exchange complex of 15% or more of exchangeable sodium or of 50% or more exchangeable sodium plus magnesium. We thus can consider Solonetz or Sodic Solonchaks as having a high alkalinity.

In the SGDBE, STUs that have in their name a reference to alkalinity are Solonetz and Sodic Solonchaks (Table 4-10). They can be considered as having a high alkalinity.

Table 4-10: **Values of the FAO90-FULL attribute that give information about alkalinity**

FAO90-FULL code	Signification	Number of STUs	Area in SGDBE (km^2)
SNm	Mollic Solonetz	14	4500
SNh	Haplic Solonetz	6	2094
SCn	Sodic Solonchak	7	148

4.3.2.3 Attribute WRB-FULL

In the WRB, soils having alkaline characteristics are Solonetz, 'natric' soils, or 'sodic' soils. In the definition of Solonetz, the reference to alkalinity is given by the presence of a natric horizon within 100 cm from the soil surface. The 'natric' soils are soils other than Solonetz that have a natric horizon within 100 cm from the soil surface. The natric horizon is a dense subsurface horizon with higher clay content than the overlying horizons and that has a high content in exchangeable sodium and/or magnesium. The diagnostic criteria for a natric horizon specify that this type of horizon must have an ESP of more than 15% within the upper 40 cm, or more exchangeable magnesium plus sodium than calcium plus exchange acidity (at pH 8.2) within the same depth if the saturation with exchangeable sodium is more than 15% in some subhorizon within 200 cm of the surface.

'Sodic' soils are soils having more than 15% exchangeable sodium or more than 50% exchangeable sodium plus magnesium on the exchange complex within 50 cm from the soil surface. Two specifiers can be used:

- endosodic soils have more than 15% exchangeable sodium or more than 50% exchangeable sodium plus magnesium on the exchange complex between 50 cm to 100 cm from the soil surface,

- hyposodic soils have more than 6% saturation with exchangeable sodium in at least some subhorizons more than 20 cm thick within 100 cm from the soil surface.

Solonetz, 'natric' soils, 'sodic' soils and 'endosodic' soils are considered having a high alkalinity. For 'hyposodic' soils, the alkalinity is medium.

In the SGDBE, STU that give information about alkalinity are Solonetz, Sodic Solonchaks, Sodic Gleysols, Sodic Phaeozems, Hyposodic Vertisols, Hyposodic Calcisols or Hyposodic Gypsisols (Table 4-11).

Table 4-11: **Values of the WRB-FULL attribute that give information about alkalinity**

WRB-FULL code	Signification	Number of STUs	Area in SGDBE (km²)
SNgl	Gleyic Solonetz	2	82810
SNha	Haplic Solonetz	3	41280
SNgy	Gypsic Solonetz	1	21469
SNcc	Calcic Solonetz	1	24
SCso	Sodic Solonchak	2	974
GLso	Sodic Gleysol	1	70499
PHso	Sodic Phaeozem	1	83211
VRsow	Hyposodic Vertisol	1	19
GYsow	Hyposodic Gypsisol	1	9
CLsow	Hyposodic Calcisol	1	23

4.3.2.4 Attribute AGLIM1

The sodic phase characterises soils having some horizons within 100 cm from the soil surface which have more than 6% saturation with exchangeable sodium (FAO, 1974). The Solonetz (FAO 1974 or 1990) generally have no sodic phase indicated because the alkalinity limitation is obvious for these soils. The sodic phase was thus used only for soils that were not classified as Solonetz. Nevertheless, in the SGDBE, the sodic phase was used also to characterise some Solonetz. Thus we considered this information as redundant with the soil name. For these soils only, the sodic phase was not considered.

Considering the soil types that are not Solonetz or sodic soils, the presence of a sodic phase can be interpreted in different ways considering the soil name:

- For FAO-UNESCO 1974 soil names, two categories of soils can be distinguished:
    - soil groups where the presence of a natric B horizon is excluded from the definition: Greyzems, Chernozems, Kastanozems, Phaeozems, Podzoluvisols, Luvic Xerosols, Luvic Yermosols, Nitosols, Acrisols and Luvisols. These soils can have an argillic horizon. The presence of a sodic phase signifies a medium alkalinity, because if the alkalinity is high, then these soils are classified as Solonetz.
    - soil groups where sodic properties can exist: Fluvisols, Gleysols, Regosols, Lithosols, Arenosols, Vertisols, Rendzinas, Rankers, Andosols, Solonchaks, Cambisols, Podzols, Ferralsols, Yermosols except Luvic, Xerosols except Luvic, Planosols, Histosols. For these soils, the presence of a sodic phase can signify a medium or a high alkalinity. In the SGDBE, there is no information available to specify it. It is proposed to consider these soils as having a medium alkalinity.
- For FAO-UNESCO 1990 soil names, two categories can be defined as well:
    - soil groups, where the presence of a natric B horizon is excluded from the definition: Planosols, Greyzems, Chernozems, Kastanozems, Phaeozems, Podzoluvisols, Luvic Gypsisols, Luvic Calcisols, Nitisols, Alisols, Acrisols, Luvisols and Lixisols. These soils can have an argillic horizon. The presence of a sodic phase signifies a medium alkalinity, because if the alkalinity is high, then these soils are classified as Solonetz.
    - soil groups where sodic properties can exist: Histosols, Anthrosols, Leptosols, Vertisols, Fluvisols, Solonchaks, Gleysols, Andosols, Arenosols, Regosols, Podzols, Plinthosols, Ferralsols,

Calcisols except Luvic, Gypsisols except Luvic and Cambisols. For these soils, the presence of a sodic phase can signify a medium or a high alkalinity. In the SGDBE, no information to specify it is available. It is proposed to consider these soils as having a medium alkalinity.

- In WRB, the concept of phase does not exist anymore. But, as the attribute AGLIM1 exists in the database, countries give information about phases. WRB, contrary to the two FAO legends, is not limited to a fixed list of soil types. Several adjectives can be used to specify the main characteristics of the soil. Concerning alkalinity, the use of the adjectives natric or sodic, with or without specifiers is thus not limited. So, it can be considered that all the soil types having a sodic phase and that are not Solonetz, neither sodic or natric soils, have a medium alkalinity.

In the SGDBE, STUs having a dominant phase sodic are, except Solonetz and sodic soils:

- original soil name in FAO-UNESCO 1974: Solonchaks, Chernozems, Gleysols or Kastanozems (Table 4-12);
- original soil name in FAO-UNESCO 1990: Vertisols (
- Table 4-13);
- original soil name in WRB:, Luvic Kastanozems, Salic Fluvisols, Solonchaks, Eutric Nitisols and Calcic Cambisols (Table 4-14).

4.3.2.5 Attribute AGLIM2

This attribute gives information about the secondary agricultural limitation the same way as for AGLIM1 attribute. The sodic phase in AGLIM2 has the same definition as for AGLIM1.

As for salinity, there are some STUs having no dominant phase and a secondary sodic phase.. In this case, only a part of the STU can have sodic constraints, not all the area of the STU. If we consider that the value of the alkalinity rule should correspond to the dominant alkalinity of the STU, we must then consider these STUs as having a low alkalinity. This is confirmed by the dominant land use that is arable land or pasture for these STUs. When there is a dominant

Table 4-12: **List of soil names having a dominant sodic phase and an original soil name in FAO-UNESCO 1974 legend**

FAO85-FULL	Signification	Number of STUs	Area in SGDBE (km^2)
Zo	Orthic Solonchak	3	4053
Ckc	Chromi-calcic Chernozem	1	640
Gmc	Calcaro-mollic Gleysol	2	151
Kkb	Vermi-calcic Kastanozem	1	124
Zg	Gleyic Solonchak	4	1901
Zt	Takyric Solonchak	1	1240

Table 4-13: **List of soil names having a dominant sodic phase and an original soil name in FAO-UNESCO 1990 legend**

FAO90-FULL	Signification	Number of STUs	Area in SGDBE (km^2)
SNm	Mollic Solonetz	1	25
SNh	Haplic Solonetz	2	38
VRe	Eutric Vertisol	1	67

Table 4-14: **List of soil names having a dominant sodic phase and an original soil name in WRB**

WRB-FULL	Signification	Number of STUs	Area in SGDBE (km^2)
SNha	Haplic Solonetz	2	41218
PHso	Sodic Phaeozem	1	83211
KSlv	Luvic Kastanozem	1	76585
SNgl	Gleyic Solonetz	2	82810
FLsz	Salic Fluvisol	1	1748
SCso	Sodic Solonchak	1	938
VRsow	Hyposodic Vertisol	1	19
CLsow	Hyposodic Calcisol	1	23
NTeu	Eutric Nitisol	2	118
CMca	Calcic Cambisol	2	141

phase, it is petrocalcic, saline or phreatic. Except for Solonetz or sodic soils where the phase (dominant or secondary) is redundant with the soil name, we propose to consider these soils as having a medium alkalinity.

4.3.3 Adapt the PTR with the information available in the SGDBE

The analysis of the available information shows that the information from the soil name can be used to characterise the presence of a horizon having sodic properties. The proposed alkalinity rule is described in Table 4-15. Three classes of alkalinity are proposed:

- low: ESP < 6%
- medium: 6 < ESP < 15%
- high: ESP > 15%

Table 4-15: **New rule for alkalinity**

FAO85-FULL	FAO85-FULL.CL	FAO90-FULL	FAO90-FULL.CL	WRB-FULL	WRB-FULL.CL	AGLIM1	AGLIM2	ALKA-LINITY	CL
*	*	*	*	*	*	*	*	low	high
*	*	*	*	*	*	8	*	medium	medium
*	*	*	*	*	*	*	8	medium	medium
*	*	*	*	*	*	1	8	low	low
S**	o	*	*	*	*	*	*	high	high
Vpn	o	*	*	*	*	*	*	medium	low
Ws	o	*	*	*	*	*	*	medium	low
*	*	SN*	o	*	*	*	*	high	high
*	*	SCn	o	*	*	*	*	high	high
*	*	*	*	SN**	o	*	*	high	high
*	*	*	*	**na	o	*	*	high	high
*	*	*	*	**so	o	*	*	high	high
*	*	*	*	**sow	o	*	*	medium	medium

4.4 Chemical Toxicity rule

4.4.1 Description of the current PTR used to derive chemical toxicity

This rule does not exist in CGMS but is in fact integrated in the salinity rule (Table 4-1).

In the salinity rule, two categories of soils concerning chemical toxicity for plants are distinguished:

- soils having a high amount of gypsum (Gypsic soils (FAO-UNESCO 1974 legend));
- soils having a high amount of sulphur (Thionic Fluvisols (FAO-UNESCO 1974 legend)).

It is proposed to create a new rule for chemical toxicity to plants in the knowledge base of the SGDBE version 4.0. Several chemical elements can be toxic for plants: sulphur, aluminium, gypsum and $CaCO_3$, manganese, etc. (FAO, 1988). But considering the information available in the SGDBE, it is proposed to consider only sulphur and gypsum. The soils with sulphur are soils generally permanently waterlogged. For cultivating them, drainage is mandatory but then, the sulphides contained in the soil transform into sulphuric acid by oxidation and the pH is thus decreased below 3.5. For gypsum, as it is not very soluble, the bad effects on crops appear when it is highly concentrated like in a gypsic horizon. The toxicity of gypsum will then depend on the concentration of gypsum (more than 40%) and the depth of appearance of the gypsic horizon.

4.4.2 Review of available information in the SGDBE for chemical toxicity estimation

The estimation of chemical toxicity due to sulphur or gypsum can be derived from the soil name (FAO85-FULL, FAO90-FULL, WRB-FULL) and the agricultural limitation (AGLIM1 and AGLIM2).

4.4.2.1 Attribute FAO85-FULL

In the FAO-UNESCO 1974 legend, presence of sulphur or gypsum appears in Thionic Fluvisol, Gypsic Yermosols and Gypsic Xerosols. Thionic Fluvisols are defined as Fluvisols having a sulphuric horizon or sulphidic materials, or both, within 125 cm from the soil surface. The sulphuric horizon forms as a result of artificial drainage and oxidation of mineral or organic materials which are rich in sulphides. It is characterised by a pH (H_2O) less than 3.5 and jarosite mottles. Sulphidic materials are waterlogged mineral or organic materials containing 0.75% or more sulphur (dry weight), mostly in the form of sulphides, and having less than three times as much carbonate ($CaCO_3$ equivalent) as sulphur. These soils are generally permanently saturated. When these soils are drained, the sulphides oxidise to form sulphuric acid and the pH drops below 3.5.

Gypsic Yermosols or Gypsic Xerosols are soils having a gypsic horizon within 125 cm from the soil surface. A gypsic horizon is a horizon of secondary calcium sulphate enrichment that is more than 15 cm thick, and that has at least 5% more gypsum than the underlying C horizon, and in which the thickness of the product in cm and the percentage of gypsum is 150 or more.

In the Soil Map of European Communities, Thioni-humic Gleysols were defined as Humic Gleysols having sulphuric horizon or sulphidic materials, or both, within 125 cm from the soil surface.

In the SGDBE, Thionic Fluvisol and Thioni-humic Gleysol are described, as well as Salo-thionic Gleysol for which no definition is available in the FAO-UNESCO 1974 legend, neither in the Soil Map of European Communities.

Table 4-16: **Values of the FAO85-FULL attribute that give information about chemical toxicity**

FAO85-FULL	Signification	Number of STUs	Area in km^2
Jt	Thionic Fluvisol	2	257
Gtz	Salo-thionic Gleysol	1	2738
Ght	Thioni-humic Gleysol	1	100
Xy	Gypsic Xerosol	13	32348
Yy	Gypsic Yermosol	28	253414

4.4.2.2 Attribute FAO90-FULL

In the FAO-UNESCO 1990 legend, the presence of sulphur or gypsum appears in Thionic Fluvisol, Thionic Gleysol, Thionic Histosol, Gypsisol, Gypsic Vertisol, Gypsic Solonetz, Gypsic Solonchak, Gypsic Kastanozem, and Gypsiric Regosol.

Thionic Fluvisol, Thionic Gleysol and Thionic Histosol are defined as soils having a sulphuric horizon or sulphidic materials, or both, within 125 cm from the soil surface.

A sulphuric horizon forms as a result of artificial drainage and oxidation of mineral or organic materials which are rich in sulphides. It is at least 15 cm thick and characterised by a pH (H_2O, 1:1) less than 3.5 and has jarosite mottles.

Sulphidic materials are waterlogged mineral or organic materials containing 0.75% or more sulphur (dry weight), mostly in the form of sulphides, and having less than three times as much calcium carbonate equivalent as sulphur, and having a pH above 3.5. Sulphidic materials accumulate in a soil that is permanently saturated and having a pH above 3.5, generally with brackish water. When these soils are drained, the sulphides oxidise to form sulphuric acid and the pH drops below 3.5. At this point, these materials become a sulphuric horizon.

Gypsisols are soils having a gypsic or a petrogypsic horizon, or both, within 125 cm from the soil surface. Haplic, Calcic and Luvic Gypsisols have no petrogypsic horizon. Petric Gypsisols have a petrogypsic horizon. Gypsic Vertisol, Gypsic Solonetz, Gypsic Solonchak and Gypsic Kastanozem are soils having a gypsic horizon within 125 cm from the soil surface. Gypsiric Regosols are Regosols which are gypsiferous at least from 20 and 50 cm from the soil surface. Nevertheless, Calcic Gleysols should be also considered because a gypsic horizon can be present (the gypsic horizon, when exists, must be within 125 cm from the soil surface). A gypsic horizon is a horizon enriched with secondary calcium sulphate, is 15 cm or thicker, and has at least 5% more gypsum than the underlying C horizon. The thickness of the product in cm and the percentage of gypsum must be of 150 or more. A petrogypsic horizon is a gypsic horizon that is so cemented with gypsum that dry fragments do not slake in water and roots cannot enter. The gypsum content is commonly far greater than the minimum requirements for the gypsic horizon and exceeds usually 60%. The term ‘gypsiferous’ applies to soil material which contains 5% or more gypsum.

In the SGDBE, there are no STUs that are thionic or gypsic.

4.4.2.3 Attribute WRB-FULL

In WRB, presence of sulphur or gypsum appears in thionic soils, Gypsisols, gypsic soils, petrogypsic soils and gypsiric soils.

Thionic soils are defined as soils having a sulphuric horizon or sulphidic materials within 100 cm from the soil surface. Two specifiers can be used and defined:

- orthithionic soils: having a sulphuric horizon within 100 cm from the soil surface;
- protothionic soils: having sulphidic soil material within 100 cm from the soil surface.

A sulphuric horizon is an extremely acidic subsurface horizon in which sulphuric acid is formed through oxidation of sulphides. It must have a pH (H_2O, 1:1) less than 3.5.

Sulphidic soil material is a waterlogged deposit containing sulphur, mostly in the form of sulphides, and only moderate amounts of calcium carbonate. It must have a pH (H_2O) of more than 3.5.

Gypsisols are soils having:

- a gypsic or a petrogypsic horizon within 100 cm from the soil surface,
- or, 15% (by volume) or more gypsum, which has accumulated under hydromorphic conditions, averaged over a depth of 100 cm.

A gypsic soil is a soil having a gypsic horizon within 100 cm from the soil surface. Several specifiers can be used to define:

- hypergypsic soils: the gypsic horizon has more than 60% of gypsum;
- hypogypsic soils: the gypsic horizon has less than 25% of gypsum.

A gypsic horizon is a non-cemented horizon containing secondary accumulations of gypsum ($CaSO_4.2H_2O$) in various forms. It must have 15% or more gypsum. If the horizon contains 60% or more gypsum, it becomes a hypergypsic horizon.

A petrogypsic soil is a soil having a petrogypsic horizon within 100 cm from the soil surface. A petrogypsic horizon is a cemented horizon containing secondary accumulations of gypsum ($CaSO_4.2H_2O$). It must have 60% or more gypsum and cementation to the extent that dry fragments do not slake in water. It cannot be penetrated by roots.

A gypsic soil is a soil having a gypsiric material at least between 20 and 50 cm from the soil surface. Gypsiric soil material is mineral soil material which contains 5% or more gypsum.

In the SGDBE, there are Thionic Fluvisols, Gypsisols, Gypsic Solonchaks and Gypsic Solonetz. There are no petrogypsic, neither gypsiric soils (Table 4-17).

Table 4-17: **Values of the WRB-FULL attribute that give information about chemical toxicity**

WRB-FULL	Signification	Number of STUs	Area in km^2
FLti	Thionic Fluvisol	1	15012
GYcc	Calcic Gypsisol	3	8172
GYgyh	Hypergypsic Gypsisol	1	76
GYha	Haplic Gypsisol	1	7054
GYpt	Petric Gypsisol	1	429
GYsow	Hyposodic Gypsisol	1	9
SCgy	Gypsic Solonchak	1	150
SCgyw	Hypogypsic Solonchak	2	52
SNgy	Gypsic Solonetz	1	21469

4.4.2.4 Attributes AGLIM1 and AGLIM2

There is no information about sulphur in the phase. On the contrary, there is a phase that gives information about gypsum. The petrogypsic phase marks soils in which the upper part of a petrogypsic horizon occurs within 100 cm from the soil surface (FAO-UNESCO, 1974). A petrogypsic horizon is a gypsic horizon that is so cemented with gypsum that dry fragments do not slake in water and roots cannot enter. The gypsum content in the petrogypsic horizon is commonly far greater than the minimum requirements for the gypsic horizon and usually exceeds 60%.

In the SGDBE, there are some STUs having a dominant phase as petrogypsic (Table 4-18) but there are no STUs having a secondary phase as petrogypsic. The STUs with a petrogypsic phase are coming from the Digital Soil Map of the World. As the petrogypsic phase doesn't exist in the European part of the SGDBE, it was not mentioned as an option for phase-naming in the Instructions Guide of the SGDBE. Thus, the phase was not used in the Mediterranean countries that give data for the SGDBE.

Table 4-18: **List of soil names having a dominant phase petrogypsic and an original soil name in FAO-UNESCO 1974 legend.**

FAO85-FULL	Signification	Number of STUs	Area in km^2
Yy	Gypsic Yermosol	6	42297
Yk	Calcic Yermosol	4	10543
I	Lithosol	3	8164
Je	Eutric Fluvisol	1	1123
Jc	Calcaric Fluvisol	1	164
Zo	Orthic Solonchak	3	2299
Re	Eutric Regosol	1	2544

4.4.3 Adapt the PTR with the information available in the SGDBE

The analysis of the available information shows that the information from the soil name can be used to characterise the presence of sulphur or gypsum. The chemical toxicity rule is described in Table 4-19. Three classes of chemical toxicity are proposed:

- low: no toxicity for most crops
- medium: toxicity for some crops possible
- high: toxicity for all crops

Table 4-19: **New rule for chemical toxicity**

FAO85-FULL	FAO85-FULL.CL	WRB-FULL	WRB-FULL.CL	AGLIM1	ROO	CHEMICAL TOXICITY	CL
*	*	*	*	*	*	low	high
Gtz	o	*	*	*	*	high	medium
Ght	o	*	*	*	*	high	medium
Jt	o	*	*	*	*	high	high
Xy	o	*	*	*		medium	medium
Xy	o	*	*	1	1	medium	high
Xy	o	*	*	1	3	medium	high

FAO85-FULL	FAO85-FULL.CL	WRB-FULL	WRB-FULL.CL	AGLIM1	ROO	CHEMICAL TOXICITY	CL
Yy	0	*	*	*	*	medium	medium
*	*	*	*	22	*	high	medium
I	0	*	*	22	*	high	high
Xy	0	*	*	22	*	high	high
Yk	0	*	*	22	*	high	high
Yy	0	*	*	22	*	high	high
*	*	FLti	0	*	*	high	high
*	*	**gy	0	*	*	medium	medium
*	*	**gy	0	*	6	high	high
*	*	**gy	0	*	4	high	high
*	*	**gyh	0	*	*	high	high
*	*	**gyw	0	*	*	medium	high
*	*	GY**	0	*	*	medium	medium
*	*	GY**	0	*	1	medium	high
*	*	GY**	0	*	2	medium	high
*	*	GYgyh	0	*	*	high	high
*	*	GYpt	0	*	*	high	medium

4.5 Drainage rule

4.5.1 Description of the current PTR used to derive drainage

The current rule used for estimating drainage in CGMS is described in (Table 4-20). It was first described by van Dam *et al.* (1994) and later updated by van Diepen (1997).

The drainage classes are derived on the basis of the FAO soil name, agricultural limiting phases and topsoil texture. The procedure is executed in the same order as the rows appear in this table. So, first the STUs with phase 21 are selected and labelled class 'W' and in the following step all remaining STUs are compared with the next rule and so on. The '*' indicates that on the considered position any character could be read.

Table 4-20: **The pedotransfer rules to derive the drainage class in CGMS**

FAO soil name	Phases	Topsoil texture	Drainage class
*	21 (drained)	*	W (well drained)
*	22 (flooded)	*	VP (very poorly drained)
G** (Gleysols)	*	*	P (poorly drained)
O** (Histosols)	*	*	P (poorly drained)
*	20 (fragic)	*	TP (temporarily poorly drained)
W** (Planosols)	*	*	TP (temporarily poorly drained)
Pp* (Placic Podzols)	*	*	TP (temporarily poorly drained)
Ap (Plinthic Acrisols)	*	*	TP (temporarily poorly drained)
Bgg (Stagno-gleyic Cambisols)	*	*	TP (temporarily poorly drained)
*gs (Stagno-gleyic soils)	*	*	TP (temporarily poorly drained)

FAO soil name	Phases	Topsoil texture	Drainage class
Lap (Plano-Albic Luvisol)	*	*	TP (temporarily poorly drained)
x (Gelic soils)	*	*	TP (temporarily poorly drained)
Bg* (Gleyic Cambisols)	*	*	MW (moderately well drained)
B*g (Gleyo- Cambisols)	*	*	MW (moderately well drained)
Ph (Humic Podzols)	*	*	MW (moderately well drained)
Cg (Gleyic Chernozems)	*	*	MW (moderately well drained)
D* (Podzoluvisols)	*	*	I (imperfectly drained)
Eh (Histic Rendzinas)	*	*	I (imperfectly drained)
J** (Fluvisols)	*	*	I (imperfectly drained)
La (Albic Luvisols)	*	*	I (imperfectly drained)
*g (Gleyic soils)	*	*	I (imperfectly drained)
**g (Gleyo- soils)	*	*	I (imperfectly drained)
Mo (Orthic Greyzems)	*	*	MW (moderately well drained)
V** (Vertisols)	*	*	MW (moderately well drained)
Q** (Arenosols)	*	*	EX (excessively drained)
*	*	1 (coarse)	EX (excessively drained)
*	*	*	W (well drained)

The drainage classes are referring to the definition of drainage classes as given by FAO in the guide for soil description (FAO, 1994). These classes take into account the frequency and the duration of the periods in the year where the soil is not saturated by water.

4.5.2 Review of available information in the SGDBE

4.5.2.1 Attribute WR

In the SGDBE, the attribute WR gives information about the water regime of the STU following 4 classes. This attribute gives information about the duration and the depth where the soil is saturated by water during the year. The relation between the values of this attribute and the drainage classes used for CGMS is given in Table 4-21. The class 4 of WR is corresponding to the VP (very poorly drained) class used in CGMS. But for the other classes of WR, there are several CGMS classes that correspond. For these WR classes, it is necessary to use other information to choose which CGMS class corresponds. To do so, the information from the soil name (FAO85-FULL, FAO90-FULL and WRB-FULL) and the agricultural limitations (AGLIM1, AGLIM2) will be used. These attributes will also be used when WR is not given (that is the case for all the data coming from the Digital Soil Map of the World).

Table 4-21: **Links between the WR attribute of the SGDBE and the CGMS drainage classes (see 4-20)**

WR code	WR signification	corresponding CGMS drainage classes
1	Not wet within 80 cm for over 3 months, nor wet within 40 cm for over 1 month	W and EX
2	Wet within 80 cm for 3 to 6 months, but not wet within 40 cm for over 1 month	MW and I
3	Wet within 80 cm for over 6 months, but not wet within 40 cm for over 11 months	P, I and TP
4	Wet within 40 cm depth for over 11 months	VP

The current CGMS rule for drainage class on the part of the SGDBE where soil names were given in the FAO-UNESCO 1974 legend is evaluated. Note that not each individual record is compared separately. First, all records of the CGMS rule have been applied. Thus, for example, not all Gleysols will receive value 'P'; only the STUs that have not been assigned 'W' or 'VP' because of a drained or flooded phase.

For each occurrence of the rule, the values taken by the WR attribute (except when WR = 0) were counted (Table 4-22). Some occurrences show a good correlation with WR:

- with a good estimation (in bold): for Gleysols, gleyic soils, Podzoluvisols, Arenosols and coarse-textured soils;
- with a bad estimation (in light grey): for Histosols, Placic Podzols, Plinthic Acrisols, Stagnic soils, Humic Podzols, Albic Luvisols, Orthic Greyzems and Vertisols.

The occurrences using the phase are generally dispatched in several WR classes. This result is not surprising because phases are generally not well defined. Moreover, the use of phases was very heterogeneous from one country to another.

Some soil types have more or less a high variability in their water regime:

- for Planosols, the water regime is mainly between 2 and 3;
- for Fluvisols, the water regime is mainly 1, but could be 2 or 3.

4.5.2.2 Attribute FAO85-FULL

In the FAO-UNESCO 1974 legend, the water regime of soils is described by:

- hydromorphic properties;
- aridic moisture regime;
- presence of an albic E horizon overlying a slowly permeable horizon;
- presence of a sulphuric horizon or sulphidic materials (see 4.4).

The different soil names for which one or more of these characteristics are present, or are not allowed, are listed in Table 4-23.

Table 4-22: **WR values for each occurrence of the current CGMS rule for drainage for STUs with an original soil name in FAO-UNESCO 1974 legend (in % of the number of STUs by occurrence)**

FAO soil name	Dominant Phase	Topsoil texture	WR				total number of STUs	CGMS drainage class
			1	2	3	4		
*	drained	*	36	29	34	2	132	W
*	flooded	*	0	50	50	0	2	VP
G**	*	*	3	23	58	16	304	P
O**	*	*	4	17	12	67	113	P
*	fragipan	*	38	13	25	25	8	TP
W**	*	*	16	47	31	6	32	TP
Pp*	*	*	4	13	21	63	24	TP
Ap	*	*	100	0	0	0	2	TP
Bgg	*	*	10	86	0	5	21	TP
*gs	*	*	12	63	23	3	102	TP
Lap	*	*	0	0	0	0	0	TP
x	*	*	0	0	0	0	0	TP
Bg*	*	*	3	83	13	0	30	MW
B*g	*	*	18	82	0	0	22	MW
Ph	*	*	83	7	7	3	29	MW
Cg	*	*	0	0	0	0	0	MW
D*	*	*	34	62	3	2	65	I
Eh	*	*	50	50	0	0	2	I
J**	*	*	46	24	26	4	204	I
La	*	*	63	38	0	0	8	I
*g	*	*	6	70	23	1	122	I
**g	*	*	0	71	29	0	7	I
Mo	*	*	100	0	0	0	9	MW
V**	*	*	70	28	2	0	43	MW
Q**	*	*	97	1	0	2	94	EX
*	*	coarse	89	8	2	1	492	EX
*	*	*	91	6	2	1	1580	W

Table 4-23: **Moisture regime information contained in the definition of soil names in the FAO-UNESCO 1974 legend**

Soil names	Information about soil moisture regime
Histosols	H horizon
Gleysols Gleyic Solonchaks Gleyic Solonetz Gleyic Podzoluvisols	hydromorphic properties < 50 cm
Gleyic Phaeozems Gleyic Greyzems	hydromorphic properties < 50 cm no albic E horizon overlying a slowly permeable horizon < 125 cm
Planosols	albic E horizon overlying a slowly permeable horizon < 125 cm showing hydromorphic properties at least in a part of the E horizon
Gleyic Luvisols Gleyic Acrisols	hydromorphic properties < 50 cm no albic E horizon overlying a slowly permeable horizon < 125 cm no aridic moisture regime
Gleyic Podzols	hydromorphic properties < 50 cm no thin iron pan in or over the spodic B horizon
Orthic, Leptic, Ferric, Humic Podzols	hydromorphic properties > 50 cm if exist no thin iron pan in or over the spodic B horizon
Placic Podzols	thin iron pan in or over the spodic B horizon
Regosols Arenosols Rendzinas Rankers Andosols Orthic, Mollic, Takyric Solonchaks Orthic, Mollic Solonetz Eutric, Dystric Podzoluvisols	hydromorphic properties > 50 cm if exist
Orthic, Chromic, Calcic, Vertic, Ferric, Albic Luvisols Orthic, Ferric, Humic Acrisols	hydromorphic properties > 50 cm if exist no albic E horizon overlying a slowly permeable horizon < 125 cm no aridic moisture regime
Haplic, Calcic Kastanozems Haplic, Calcic, Glossic Chernozems Haplic, Calcaric, Luvic Phaeozems Orthic Greyzems	hydromorphic properties > 50 cm if exist no albic E horizon overlying a slowly permeable horizon < 125 cm
Gelic Cambisols	hydromorphic properties > 50 cm if exist no aridic moisture regime
Eutric, Dystric, Humic, Calcic, Chromic, Vertic and Ferralic Cambisols.	hydromorphic properties > 100 cm if exist no aridic moisture regime
Gleyic Cambisols	hydromorphic properties between50 cm to 100 cm no aridic moisture regime
Yermosols Xerosols	aridic moisture regime
Thionic Fluvisols	sulphuric horizon or sulphidic materials, or both, within 125 cm from the soil surface
Luvic Kastanozems Luvic Chernozems	hydromorphic properties < 50 cm can exist no albic E horizon overlying a slowly permeable horizon < 125 cm
Plinthic Luvisols Plinthic Acrisols Nitosols	no albic E horizon overlying a slowly permeable horizon < 125 cm no aridic moisture regime

Hydromorphic properties mark soils showing one or more of the following properties:

- saturation by groundwater;
- occurrence of a Histic H horizon;
- dominant hues that are neutral N, or bluer than 10Y;
- saturation with water at some periods of the year, or artificially drained, with evidence of reduction processes or of reduction and segregation of iron reflected by different criteria like for example:
  - in Podzols, the presence of a duripan or a thin iron pan;
  - in soils having an argillic horizon, iron-manganese concretions larger than 2 mm;
  - in Ferralsols, plinthite that forms a continuous phase within 30 cm.

For some soil groups, the presence of hydromorphic properties was not defined because it was not possible to separate them at the scale of the Soil Map of the World. It is the case for Fluvisols, Regosols, Luvic Kastanozems, Luvic Chernozems and Nitosols. In the Soil Map of the European Communities (CEC, 1985), several subdivisions were added:

- showing hydromorphic properties:
  - within 50 cm from the soil surface: Gleyo-eutric, Gleyo-calcaric and Gleyo-dystric Fluvisols,
  - related to surface water stagnation during most of the year: Stagno-eutric, Stagno-Calcaric Stagno-dystric Gleysols, Stagno-gleyic Cambisols, Stagno-gleyic Luvisols, Stagno-gleyic Podzoluvisols, Stagno-gleyic Podzols.
- having a thin iron pan: Placi-dystric Histosols.

If the soil name can give information about the presence of hydromorphic properties and their depth of appearance, it gives no information about the duration of the saturation by water periods.

In the Digital Soil Map of the World, there is a rule for drainage estimation based on FAO soil name, topsoil texture, slope and phases (Table 4-24). The estimation gives a repartition in % to each drainage class that enables calculation of areas.

Table 4-24: **FAO rule for estimation of drainage class**

Soil name	Topsoil texture	Slope	Phase	FAO drainage class
Histosols	*	*	*	VP
Gleysols	*	*	*	VP (50%), P (50%)
Fluvisols	clayey	*	*	VP (50%), P (50%)
Planosols Gleyic soils except Cambisols	*	*	*	P (50%), I (50%)
Vertisols	*	*	*	I (66%), P (34%)
Plinthic Ferralsols Plinthic Acrisols Gleyic Cambisols	*	*	*	I (50%), MW (50%)
Arenosols Podzols except gleyic	*	< 8%	*	E (50%), SE (50%)
Regosols	coarse	< 8%	*	E (50%), SE (50%)
Arenosols Podzols except gleyic	*	> 8%	*	E
Regosols	coarse	> 8%	*	E
Lithosols Rankers Rendzinas	coarse	< 8%	*	MW
Lithosols Rankers Rendzinas	loamy clayey	< 8%	*	I
Lithosols Rankers Rendzinas	*	> 8%	*	W (50%), SE (50%)
Luvisols except gleyic Acrisols except gleyic Podzoluvisols except gleyic Nitosols Luvic Xerosols Luvic Yermosols Luvic Kastanozems Luvic Chernozems Luvic Phaeozems	coarse	< 8%	*	MW (50%), W (50%)
Luvisols except gleyic Acrisols except gleyic Podzoluvisols except gleyic Nitosols Luvic Xerosols Luvic Yermosols Luvic Kastanozems Luvic Chernozems Luvic Phaeozems	loamy clayey	< 8%	*	MW (75%), W (25%)

Soil name	Topsoil texture	Slope	Phase	FAO drainage class
Luvisols except gleyic Acrisols except gleyic Podzoluvisols except gleyic Nitosols Luvic Xerosols Luvic Yermosols Luvic Kastanozems Luvic Chernozems Luvic Phaeozems	*	> 8%	*	W (50%), MW (25%), SE (25%)
Luvisols except gleyic Acrisols except gleyic Podzoluvisols except gleyic Nitosols Luvic Xerosols Luvic Yermosols Luvic Kastanozems Luvic Chernozems Luvic Phaeozems	coarse	< 8%	petrocalcic petrogypsic petroferric duripan	MW (75%), W (25%)
Luvisols except gleyic Acrisols except gleyic Podzoluvisols except gleyic Nitosols Luvic Xerosols Luvic Yermosols Luvic Kastanozems Luvic Chernozems Luvic Phaeozems	loamy clayey	< 8%	petrocalcic petrogypsic petroferric duripan	I (50%), MW (37.5%), W (12.5%)
Luvisols except gleyic Acrisols except gleyic Podzoluvisols except gleyic Nitosols Luvic Xerosols Luvic Yermosols Luvic Kastanozems Luvic Chernozems Luvic Phaeozems	*	> 8%	petrocalcic petrogypsic petroferric duripan	W (50%), MW (12.5%), SE (37.5%)
other soils	coarse	< 8%	*	W (50%), SE (25%), E (25%)
other soils	loamy clayey	< 8%	*	MW (50%), W (50%)
other soils	coarse	> 8%	*	MW (50%), W (50%)[2]
other soils	loamy clayey	> 8%	*	W (50%), SE (25%), MW (25%)
other soils	coarse	< 8%	petrocalcic petrogypsic petroferric duripan	W (25%), SE (12.5%), E (12.5%), MW (50%)

[2] It seems that in this case there is a mistake in the FAO document. In all other cases, when the slope is more than 8%, the corresponding drainage classes are classes more drained than those for the slope less than 8%.

Soil name	Topsoil texture	Slope	Phase	FAO drainage class
other soils	loamy clayey	< 8%	petrocalcic petrogypsic petroferric duripan	MW (25%), W (25%), I (50%)
other soils	coarse	> 8%	petrocalcic petrogypsic petroferric duripan	MW (25%), W (50%), SE (25%)
other soils	loamy clayey	> 8%	petrocalcic petrogypsic petroferric duripan	W (50%), SE (37.5%), MW (12.5%)

The FAO rule for drainage class on the part of the SGDBE where soil names were given in the FAO-UNESCO 1974 legend was evaluated. For each occurrence of the rule, the values taken by the WR attribute (except when WR = 0) were counted (Table 4-25). All the occurrences for which we have WR values show a good correlation with WR:

- with a good estimation (in bold)
- with a bad estimation (in light grey): An estimation is considered as bad if the dominant FAO drainage class doesn't correspond to the WR value, or if there are two classes having equal percentage, even if one corresponds to the WR value.

Topsoil texture, slope and phase don't show an impact on WR values.

Table 4-25: **WR values for each occurrence of the FAO rule for drainage for STUs with an original soil name in FAO-UNESCO 1974 legend (in % of the number of STUs by occurrence)**

Soil name	Dominant topsoil texture	Dominant slope	Dominant phase	WR				Total number of STUs
				1	2	3	4	
O**	*	*	*	3	16	16	64	121
G**	*	*	*	3	23	59	15	333
J**	clayey	*	*	27	21	52	0	33
W**, *g* sauf Bg	*	*	*	10	64	24	2	301
V**	*	*	*	62	29	8	0	48
Fp, Ap, Bg	*	*	*	8	77	9	5	61
Q**, P** sauf Pg	*	< 8%	*	93	3	2	2	157
R**	coarse	< 8%	*	92	4	4	0	26
Q**, P** sauf Pg	*	> 8%	*	77	8	4	10	145
R**	coarse	> 8%	*	96	4	0	0	26
I**, E**, U**	coarse	< 8%	*	100	0	0	0	5
I**, E**, U**	loamy clayey	< 8%	*	96	4	0	0	26
I**, E**, U**	*	> 8%	*	89	6	2	3	379

Soil name	Dominant topsoil texture	Dominant slope	Dominant phase	WR				Total number of STUs
				1	2	3	4	
L** except Lg, A** except Ag, D** except Dg, N**, Xl, Yl, Kl, Cl, Hl	coarse	< 8%	*	85	15	0	0	40
L** except Lg, A** except Ag, D** except Dg, N**, Xl, Yl, Kl, Cl, Hl	loamy clayey	< 8%	*	80	18	1	1	257
L** except Lg, A** except Ag, D** except Dg, N**, Xl, Yl, Kl, Cl, Hl	*	> 8%	*	90	7	0.5	3	203
L** except Lg, A** except Ag, D** except Dg, N**, Xl, Yl, Kl, Cl, Hl	coarse	< 8%	petrocalcic petrogypsic petroferric duripan	0	0	0	0	0
L** except Lg, A** except Ag, D** except Dg, N**, Xl, Yl, Kl, Cl, Hl	loamy clayey	< 8%	petrocalcic petrogypsic petroferric duripan	100	0	0	0	3
L** except Lg, A** except Ag, D** except Dg, N**, Xl, Yl, Kl, Cl, Hl	*	> 8%	petrocalcic petrogypsic petroferric duripan	0	100	0	0	2
other soils	coarse	< 8%	*	71	12	15	1	98
other soils	loamy clayey	< 8%	*	73	17	8	2	468
other soils	coarse	> 8%	*	95	4	1	0	97
other soils	loamy clayey	> 8%	*	89	7	3	1	584
other soils	coarse	< 8%	petrocalcic petrogypsic petroferric duripan	0	0	0	0	0
other soils	loamy clayey	< 8%	petrocalcic petrogypsic petroferric duripan	100	0	0	0	6
other soils	coarse	> 8%	petrocalcic petrogypsic petroferric duripan	0	0	0	0	0
other soils	loamy clayey	> 8%	petrocalcic petrogypsic petroferric duripan	0	0	0	0	0

4.5.2.3 Attribute FAO90-FULL

In the FAO-UNESCO 1990 legend, the water regime of soils is described by:

- gleyic properties;
- stagnic properties;
- presence of an E horizon abruptly overlying a slowly permeable horizon;
- presence of a sulphuric horizon or sulphidic materials (see 4.4);
- well drained;
- imperfect to very poor drainage;
- very poor drainage or undrained.

The different soil names for which one or more of these characteristics are present or are not allowed, are listed in Table 4-26.

Table 4-26: **Moisture regime information contained in the definition of soil names in the FAO-UNESCO 1990 legend**

Soil names	Information about soil moisture regime
Folic Histosols	well drained
Terric Histosols	imperfect to very poor drainage
Fibric Histosols	very poor drainage or undrained
Thionic Fluvisols Thionic Histosols	sulphuric horizon or sulphidic materials, or both, within 125 cm from the soil surface
Gleysols	gleyic properties < 50 cm
Gleyic Cambisols	gleyic properties between 50 cm to 100 cm
Gleyic Arenosols Gleyic Solonetz Gleyic Solonchaks Gleyic Chernozems Gleyic Podzoluvisols Gleyic Podzols	gleyic properties < 100 cm
Gleyic Phaeozems Gleyic Greyzems	gleyic properties < 100 cm no E horizon abruptly overlying a slowly permeable horizon < 125 cm
Gleyic Luvisols Gleyic Lixisols Gleyic Acrisols Gleyic Alisols	gleyic properties < 100 cm no E horizon abruptly overlying a slowly permeable horizon
Stagnic Solonetz	stagnic properties no gleyic properties < 100 cm
Stagnic Phaeozems	stagnic properties no gleyic properties < 100 cm no E horizon abruptly overlying a slowly permeable horizon < 125 cm
Stagnic Luvisols Stagnic Lixisols Stagnic Alisols	stagnic properties < 50 cm no gleyic properties < 100 cm no E horizon abruptly overlying a slowly permeable horizon
Stagnic Podzoluvisols	stagnic properties < 50 cm no gleyic properties < 100 cm
Planosols	E horizon abruptly overlying a slowly permeable horizon < 125 cm showing stagnic properties at least in a part of the E horizon
Regosols Andosols	no gleyic properties < 50 cm

Soil names	Information about soil moisture regime
Haplic, Ferric, Humic Acrisols	no gleyic properties < 100 cm no E horizon abruptly overlying a slowly permeable horizon
Haplic, Calcic, Gypsic Kastanozems Haplic, Calcic, Glossic Chernozems	no gleyic properties < 50 cm no E horizon abruptly overlying a slowly permeable horizon < 125 cm
Gelic Cambisols	no gleyic properties < 50 cm
Haplic, Cambic, Luvic, Ferralic, Albic, Calcaric Arenosols Eutric, Dystric, Humic, Calcaric Chromic, Vertic and Ferralic Cambisols. Calcisols Gypsisols Haplic, Mollic, Gypsic, Sodic Solonchaks Haplic, Cambic, Ferric, Carbic Podzols	no gleyic properties < 100 cm
Haplic, Mollic, Calcic, Gypsic Solonetz	no stagnic properties no gleyic properties < 100 cm
Eutric, Dystric Podzoluvisols Plinthic Ferralsols	no stagnic properties < 100 cm no gleyic properties < 100 cm
Haplic, Calcaric, Luvic Phaeozems	no stagnic properties no gleyic properties < 100 cm no E horizon abruptly overlying a slowly permeable horizon < 125 cm
Haplic, Ferric, Chromic, Calcic, Vertic, Albic Luvisols Haplic, Ferric, Plinthic, Albic Lixisols Haplic, Ferric, Humic Alisols	no stagnic properties < 100 cm no gleyic properties < 100 cm no E horizon abruptly overlying a slowly permeable horizon
Luvic Kastanozems	no albic E horizon overlying a slowly permeable horizon < 125 cm
Luvic Chernozems Haplic Greyzems	no gleyic properties < 100 cm no E horizon abruptly overlying a slowly permeable horizon < 125 cm
Plinthic Acrisols Plinthic Alisols	no E horizon abruptly overlying a slowly permeable horizon

Gleyic and stagnic properties refer to soil material which is saturated with water at some periods of the year, or throughout the year, in most years, and which show evidence of reduction processes or of reduction and segregation of iron. Gleyic properties are related to saturation by groundwater. Stagnic properties are related to saturation by surface water within 50 cm.

4.5.2.4 Attribute WRB-FULL

In WRB the water regime is described by:

- Gleysols: soils having gleyic properties within 50 cm from the soil surface;
- Planosols: soils having an eluvial horizon, the lower boundary of which is marked, within 100 cm from the soil surface, by an abrupt textural change associated with stagnic properties above that boundary;

- Histosols: soils having:
  - a folic horizon which one of its characteristics is to have water saturation for less than one month in most years;
  - or a histic horizon which one of its characteristics is to have water saturation for at least one month in most years;
- Gelistagnic soils present a temporary water saturation at the surface caused by a frozen subsoil;
- Gleyic soils are soils having gleyic properties within 100 cm from the soil surface. Two specifiers can be used:
  - endogleyic: soils having gleyic properties between 50 and 100 cm from the soil surface;
  - epigleyic: soils having gleyic properties within 50 cm from the soil surface.
- Oxyaquic Cryosols: Cryosols saturated with water during the thawing period and lacking redoximorphic features within 100 cm from the soil surface;
- Planic soils are soils having an eluvial horizon abruptly overlying a slowly permeable horizon within 100 cm from the soil surface;
- Rheic Histosols: Histosols having a water regime conditioned by surface water;
- Stagnic soils are soils having stagnic properties within 50 cm from the soil surface;
- Endostagnic soils are soils having stagnic properties between 50 and 100 cm from the soil surface.

Gleyic properties refer to soil materials which are, at least temporarily, completely saturated with groundwater for a period that allows reducing conditions to occur and show a gleyic colour pattern. Stagnic properties refer to soil materials which are completely saturated with surface water for a period long enough to allow reducing conditions to occur and show a stagnic colour pattern.

4.5.2.5 Attributes AGLIM1 and AGLIM2

Several phases are related with the water regime of the soils: drained, fragipan, flooded, phreatic. The drained phase has no definition, and becomes 'excessively drained' in the Instructions guide for version 4.0. When looking at the STUs having a dominant phase drained, all the values for WR are represented; the values 1, 2 and 3 are representing each of them around 30% of these STUs, the value 4 representing 8%. There is a low correlation between the phase drained and the water regime showing its bad quality. It is proposed to ignore this value in the rule.

The fragipan phase is defined in the FAO-UNESCO 1974 legend. It marks soils which have the upper level of the fragipan occurring within 100 cm from the soil surface. A fragipan is a loamy (uncommonly a sandy) subsurface horizon which has a high bulk density relative to the horizons above it. It is slowly to very slowly permeable.

The flooded phase has no definition.

The phreatic phase is defined in the FAO-UNESCO 1974 legend. It marks soils which have a groundwater table between 3 and 5 m from the soil surface. At this depth the presence of a groundwater is not normally reflected in the morphology of the solum; however, its presence is important for the water regime of the soil.

The petrocalcic phase marks soils in which the upper part of a petrocalcic horizon occurs within 100 cm from the soil surface (FAO-UNESCO, 1974). The petrocalcic horizon is a continuous cemented or indurated calcic horizon. The hydraulic conductivity is moderately slow to very slow.

When the current CGMS rule for drainage was evaluated, it appears that phases have often a high variability for the WR attribute. In this case it is proposed not to use them for estimating the drainage class.

4.5.3 Adapt the PTR with the information available in the SGDBE

The new rule for drainage is given in Annex 3.

5 Redefinition of new Soil Physical Groups

The soil moisture parameters required for the CGMS include soil moisture content at saturation, wilting point (pF 4.2) and field capacity (pF 2.0). Redefinition should be based on available soil water retention data from literature, existing digital soil physical databases and expertise drawn from a long experience of working with these parameters at local, national and European levels.

5.1 Current situation

In the CGMS, Soil Physical Groups were introduced per STU to determine the Available Water Capacity (AWC) of a soil. The AWC in CGMS was first based on rules described by van Dam et al. (1994) and later updated by van Diepen (1997). An AWC estimation program was developed by the Soil Survey Staff in France from INRA in collaboration with the Soil Survey and Land Research Centre of England and Wales (King et al., 1995). This program calculates for each STU: a profile AWC-estimate for the main horizons (maximum 3) on the basis of pedotransfer rules, an estimated maximum possible rooting depth, and an indication whether moisture could become available through capillary rise (Le Bas et al., 1997).

The values of the AWC database, based on the AWC-program, were grouped into 7 soil physical groups and inserted into the CGMS as shown in Table 5-1 (van Diepen and Boogaard, 1998).

Table 5-1: **The definition of soil physical groups as they occur in the CGMS database**

AWC range	Soil physical group	Volumetric soil moisture content at wilting point	Volumetric soil moisture content at field capacity	Volumetric soil moisture content at saturation	Available water capacity
< 0.075	1	0.1	0.163	0.4	0.063
0.075-0.100	2	0.1	0.188	0.4	0.088
0.100-0.125	3	0.1	0.213	0.4	0.113
0.125-0.150	4	0.1	0.238	0.4	0.138
0.150-0.175	5	0.1	0.263	0.4	0.163
0.175-0.200	6	0.1	0.288	0.4	0.188
>0.200	7	0.1	0.313	0.4	0.213

5.2 Calculation of Available Water Capacity (AWC)

5.2.1 Determine SWAP with CERU32

The starting point for the calculation of Soil Water Available for Plants (SWAP) is the CERU32 program of INRA (ArcInfo AML and Fortran) which calculates the SWAP for each STU.

First, the soil profile is schematized in three layers (Le Bas et al., 1997) (see Figure 5-1):

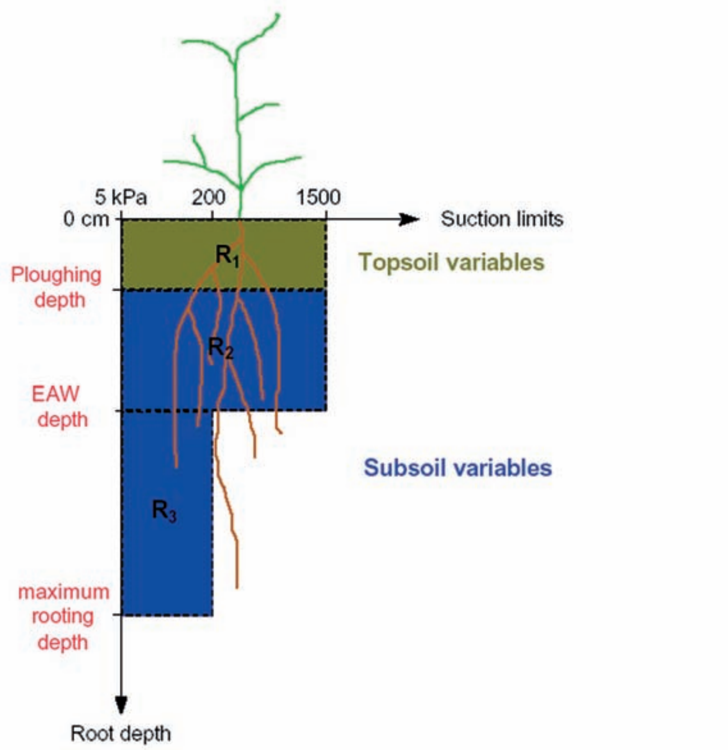
1) a worked surface layer, defined by ploughing depth. The available water for this layer corresponds to the total available water (water volume between –1500 kPa suction (wilting point) and –5 kPa (field capacity)) estimated by rules using the **topsoil** input variables.

2) a subsurface layer, between the ploughing depth and the EAW (Easily Available Water) depth. The latter is user defined. The available water for this layer corresponds to the total available water (water volume between –1500 kPa suction (wilting point) and –5 kPa (field capacity)) estimated by rules valid for the subsoil, using the **subsoil** input variables. But if the soil layer is less than the depth to textural change the rules for subsoil uses **topsoil** input variables.

3) a deeper layer, between the EAW depth and the maximum rooting depth. The available water for this layer corresponds to the easily available water (water volume between –200 kPa suction and –5 kPa (field capacity)) estimated by rules valid for the subsoil, using the **subsoil** input variables. But if the soil layer is less than the depth to textural change the rules for subsoil uses **topsoil** input variables.

The main rule estimates the AWC and EAWC using texture class and packing density class (see rule 9 and 10 in Annex 4). Other rules are used to estimate input variables like topsoil and subsoil texture class, topsoil and subsoil structure class and topsoil and subsoil packing density, depth of soil and depth to textural change (see rules 1 to 8 in Annex 4).

Figure 5-1: **Schematization of the soil profile in the AWC calculation of the CERU32 program (Le Bas et al., 1997)**



The total SWAP is obtained by summing the available water for each layer taking into account the worked surface layer, the depth to textural change and the maximum rooting depth. If gravel or stones are present, a percentage of water is removed from the calculated SWAP (see rule 11 in Annex 4). In the same manner, for taking account of capillary rises, an amount of water is added to the SWAP for particular substrata such as loess or chalk (see rule 12 in Annex 4).

The rules are summarized below.

PTR01: This rule mainly converts the soil parameter 'depth class to a textural change' on the basis of soil name and the difference between texture of top and subsoil into **depth of textural change** (cm).

PTR02: This rule determines **rooting depth** (see chapter 6).

PTR03: This rule corrects the **topsoil texture class** on the basis of soil name, parent material and subsoil texture class. The texture classification is changed by adding classes 7 for rocks and 8 for peat.

PTR04: This rule corrects the **subsoil texture class** on the basis of topsoil texture class (PTR03), secondary subsoil texture class, rooting depth, depth to textural change (PTR01) and parent material. As in PTR03 the texture classification is changed by adding classes 7 for rocks and 8 for peat.

PTR05: This rule determines the **topsoil structure class** on the basis of topsoil texture class and soil name.

PTR06: This rule determines the **subsoil structure class** on the basis of subsoil texture class and soil name.

PTR07: This rule determines the **topsoil packing density** class on the basis of the topsoil texture class and the topsoil structure class.

PTR08: This rule determines the **subsoil packing density class** on the basis of the subsoil texture class, subsoil structure class and soil name.

PTR09: This rule determines **(easy) available water capacity of the topsoil** on the basis of topsoil texture class and topsoil packing density class.

PTR10: This rule determines **(easy) available water capacity of the subsoil** on the basis of subsoil texture class and subsoil packing density class.

PTR11: This rule determines a correction **factor to decrease the SWAP due to agricultural constraints**. The factor is based on parent material and agricultural limiting phase.

PTR12: This rule determines a correction **factor to increase the SWAP due to capillary rise** originating from retained water stored in the parent material. This factor is based on parent material.

5.2.2 Review and adaptation of current rules to derive SWAP

The current rules, described in Annex 4 and listed above, have been reviewed and extended for the SGDBE version 4.0. The extension was needed because of the other soil classifications. Rules have been defined in a more general way so that they can handle all possible values that occur for the different attributes. The review and the new rules are described in Annex 4.

The program CERU32 that determines for each STU the result of a PTR has been slightly changed. The program compares soil properties of one STU with the set of records of a rule. Each record of the rule is compared with the STU data. If more than one record is found that matches with the STU data the last record that matches the STU is selected as the final result. Thus the order of the records is important.

To explain this in more detail we present the following dummy example:

Input column 1 = x1
1 low
2 high

Input column 2 = x2
1 low
2 high

Output column 3 = y1 (mm water)

Rule

*	*	100
1	2	130
1	*	80
*	2	30

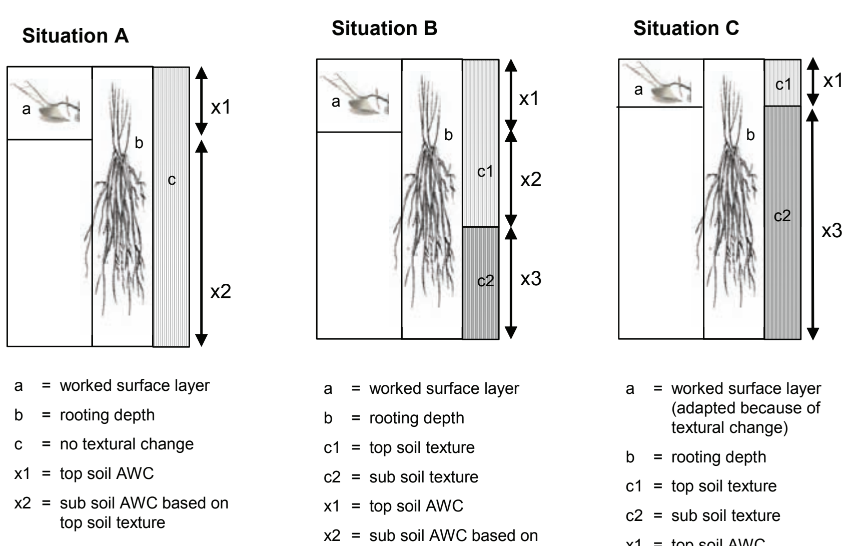
This dummy PTR first assigns value 100 for y1 to all STUs. All STUs are selected by this first record because of the wild cards of both input columns. Next, all STUs that have value 1 for x1 and value 2 for x2 will receive value 130. In the following step this sub set of STUs, plus all STUs that have value 1 for x1 (regardless column x2), will receive a value of 80 because x1 is 1 and x2 has a wild card. Finally, all STUs with value 2 for x2 will receive value 30. Thus, the sub set of STUs that have value 1 for x1 and value 2 for x2 will finally receive value 30. As shown, the order of the records within a rule is important. This only is true when more than one record within the rule matches the properties of the STU. The next example shows a dummy rule for which the order is not important.

Rule

1	1	100
1	2	130
2	1	80
2	2	30

For each STU a vertical stratification of available water capacity (AWC) is derived as indicated in Figure 5-2. The worked surface layer (symbol x1 of situation A, B and C shown in Figure 5-2) has been assigned the AWC-value determined with rules valid for topsoil (see rule 9 in Annex 4). In the CERU32 program, topsoil AWC is only based on topsoil texture because topsoil packing density does not differentiate. Peat has one value (439 mm per meter rooting depth). Texture class 'medium fine' is optimum (210), values for 'medium fine' and 'very fine' are in the middle (170-180) and 'coarse' is lower (130). Texture classes 'no information' and 'rocks' are assigned 'no information'. Table 5-3 summarizes the rule. This rule is based on the study of Thomasson (1988).

Figure 5-2: **Schematization of different soil profiles in relation to the application of expert rules to derive Available Water Capacity**



The soil layer between the worked surface layer and the depth at which a textural change occurs (symbol x2 of situation B shown in Figure 5-2), has an AWC-value based on expert rules developed for the subsoil but entered with topsoil attribute values. The same is true for soil profiles where the texture does not change within the rooting depth (symbol x2 of situation A). Finally, the soil layer between the depth at which a textural change occurs and the maximum rooting depth (symbol x3 of situation B and C shown in Figure 5-2) has an AWC-value based on the same expert rules developed for the subsoil and entered with subsoil attribute values.

These subsoil AWC rules are based on texture and packing density (see also Thomasson, 1988). Packing density is derived from structure class (see PTR08 in Annex 4) and structure class is derived from texture (see PTR06 in Annex 4). Peat has one value (439 mm per meter rooting depth). High packing density classes give lower estimates. There is not much difference between texture classes; only texture class 'coarse' has a lower AWC-value. For low or medium packing density classes texture class 'medium fine' is optimal. Texture class 'coarse' is always lower. Texture classes 'no information' and 'rocks' have the label 'no information'. Table 5-3 summarizes the rule.

The CERU32 program distinguishes one single user-defined EAW depth that is applied on the whole database. Below this depth only water between 5 and 200 kPa suction is available for the plants. For CGMS only, the AWC between field capacity (5 kPa) and wilting point (1500 kPa) is needed which explains why the EAW depth is not included the underlying study.

CGMS can only handle one water retention curve per STU. Therefore the vertical stratification of AWC-values will be translated into one AWC-value that has been weighed for different lengths of soil layers and their related AWC-values. However the water capacity per soil layer of a STU will also be saved **in case CGMS will be extended with a multi-layer soil water balance**. In case of rocks, no information on texture class etc. the AWC is given a standard low value of 10 mm per 1 metre rooting depth. This value has been assigned during the process of translating the calculated AWC into soil physical groups ready for the CGMS database.

5.2.3 Comparison of calculated AWC with HYPRES

The AWC values used in the CERU32 program are compared with AWC-values derived from class pedotransfer functions derived in the framework of the HYPRES (Hydraulic Properties of European Soils) database. The class pedotransfer rules have been set up for 11 different top and subsoil texture classes. A prerequisite for deriving these class pedotransfer functions which can be applied at a European scale is the availability of this basic soil data and soil hydraulic properties from a wide range of soils across Europe. Before the HYPRES database, this data was fragmented, with varying degrees of detail and reliability and held by different institutions scattered throughout Europe. However, a group of 20 institutions from 12 European countries collaborated to bring together the available measured hydraulic properties held by different institutions in Europe into one central database: the HYPRES database (Wösten et al., 1998 and 1999). The twenty institutions who contributed to HYPRES are located in 12 Western European countries with the exception of Slovakia. As a result, the average hydraulic properties are based on data measured in Western Europe. One should realize this when using the pedotransfer rules. Caution is needed when applying these rules to Central and Eastern Europe or Mediterranean countries.

The parameters of the class transfer rules are presented in the following Table 5-2 (Wösten et al., 1999).

Table 5-2: **Mualem-van Genuchten parameters for the fits on the geometric mean curves (Wösten et al., 1999)**

	θr	θs	α	n	m	l	Ks
Topsoil							
Coarse	0.025	0.403	0.0383	1.3774	0.2740	1.2500	60.000
Medium	0.010	0.439	0.0314	1.1804	0.1528	-2.3421	12.061
Medium Fine	0.010	0.430	0.0083	1.2539	0.2025	-0.5884	2.272
Fine	0.010	0.520	0.0367	1.1012	0.0919	-1.9772	24.800
Very Fine	0.010	0.614	0.0265	1.1033	0.0936	2.5000	15.000
Subsoil							
Coarse	0.025	0.366	0.0430	1.5206	0.3424	1.2500	70.000
Medium	0.010	0.392	0.0249	1.1689	0.1445	-0.7437	10.755
Medium Fine	0.010	0.412	0.0082	1.2179	0.1789	0.5000	4.000
Fine	0.010	0.481	0.0198	1.0861	0.0793	-3.7124	8.500
Very Fine	0.010	0.538	0.0168	1.0730	0.0680	0.0001	8.235
Organic*	0.010	0.766	0.0130	1.2039	0.1694	0.4000	8.000

* Within the organic soils no distinction is made in topsoils and subsoils.

The resulting AWC values calculated with the class pedotransfer rules of Table 5-2 are largely influenced by the definition of the field capacity. Field capacity is usually defined as the amount of water remaining in a soil system after downward gravity drainage has ceased, or materially done so, after a period of rain or excessive irrigation to thoroughly wet the soil system (Bear, 1972; Marshall and Holmes, 1988). In literature you can find pressure heads between -10 kPa and -33 kPa defining the field capacity. In the description of the CERU32 program (Le Bas et al., 1997) a relatively low value of -5 kPa is used as field capacity.

In the following table, the AWC values of the CERU program are compared with AWC value based on the HYPRES class pedotransfer rules using a range of different field capacities.

Table 5-3: **Comparison of AWC value used in the CERU32 program and AWC values calculated with the class pedotransfer rules based on the HYPRES database using three different definitions of field capacity (-5 kPa, -10 kPa and -20 kPa)**

Texture class	CERU32 program			HYPRES							
	AWC ρ_{low}	AWC ρ_{medium}	AWC ρ_{high}	θ_{sat}	θ_{wp}	θ_{fc-5}	θ_{fc-10}	θ_{fc-20}	AWC_{-5}	AWC_{-10}	AWC_{-20}
Topsoil											
Coarse	130	130	130	0.403	0.06	0.294	0.243	0.197	234	183	137
Medium	180	180	180	0.439	0.152	0.379	0.347	0.313	227	195	161
Medium Fine	210	210	210	0.43	0.134	0.406	0.383	0.349	272	249	215
Fine	170	170	170	0.52	0.28	0.472	0.448	0.423	192	168	143
Very Fine	170	170	170	0.614	0.336	0.567	0.541	0.511	231	205	175
Subsoil											
Coarse	120	80	80	0.366	0.037	0.233	0.179	0.135	196	142	98
Medium	210	160	120	0.392	0.151	0.349	0.324	0.296	198	173	145
Medium Fine	220	190	130	0.412	0.151	0.392	0.373	0.344	241	222	193
Fine	200	150	130	0.481	0.299	0.456	0.441	0.422	157	142	123
Very Fine	210	150	130	0.538	0.363	0.517	0.503	0.486	154	140	123
Organic	439	439	439	0.766	0.269	0.708	0.663	0.604	439	394	335

The AWC values estimated with the CERU32 rules have been compared with the AWC estimates according to the HYPRES rules. Therefore both groups of AWC values have been listed (see Table 5-3). The comparison cannot be done on a one to one basis. While both approaches give values for the same texture classes and distinguish between topsoil and subsoil, the CERU32 program makes an additional distinction between the subsoil AWC-values on the basis of packing density class (mineral soils only). In case of the HYPRES rules no pressure head limit at field capacity is defined, so that the moisture content at field capacity and related AWC can only be given as a plausible range. The HYPRES data include a specification of the points on the soil moisture retention curve. The CERU32 program, gives only the difference between wilting point and field capacity, and not the values for the points, while the soil water model in CGMS requires values for saturation, field capacity and wilting point. The HYPRES rules base can be used to generate realistic values for these points, which should be specified in such a way that they remain consistent with the given CERU32 AWC values.

For the topsoil the CERU32 AWC values range from 130 to 210 mm/m (Table 5-3). Let us assume that the soil moisture content at wilting point in the HYPRES rules is a realistic value. Then the value for field capacity corresponding with the CERU32 AWC value can be found as follows:

$$\theta fc = \theta wp_{\text{of HYPRES}} + AWC_{\text{CERU32}} / 1000$$

This gives values for soil moisture of the topsoil at field capacity ranging from 0.190 to 0.506 (see Table 5-4), which correspond with pressure heads between 10 and 20 kPa according to the HYPRES rules (see Table 5-3), well above the 5 kPa mentioned as reference value by Le Bas et al, 1997. Inversely, when we take a pressure head as starting point to determine the AWC on the basis of the HYPRES rules, then a pressure head of 5 kPa would correspond to AWC values of 192 to 272 mm/m (see Table 5-3), so much higher and with less differences between the texture classes. Notably, the largest difference is found for the coarse texture class, for which the HYPRES rules estimates an AWC of 137 mm/m at a pressure head of 20 kPa, and 234 mm/m at 5 kPa. For the organic soils, the new CERU32 AWC value of 439 mm/m corresponds perfectly with the AWC value calculated on the basis of the HYPRES rules as difference between the amount of soil water retained between 5 kPa and wilting point. This is because the HYPRES database has been used as basis for the new CERU32 rule.

It can be concluded that the AWC values given by the CERU32 program are comparable with the HYPRES rules when using different pressure heads for field capacity for different texture classes with the class PTR rules of HYPRES. The more coarse soils have pressure heads between 10 and 20 kPa and the finer texture classes in the subsoil have pressure heads of 10 kPa and peat soils a pressure head of 5 kPa. This seems very logical regarding the behaviour of different soils with different texture in the way these soils retain the water. Therefore we decided to define the soil moistures contents at wilting point and saturation using the water retention curves defined by the HYPRES while the definition of the field capacity is based on the AWC given by the CERU32 program. The field capacity is given by the formula presented above.

The comparison of subsoil values for AWC and field capacity between the CERU32 program and the HYPRES rules is complicated by the various packing densities considered in the CERU32 program. It may be assumed that differences in packing density mainly affect the volume of the larger pores, and the size distribution of pores. This means that the HYPRES values for soil moisture content at saturation (total pore space) and at field capacity should be reduced as a result of compaction, while the moisture content at wilting point will increase somewhat due to the conversion of larger pores into smaller pores. However, in our approximation, it is assumed that for a given texture class, soil moisture at wilting point is constant over all packing densities. Medium packing density as central reference value for all five texture classes is used.

Table 5-4: **Definition of soil moisture contents at saturation, field capacity and saturation using the water retention curves based on the HYPRES rules and the AWC value given by the CERU32 program**

Texture class	CERU32 program			HYPRES	θwp HYPRES + AWC CERU32			θsat HYPRES		
	AWC ρ_{low}	AWC ρ_{medium}	A_{WC} ρ_{high}	θ_{wp}	θ_{fc} ρ_{low}	θ_{fc} ρ_{medium}	θ_{fc} ρ_{high}	θsat ρ_{low}	θ_{sat} ρ_{medium}	θsat ρ_{high}
Topsoil										
Coarse	130	130	130	0.06	0.19	0.19	0.19	0.403	0.403	0.403
Medium	180	180	180	0.152	0.332	0.332	0.332	0.439	0.439	0.439
Medium Fine	210	210	210	0.134	0.334	0.334	0.334	0.43	0.43	0.43
Fine	170	170	170	0.28	0.45	0.45	0.45	0.52	0.52	0.52
Very Fine	170	170	170	0.336	0.506	0.506	0.506	0.614	0.614	0.614
Subsoil										
Coarse	120	80	80	0.037	0.157	0.117	0.117	0.366	0.366	0.366
Medium	210	160	120	0.151	0.361	0.311	0.271	0.421*	0.392	0.392
Medium Fine	220	190	130	0.151	0.371	0.341	0.281	0.431*	0.412	0.412
Fine	200	150	130	0.299	0.499	0.449	0.429	0.559*	0.509*	0.489*
Very Fine	210	150	130	0.363	0.573	0.513	0.493	0.633*	0.573*	0.553*
Organic	439	439	439	0.269	0.708	0.708	0.708	0.768*	0.768*	0.768*

* The volumetric soil moisture content has been corrected to ensure a minimum soil volume of 6% between field capacity and saturation

Table 5-4 gives the soil moisture at field capacity when combining the wilting point from the HYPRES rules and the AWC from the CERU32 program. These soil moisture contents correspond with values for pressure head which vary from more than 20 kPa for coarse texture class to 5 kPa for the very fine texture class. A necessary consistency check is that total pore space should be larger than field capacity. As a rule of thumb the minimum difference could be set at 6 percent of the total soil volume, an arbitrary, but realistic value, representing the volume of air at field capacity. It seems logical that the total volume of pores is larger in loosely packed soils than in more densely packed soils.

5.3 Analysis AWC based on CERU32 compared to current AWC in CGMS

There are differences in new AWC estimates according to CERU32 and the estimates used in the current CGMS since 1998. The differences can be traced back through the more refined set of pedotransfer rules, which have been applied to the STUs, and from the new soil parameter values in the soil database. For the analysis of these differences the STUs have been grouped by FAO85 soil name into 222 groups, for which AWC values were known in both the old MARS-CGMS and the new CERU32. Of these groups, 65 have AWC values in CERU32 of more than 10 mm/m above the MARS-CGMS values, and 85 groups have AWC values, which are more than 10 mm/m lower, and for 73 groups the difference is less than 10 mm/m.

Overall, the AWC value has increased. The largest differences are due to the recognition that organic soils have very high AWC values. This affects the five groups of Histosols (soil name O), where the AWC has more than doubled from about 170 mm/m in MARS-CGMS to 439 according to the CERU32 program.

The second largest effect is that in subsoils of secondary chalk and loess, the sponge effect of the subsoil, leading to capillary rise of moisture during the growing season, has been translated into a much higher AWC value (an additional amount of about 100 mm of water). This effect concerns some 10 groups of soil units.

A next factor leading to higher AWCs is the lower packing density of the subsoil in soils derived from calcaric and volcanic material or having very thick humous layers. Typical soils for this effect are Rendzina (soil code E0), Andosols (T), Phaeozems (H), Chernozems (C) and plaggen soils (p).

The factor that leads to lower AWC estimates in CERU32 is the higher packing density in the subsoil. This affects the Panosols (soil code W), many soils with stagnic properties (soil subunit code s), and gleyic (g) and vertic (v) properties, and the non-humic and non-mollic subgroups of alluvial soils (F, Fluvisols) and Gleysols (G). The effect plays more in the heavy (fine) textures than in the light (coarse) texture classes.

The updating of the texture codes notably for the soils units on the FAO soil map of the world has caused some shifts in AWC values. This concerns the soil units Solonetz (S), Xerosols (X), Yermosols (Y) and Solonchaks (Z).

When comparing the two AWC-maps on a country basis, the CERU32-AWC map (see Figure 5-3) shows a larger differentiation within most countries. In the northern regions of Europe the CERU32-AWC is higher than the current CGMS-AWC (see Figure 5-4), especially in Scotland, Sweden, North Finland, the Northern half of Russia and Belarus the shift in AWC values is considerable. In contrast, in Norway and southern Finland the CERU32 AWC values are lower. Countries with clearly higher AWC values on the AWC-CERU32 map are the Netherlands, Belgium, Spain and Portugal. In central Europe this is the case for Poland, the Czech and Slovak Republics, and Hungary. Clearly much lower AWC values are mapped for Southern Russia and Turkey. All the other countries the average level of AWC values is more or less the same on the two maps.

5.4 Definition of soil physical groups

In CGMS the soil physical group is defined by the volumetric soil moisture content at wilting point, field capacity and saturation. To link the AWC values produced by the CERU32 program to soil physical groups we use the volumetric soil moisture content of wilting point given by the HYPRES rules (see 5.2.3) and calculate the volumetric soil moisture content at field capacity by adding up the AWC value.

$$\theta fc = \theta wp_{\text{of HYPRES}} + AWC_{\text{CERU32}} / 1000$$

The volumetric soil moisture content at saturation is also taken from the HYPRES rules. This value is corrected when the difference between the volumetric soil moisture content at field capacity and saturation is less than 6% of the total soil volume.

Next, the distinct unique combinations of values of volumetric soil moisture content at wilting point, field capacity, saturation have been determined. This resulted in 743 unique groups using the new AWC data derived with the adapted CERU32 program.

Figure 5-3: **Available Water Capacity estimated with the adapted CERU32 program**

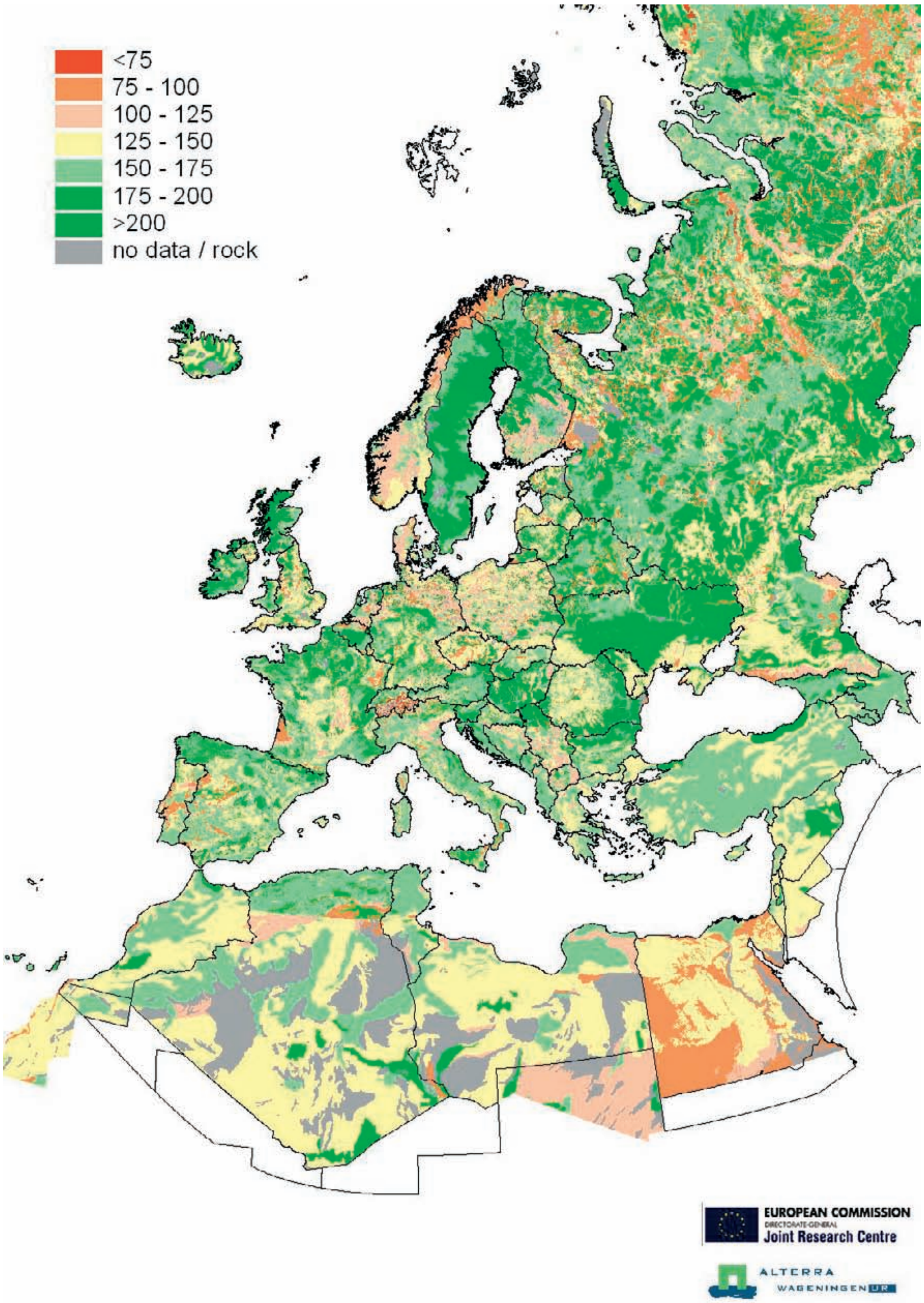
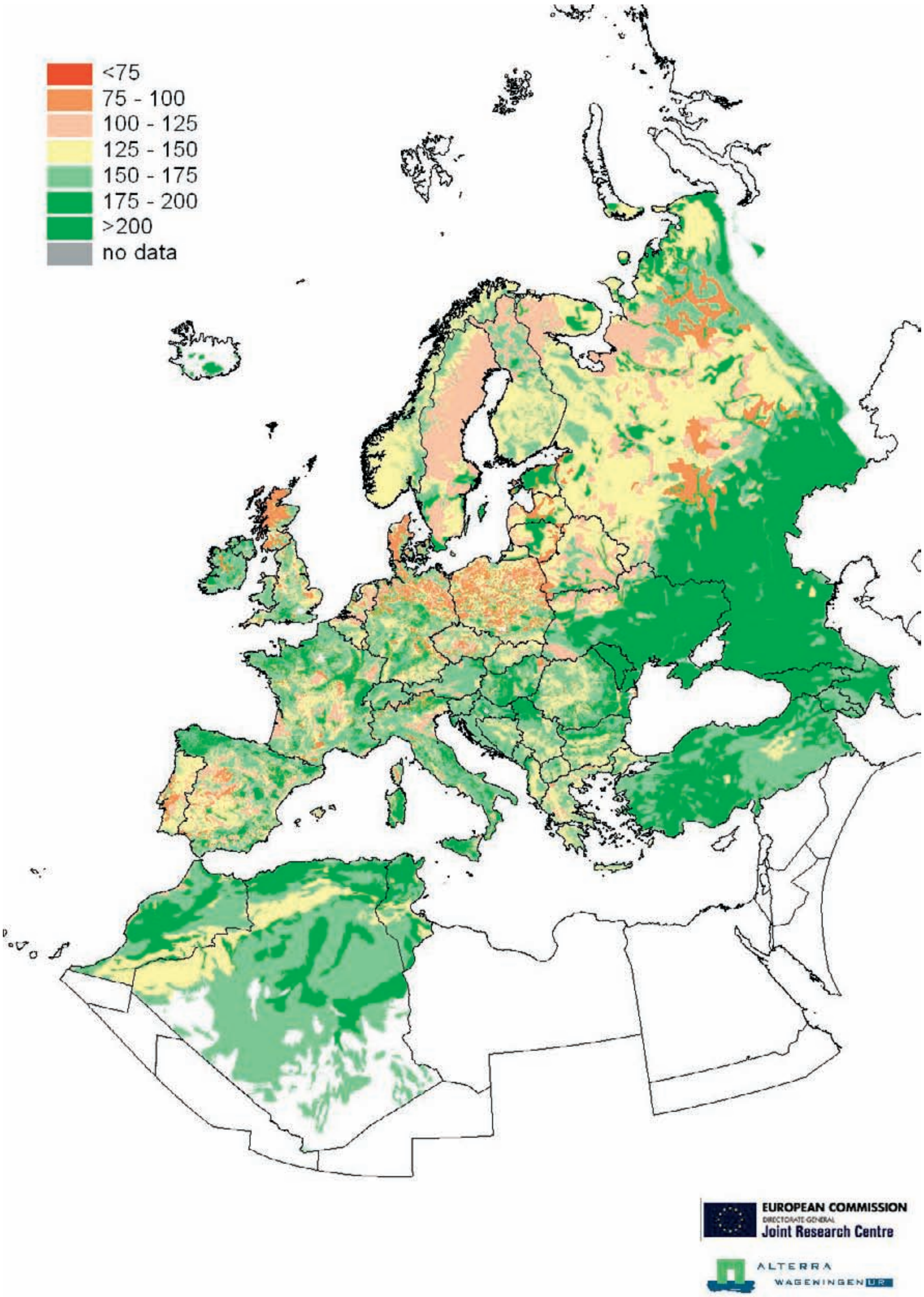


Figure 5-4: **Available Water Capacity as used in the current CGMS**



6 Redefinition of new Rooting Depth classes

6.1 Current situation

The rooting depth in CGMS was first based on rules described by van Dam et al. (1994) and later updated by van Diepen (1997). Around 1998 rooting depth was updated again using pedotransfer rules described by King et al. (1995) and based on the three attributes:

- FAO soil name,
- parent material and
- phase.

Table 6-1 shows the different rooting depth classes used in CGMS.

Table 6-1: **Different rooting depth classes in the CGMS**

Class	Depth (cm)	Range (cm)
1	10	< 10
2	20	10-20
3	40	20-40
4	60	40-60
5	80	60-80
6	110	80-110
7	140	110-140

6.2 Analysis of the current CGMS rule used to estimate rooting depth

Table 6-2 gives the current CGMS rule used to estimate rooting depth classes. The procedure is executed in the same order as the rows appear in this table. So, first the STUs with soil name I** are selected and labelled class '1' and in the following step all remaining STUs are compared with the next rule and so on. The '*' indicates that on the considered position any character could be read.

Table 6-2: **Current CGMS rule for rooting depth estimation**

soil name	phase	slope	rooting depth class
I**	*	*	1
r0	*	*	1
U**	*	*	2
E**	*	*	3
R**	*	*	3
Pp	*	*	3
*x	*	*	3
Jt	*	*	3
Qcc	*	*	3
S**	*	*	3

soil name	phase	slope	rooting depth class
Z**	*	*	3
*	22 (flooded)	*	3
*	30 (eroded)	*	3
*	4 (lithic)	*	3
*	6 (petrocalcic)	*	3
*	7 (saline)	*	3
*	8 (sodic)	*	3
*	*	3	3
*	*	4	3
X**	*	*	4
Y**	*	*	4
O**	*	*	4
W**	*	*	4
Bgg	*	*	4
*gs	*	*	4
Lap	*	*	4
T**	*	*	4
*	20 (fragic)	*	4
*	21 (drained)	*	6
G**	*	*	5
*g	*	*	5
J**	*	*	5
P**	*	*	5
Q**	*	*	5
p	*	*	5
Ne	*	*	7
other soils	*	*	6

Because some soil characteristics, like depth to textural change, depth to an obstacle to roots or depth to an impermeable layer, use 100 cm and 120 cm as limits, it was decided to change the definition of the rooting depth classes for the CGMS (see Table 6-3).

Table 6-3: **New definition of rooting depth classes**

Class	Depth (cm)	Range (cm)
1	10	< 10
2	20	10-20
3	40	20-40
4	60	40-60
5	80	60-80
6	100	80-100
7	120	100-120
8	150	120-150

6.3 Analysis of available information in the SGDBE

6.3.1 Attribute ROO

In the SGDBE, the attribute ROO gives the depth of an obstacle to roots following 6 classes (Table 6-4).

Table 6-4: **ROO classes of the SGDBE and corresponding rooting depth classes in CGMS**

ROO code	Signification	CGMS classes
1	no obstacle between 0 and 80 cm	6, 7, 8
2	obstacle between 60 and 80 cm	5
3	obstacle between 40 and 60 cm	4
4	obstacle between 20 and 40 cm	3
5	obstacle between 0 and 80 cm	1, 2, 3, 4, 5
6	obstacle between 0 and 20 cm	1, 2

The ROO class 6 was introduced for the extension to Mediterranean countries. For the other countries, as the class 6 did not exist, for some soil types, like Lithosols, some country experts chose to use the ROO class 4 for soil types that have an obstacle to roots between 0 to 20 cm. The class 4 must be used with care in this context.

For STUs having an original soil name in the FAO-UNESCO 1974 legend and ROO not equal to 0, we compared the current CGMS rule with the value taken by the attribute ROO (Table 6-5). Note that each individual record is not compared separately. First, all records of the CGMS rule have been applied. Thus, for example, not all soils with phase is 'flooded' will receive value '3', only the STUs that have not been assigned '1', '2' or '3' on the basis of previous records like 'I**', 'rO' etc.

Table 6-5: **ROO values for each occurrence of the current CGMS rule for rooting depth for STUs with an original soil name in FAO-UNESCO 1974 legend (in % of the number of STUs by occurrence)**

soil name	phase	slope	CGMS class	ROO classes						Number of STUs
				1	2	3	4	5	6	
I**	*	*	1	4	4	15	***77***	0	0	181
r0	*	*	1	0	0	0	**100**	0	0	5
U**	*	*	2	6	1	42	***51***	0	0	93
E**	*	*	3	8	3	38	***50***	0	0	119
R**	*	*	3	**73**	3	14	9	0	0	181
Pp	*	*	3	0	17	***54***	29	0	0	24
*x	*	*	3	0	0	0	0	0	0	0
Jt	*	*	3	***50***	***50***	0	0	0	0	2
Qcc	*	*	3	**100**	0	0	0	0	0	1
S**	*	*	3	88	0	0	13	0	0	8
Z**	*	*	3	**79**	0	17	4	0	0	24
*	flooded	*	3	0	0	**100**	0	0	0	2
*	eroded	*	3	**75**	0	0	0	25	0	4
*	lithic	*	3	32	8	***40***	20	0	0	124

soil name	phase	slope	CGMS class	ROO classes						Number of STUs
				1	2	3	4	5	6	
*	petrocalcic	*	3	25	8	25	***42***	0	0	12
*	saline	*	3	**100**	0	0	0	0	0	28
*	sodic	*	3	**100**	0	0	0	0	0	4
*	*	3	3	***52***	24	15	5	4	0	236
*	*	4	3	***50***	10	10	30	0	0	10
X**	*	*	4	***56***	0	22	22	0	0	9
Y**	*	*	4	0	0	0	0	0	0	0
O**	*	*	4	**87**	5	3	4	1	0	115
W**	*	*	4	**91**	3	3	3	0	0	32
Bgg	*	*	4	**74**	9	17	0	0	0	23
*gs	*	*	4	**90**	9	1	0	0	0	99
Lap	*	*	4	0	0	0	0	0	0	0
T**	*	*	4	***50***	25	0	25	0	0	4
*	fragipan	*	4	25	**75**	0	0	0	0	4
*	drained	*	6	**73**	18	9	0	0	0	113
G**	*	*	5	94	4	2	0	0	0	284
*g	*	*	5	**90**	7	3	0	0	0	150
J**	*	*	5	**93**	3	0	0	4	0	185
P**	*	*	5	**66**	12	20	1	0	0	134
Q**	*	*	5	**99**	1	0	0	0	0	90
p	*	*	5	**100**	0	0	0	0	0	4
Ne	*	*	7	0	0	0	0	0	0	0
other soils	*	*	6	**79**	13	7	1	0	0	1110

There are good correlations between the occurrences of the current CGMS rule and ROO for 23 occurrences (in bold) over 37. For 10 occurrences (in bold italic light grey), the correlation is medium. There are no corresponding STUs for 4 occurrences. But, only 6 occurrences have a good estimation of rooting depth (underlined) and for 27 occurrences the estimation of rooting depth is bad and often underestimated. The last occurrence has a good correlation with ROO (79%) but represents 1110 STUs that means that 21% of these STUs have a bad estimation which represents more than 230 STUs. It seems important to detail this last occurrence.

The lithic and petrocalcic phases that represent a high constraint to roots have a high variability of ROO that confirms the imprecision of the information given by the phases. The occurrences with slope have a medium correlation. It seems that they don't give very precise information about rooting depth. It is proposed to drop slope from the rule.

For STUs having an original soil name in the FAO-UNESCO 1974 legend and ROO not equal to 0, the rule that estimates the depth to rock in the current knowledge base of the SGDBE with the value taken by the attribute ROO (Table 6-6) was also compared.

Table 6-6: **ROO values for each occurrence of the current DR rule from the knowledge base of the SGDBE (for depth to rock estimation) for STUs with an original soil name in FAO-UNESCO 1974 legend (in % of the number of STUs by occurrence).**

FAO85-FULL	MAT1	AGLIM1	AGLIM2	DR	CL	ROO class						number of STUs
						1	2	3	4	5	6	
A**	***	**	**	> 120 cm	m	***59***	27	0	14	0	0	22
F**	***	**	**	> 120 cm	m	0	0	0	0	0	0	0
J**	***	**	**	> 120 cm	h	**90**	5	1	0	4	0	228
R**	***	**	**	40 – 80 cm	m	**82**	1	9	8	0	0	155
I**	***	**	**	< 40 cm	h	4	3	14	**79**	0	0	132
Q**	***	**	**	80 – 120 cm	m	**99**	1	0	0	0	0	109
E**	***	**	**	40 – 80 cm	h	14	4	***54***	28	0	0	57
U**	***	**	**	< 40 cm	h	15	2	**66**	17	0	0	41
T**	***	**	**	40 – 80 cm	m	**73**	9	9	9	0	0	11
V**	***	**	**	80 – 120 cm	h	**100**	0	0	0	0	0	48
Z**	***	**	**	< 40 cm	h	**79**	0	17	4	0	0	24
H**	***	**	**	80 – 120 cm	m	**98**	2	0	0	0	0	51
C**	***	**	**	80 – 120 cm	m	**100**	0	0	0	0	0	61
M**	***	**	**	40 – 80 cm	m	**100**	0	0	0	0	0	9
S**	***	**	**	< 40 cm	h	**88**	0	0	13	0	0	8
B**	***	**	**	40 – 80 cm	l	**83**	6	9	0	2	0	64
Be*	***	**	**	80 – 120 cm	l	**85**	10	3	0	3	0	214
Be*	45*	**	**	40 – 80 cm	m	**69**	31	0	0	0	0	13
Be*	7**	**	**	40 – 80 cm	m	***46***	39	11	0	4	0	28
Bd*	***	**	**	40 – 80 cm	l	**63**	21	10	3	3	0	156
Bd*	5**	**	**	80 – 120 cm	m	***55***	35	5	5	0	0	20
Bec	***	**	**	40 – 80 cm	l	***42***	24	33	0	0	0	33
Bec	23*	**	**	40 – 80 cm	m	**88**	13	0	0	0	0	8
Bec	24*	**	**	40 – 80 cm	m	0	0	0	0	0	0	0
Bec	3**	**	**	40 – 80 cm	m	**75**	25	0	0	0	0	4
Bc*	***	**	**	80 – 120 cm	l	***52***	24	24	0	0	0	42
Bk*	***	**	**	40 – 80 cm	l	***43***	14	***43***	0	0	0	77
Bk*	23*	**	**	80 – 120 cm	m	**86**	6	3	6	0	0	35
Bk*	24*	**	**	80 – 120 cm	m	0	0	0	0	0	0	0
Bv*	***	**	**	80 – 120 cm	h	**92**	4	0	4	0	0	24
Bh*	***	**	**	40 – 80 cm	l	31	***54***	8	8	0	0	13
L**	***	**	**	80 – 120 cm	l	**89**	9	1	0	0	0	223
Lo*	***	**	**	> 120 cm	h	**94**	5	0	2	0	0	171
Lo*	2**	**	**	80 – 120 cm	m	**100**	0	0	0	0	0	7
Lo*	23*	**	**	> 120 cm	h	**100**	0	0	0	0	0	4
Lo*	34*	**	**	80 – 120 cm	m	0	0	0	0	0	0	0
Lo*	45*	**	**	80 – 120 cm	m	**71**	29	0	0	0	0	7
Lo*	6**	**	**	80 – 120 cm	m	**100**	0	0	0	0	0	9

FAO85-FULL	MAT1	AGLIM1	AGLIM2	DR	CL	ROO class						number of STUs
						1	2	3	4	5	6	
Lo*	7**	**	**	80 – 120 cm	m	***48***	38	14	0	0	0	21
Lc*	***	**	**	80 – 120 cm	m	**73**	14	8	4	0	0	98
D**	***	**	**	> 120 cm	m	**95**	4	1	0	0	0	73
P**	***	**	**	80 – 120 cm	m	***58***	11	27	5	1	0	200
W**	***	**	**	40 – 80 cm	m	**90**	3	3	3	0	0	31
O**	***	**	**	< 40 cm	h	**87**	5	3	4	1	0	119
G**	***	**	**	80 – 120 cm	m	**94**	3	3	0	0	0	227
Gm*	***	**	**	< 40 cm	h	**97**	3	0	0	0	0	33
Gh*	***	**	**	< 40 cm	h	**83**	14	3	0	0	0	65
X**	***	**	**	40 – 80 cm	m	***58***	0	17	25	0	0	12
K**	***	**	**	80 – 120 cm	m	**100**	0	0	0	0	0	6
Qcc	***	**	**	40 – 80 cm	m	**100**	0	0	0	0	0	1
pL	***	**	**	40 – 80 cm	m	**80**	0	20	0	0	0	5
r0	***	**	**	< 40 cm	h	0	0	0	**100**	0	0	4
***	***	4	**	< 40 cm	h	16	5	29	***50***	0	0	280
***	***	**	4	< 40 cm	h	17	***45***	25	12	0	0	130

There are good correlations between the occurrences of the Depth to Rock (DR) rule and ROO for 37 occurrences (in bold) over 53. For 12 occurrences (in light grey), the correlation is medium. There are no corresponding STUs for 4 occurrences. But, 28 occurrences have a good estimation of rooting depth (underlined) and for 21 occurrences the estimation of rooting depth is bad and often underestimated. Globally, the DR rule seems to estimate better the rooting depth than the CGMS rule. It can be used to give more detail to the last occurrence of the CGMS rule.

The introduction of parent material gives a good improvement of the rooting depth estimation in some cases (especially with carbonated rocks like for Bk or Lo soils). So it is proposed to introduce the parent material information in the rooting depth rule for CGMS.

The lithic phase presents a high variability of ROO classes, especially when it appears as secondary phase.

When the value for ROO attribute is missing or takes the value 1 (no obstacle to roots between 0 and 80 cm), we must use other attributes to estimate the rooting depth class, like TEXT_DEP_CHANGE and IL that gives information about the subsoil, and the soil name that could give information about the soil depth.

6.3.2 Attributes TEXT_DEP_CHG and IL

These attributes can be used to specify the soil depth when ROO is not given or when ROO has the value 1 (no obstacle to roots between 0 and 80 cm). When there is a presence of an impermeable layer (IL has the value 2, 3 or 4) and/or of a textural change (TEXT_DEP_CHG has the value 1, 2, 3, 4, 6, 7), we can consider that the soil depth is equal or greater than the TEXT_DEP_CHG or IL class. The value of the subsoil texture class must be used also to determine if the textural change corresponds to a change in texture or to the appearance of the parent material. In some cases, the obstacle to roots (given by the ROO attribute) can appear before the impermeable layer or the textural change due to the presence of a specific horizon that cannot be penetrated by the roots.

6.3.3 Attribute FAO85-FULL

In the FAO-UNESCO 1974 legend, only Lithosols give information about soil depth as they are soils limited in depth by continuous coherent hard rock within 10 cm. For some soil names, there are some information about the thickness of some diagnostic horizons like for Vertisol which are soils having 30% or more clay in all horizons to a depth of at least 50 cm, or Kastanozems, Chernozems and Greyzems which have a mollic A horizon of at least 15 cm, or Histosols that have an H horizon of 40 cm or more, etc. But this is not sufficient to determine the soil depth.

To help determine the soil depth where ROO is lacking, we looked at the correlations that exist between the soil name and ROO when the latter is known (Table 6-7).

Table 6-7: **Repartition of ROO classes by groups in FAO-UNESCO 1974 original soil name in % on the number of STUs.**

soil group	ROO classes						Number of STUs
	1	2	3	4	5	6	
A	59	27	0	14	0	0	22
B	62	19	14	3	2	0	859
C	100	0	0	0	0	0	61
D	95	4	1	0	0	0	73
E	8	3	38	50	0	0	119
G	91	6	3	0	0	0	329
H	96	2	2	0	0	0	53
I	4	4	15	77	0	0	181
J	90	5	1	0	4	0	228
K	75	13	13	0	0	0	8
L	81	10	6	2	0	0	594
M	100	0	0	0	0	0	9
O	87	5	3	4	1	0	119
P	53	14	26	6	0	0	221
Q	99	1	0	0	0	0	112
R	73	3	14	9	0	0	181
S	88	0	0	13	0	0	8
T	71	18	6	6	0	0	17
U	6	1	42	51	0	0	93
V	100	0	0	0	0	0	48
W	91	3	3	3	0	0	32
X	58	0	17	25	0	0	12
Z	79	0	17	4	0	0	24
p	80	0	20	0	0	0	5

The example below shows how these correlations for Cambisols were determined. For all Cambisols, the ROO class 1 represents 62% of the STUs. If a second level is considered, this correlation can be improved in two ways (Table 6-8):

- by separating the soil types having a better correlation like for Eutric Cambisols (Be) where the ROO class 1 represents 70%, or Vertic Cambisols (Bv) where it represents 92%.
- by separating the soil types having a high variability, like for Chromic Cambisols (Bc) where ROO class 1 represents only 46%, Dystric Cambisols (Bd) and Calcic Cambisols (Bk) where it represents 52%, or Humic Cambisols where it is the ROO class 2 which has the greater representation with 43% of the STUs.

Then, if Chromic, Dystric, Eutric, Humic, Calcic and Vertic Cambisols are excluded, the ROO class 1 represents 83% of the STUs of Cambisols. It thus can be considered that STUs of Cambisols, except Chromic, Dystric, Eutric, Humic, Calcic and Vertic, have a rooting depth of more than 80 cm with a high confidence level. In the same way, it can also be considered that:

- for Eutric and Vertic Cambisols, the rooting depth is more than 80 cm with a high confidence level,
- for Chromic, Dystric and Calcic Cambisols, the rooting depth is more than 80 cm but with a medium confidence level,
- for Humic Cambisols, the rooting depth is between 60 to 80 cm with a low confidence level.

Table 6-8: **Repartition of ROO classes for Cambisols (original soil name in FAO-UNESCO 1974 legend) in % of the number of STUs.**

soil name	1	2	3	4	5	6	Nb
B	62	19	14	3	2	0	859
Bc	46	24	28	2	0	0	50
Bd	52	28	12	6	2	0	225
Be	70	17	10	1	2	0	345
Bh	25	43	14	18	0	0	28
Bk	52	12	33	3	0	0	121
Bv	92	4	0	4	0	0	26
B without Bc, Bd, Be, Bh, Bk, Bv	83	6	9	0	2	0	64

We also take the parent material and the phase in account to see if they can improve the correlation with ROO. For example, for Humic Cambisols with a lithic phase, the dominant ROO class is the class 4 which represents 67%. For Calcic Cambisols developed on marl, the ROO class 1 represents 83%.

6.3.4 Attribute FAO90-FULL

In the FAO-UNESCO 1990 legend, soils names that give information about soil depth or presence of an obstacle to roots are:

- Leptosols: soils limited in depth by continuous hard rock or highly calcareous material (calcium carbonate equivalent of more than 40%) or a continuous cemented layer within 30 cm of the surface, or having less than 20% of fine earth over a depth of 75 cm of the soil surface.
  - Lithic Leptosols.: soils limited in depth by continuous hard rock or a continuous cemented layer within 10 cm of the surface.
- Arenosols: soils which are coarser than sandy loam to a depth of at least 100 cm of the surface.

- Plinthosols are soils having 25% or more plinthite by volume in a horizon which is at least 15 cm thick within 50 cm of the surface or within a depth of 125 cm when underlying an albic E horizon or a horizon which shows gleyic or stagnic properties within 100 cm of the surface.
- Gypsisols are soils having a petrogypsic or a gypsic horizon, or both, within 125 cm from the soil surface.
  - Petric Gypsisols.: having a petrogypsic horizon, the upper part of which occurs within 100 cm of the surface.
  - Calcisols are soils having a calcic horizon, a petrocalcic horizon, or concentrations of soft powdery lime within 125 cm from the soil surface.
  - Petric Calcisols: having a petrocalcic horizon, the upper part of which occurs within 100 cm of the surface.

For some soil names, there is some information about the thickness of some diagnostic horizons like for Andosols which have andic properties to a depth of 35 cm or more from the surface, Vertisol which are soils having 30% or more clay in all horizons to a depth of at least 50 cm, or Kastanozems, Chernozems and Greyzems which have a mollic A horizon of at least 15 cm, or Histosols that have 40 cm or more of organic materials, etc. But this is not sufficient to determine the soil depth.

To help determine the soil depth where ROO is lacking, we looked at the correlations that exist between the soil name and ROO when the latter is fulfilled, the same way as it was done with the soil name in FAO-UNESCO 1974 legend (Table 6-9).

Table 6-9: **Repartition of ROO class by groups of FAO-UNESCO 1990 original soil name in % of the number of STUs.**

soil group	ROO classes						Number of STUs
	1	2	3	4	5	6	
AR	96	4	0	0	0	0	106
AT	100	0	0	0	0	0	5
CH	100	0	0	0	0	0	19
CM	87	4	4	5	0	0	296
FL	94	4	2	0	0	0	53
GL	88	3	10	0	0	0	112
GR	100	0	0	0	0	0	1
HS	57	0	5	38	0	0	128
KS	100	0	0	0	0	0	2
LP	6	1	18	76	0	0	142
LV	75	12	13	1	0	0	147
PD	100	0	0	0	0	0	42
PH	81	7	6	5	0	0	81
PL	47	0	12	41	0	0	17
PZ	33	0	67	0	0	0	119
RG	28	0	63	9	0	0	101
SC	93	0	0	7	0	0	14
SN	5	0	55	40	0	0	20
VR	100	0	0	0	0	0	26

6.3.5 Attribute WRB-FULL

In WRB, soil names that give information about rooting depth are:

- Leptosols: soils limited in depth by continuous hard rock within 25 cm from the soil surface, or overlying material with a calcium carbonate equivalent of more than 40% within 25 cm from the soil surface, or containing less than 10% (by weight) fine earth to a depth of 75 cm or more from the soil surface.
- Plinthosols are soils having a petroplinthic or a plinthic horizon starting within 50 cm from the soil surface, or a plinthic horizon starting within 100 cm from the soil surface when underlying an albic horizon or a horizon with stagnic properties.
- Gypsisols are soils having a petrogypsic or a gypsic horizon within 100 cm from the soil surface, or 15% (by volume) or more gypsum, which has accumulated under hydromorphic conditions, averaged over a depth of 100 cm.
- Durisols are soils having a duric or petroduric horizon within 100 cm from the soil surface.
- Calcisols are soils having a calcic or a petrocalcic horizon within 100 cm from the soil surface.
- Leptic soils are soils having a continuous hard rock between 25 and 100 cm from the soil surface.
- endoleptic soils.: soils having a continuous hard rock between 50 and 100 cm
- epileptic soils: soils having a continuous hard rock between 25 and 50 cm.
- Lithic soils have a continuous hard rock within 10 cm from the soil surface.
- paralithic soils have, within 10 cm from the soil surface, a broken rock contact with fissures less than 10 cm apart which allow roots to penetrate the underlying rocks.
- Petric soils are soils strongly cemented or indurated within 100 cm from the soil surface.
- endopetric soils: soils strongly cemented or indurated between 50 cm and 100 cm
- epipetric soils: soils strongly cemented or indurated within 50 cm.
- petrocalcic soils: soils having a petrocalcic horizon within 100 cm from the soil surface.
- petroduric soils: soils having a petroduric horizon within 100 cm
- petrogypsic soils: soils having a petrogypsic horizon within 100 cm
- petroplinthic soils: soils having a petroplinthic horizon within 100 cm
- petrosalic soils: soils having an horizon, 10 cm or more thick, cemented by salts more soluble than gypsum, within 100 cm from the soil surface.
- placic Podzols: are Podzols with a subhorizon of the spodic horizon cemented by combination of aluminium and organic matter within100 cm from the soil surface (previously named thin iron pan).

A petroduric horizon, also known as duripan, is a subsurface horizon which is cemented mainly by secondary silica. Roots cannot penetrate except along vertical fractures.

A petrocalcic horizon is an indurated calcic horizon, which is cemented by calcium carbonate and, in places, by calcium and some magnesium carbonates. It is extremely hard and roots cannot enter.

A petrogypsic horizon is a cemented horizon containing secondary accumulations of gypsum. It cannot be penetrated by roots. A petroplinthic horizon is a continuous layer of indurated material, in which iron is important cement and in which organic matter is absent. It cannot be penetrated by roots.

To help determine the soil depth where ROO is lacking, the correlations that exist between the soil name and ROO when the latter is fulfilled were looked at, the same way as it was done with the soil name in the FAO-UNESCO 1974 and 1990 legends (Table 6-10). There are less STUs with an original soil name in WRB, so it is difficult to make subdivisions on the soil name.

Table 6-10: **Repartition of ROO class by groups of WRB original soil name in % of the number of STUs.**

soil name	ROO classes						Number of STUs
	1	2	3	4	5	6	
AB	100	0	0	0	0	0	8
AN	100	0	0	0	0	0	4
AR	100	0	0	0	0	0	13
AT	100	0	0	0	0	0	2
CH	100	0	0	0	0	0	4
CL	80	7	0	7	7	0	15
CM	86	7	4	0	4	0	28
CR	20	0	50	30	0	0	10
FL	81	0	0	5	10	5	21
GL	88	0	0	0	13	0	8
GY	43	29	14	14	0	0	7
HS	0	17	0	0	83	0	6
KS	100	0	0	0	0	0	4
LP	27	5	9	0	23	36	22
LV	73	18	0	0	9	0	11
NT	100	0	0	0	0	0	1
PH	100	0	0	0	0	0	7
PL	100	0	0	0	0	0	5
PZ	67	17	0	0	17	0	6
RG	45	0	9	27	18	0	11
SC	40	10	20	10	0	20	10
SN	83	17	0	0	0	0	6
UM	100	0	0	0	0	0	1
VR	100	0	0	0	0	0	13

6.4 Adapting the PTR with the information available in the SGDBE

Using the values taken by the different attributes and the correlations established within the soil name and the ROO attribute, a new rule for estimating rooting depth has been established and is listed in Annex 2.

7 CGMS soil Suitability Criteria

7.1 Current situation

Besides the simulation of crop growth, soil information is used in CGMS to create a 'land use probability map' defining which crops have to be included in the simulation for a given soil unit. Ideally, this decision would be taken on the basis of actual land-use information, but a European-wide detailed classification of land cover is not available. Hence, within the CGMS the decision is simply based on the soil suitability of the different crops: if at least part of the soil mapping unit (one or more STUs) is deemed appropriate then the simulation will be performed. The result of this strategy is that the yield figures produced by the CGMS are assessed for suitable soils only.

Suitable soils are determined per crop group on the basis of crop growth limiting properties of these soils. The limiting soil properties are:
- slope,
- texture,
- agriculture limiting phase,
- rooting depth,
- drainage,
- salinity and
- alkalinity.

The slope, texture and phase data can be obtained directly from the soil database, while rooting depth, drainage conditions, salinity and alkalinity have to be derived from basic soil properties using PTR (see chapter 4 and 6).

7.2 Analysis of the suitability criteria

7.2.1 Introduction

The assessment of yield level at national and sub-national scale with CGMS requires information on locations and soils where the major crops are grown. This information is especially important for the spatial aggregation from simulated crop indicators from simulation units to administrative regions. Most logically, this information could be obtained by combining a European land use map and the European soil map. However, the main constraint for application of this procedure is formed by the lack of a harmonized land use map at the level of major crops. Besides, a geometric mismatch between the land use map and the soil map may contribute to inaccuracies as well. The solution found to overcome these constraints was to derive from the soil map a new map of plausible land use based on soil suitability rules. One should keep in mind that soil is not the only source of biophysical constraints for agriculture. Climate is certainly more important in some areas than soil. In CGMS, climate suitability is determined by the crop calendar table. So climate suitability is not part of the underlying study. Therefore within the analysis of soil suitability we focus on the areas where the climate is not the constraining factor. Within these areas, with suitable climates, soils could be a limiting factor to use the land. Although one should realize that crop area patterns are explained also by socio-economic and historic factors.

The aim of the present study is **to define a set of soil suitability rules for each major crop group.** A rule is defined by listing the unsuited classes of soil parameters, or by specifying a threshold value for a given soil parameter. The soil suitability assessment for a given crop group uses at least one but usually several soil parameters as indicators.

The present study describes the testing of a model for the assessment of soil suitability using data derived from SGDBE. We used the existing model ESCAPE, developed by INRA (Le Bas et al, 1999). ESCAPE is basically a tool offering a selection procedure for separating suited and unsuited soils (or rather soil typological units) on the basis of soil properties e.g. rooting depth, where the selection criteria can be modified by the model user. As a starting point, the selection criteria given by INRA for the following crop groups were used: grass, cereals and maize. These criteria have been regrouped in order to create new sets of systematically varying criteria and applied to the European soil data base. Each selection results in a suitability map, which was compared visually with a recent European Land Cover map (Mucher, 2004) as a plausibility check to distinguish the major agricultural areas.

7.2.2 Available soil data

In the context of CGMS, the soil suitability assessment method has to be applied to the whole territory of Europe and to all crops. This requires simple selection criteria, which can be applied uniformly to all soil types, preferably using a minimum of standard soil parameters. The seven parameters applied in an earlier study using ESCAPE were rooting depth, slope, and volume of stones, texture, drainage, salinity and sodicity (alkalinity). It was decided to stick to these parameters, although it should be understood that ESCAPE allows including any other parameter from the soil database as selection criterion, as long as it can be related to the soil typological units. The soil parameter values are stored in the database as class values, and are either original values, or derived with pedotransfer rules. Note that texture class has been corrected using the pedotransfer rule PTR03 (see Annex 4); rooting depth, drainage, salinity and sodicity have been derived using the PTR described in chapter 4 and 6; volumes of stones has been derived using PTR413. The latter rule did not have to be adapted for the SGDBE version 4.0 because the agricultural limiting phase and parent material code have the same meaning in version 3.2 and 4.0.

The selection criteria are defined for each parameter as the range of unsuitable classes. Table 7-1 gives for each parameter the class values in the soil database. The green background marks the range of values associated with suited soils without use constraints to any kind of use, and the white background marks the range of values where choices must be made to decide if such soils should be considered as suited or not suited for a specific land use due to the presence of land use constraining soil conditions. In the tables, the soil parameter classes are ranked top-down from usually most favourable to usually most constraining. The class 'no information' of slope in the database has been given the benefit of the doubt, and is ranked as suitable. The same has been done in the case of texture. However, all soil typological units with 'no information' as texture class are unsuitable because all these units have a shallow rooting depth.

Note that a few differences in used criteria between CGMS and the ESCAPE rules are not shown in Table 7-1. CGMS uses the agricultural limiting phases directly as criteria, while ESCAPE uses only derived parameters, based on the assumption that the limiting effect of the soil phases can be expressed adequately in the values of derived parameters (rooting depth, drainage class, volume of stones, etc).

Table 7-1: **Overview of soil parameters used as criteria for suitability; the range of class values that are always considered non-limiting (light grey); and the values that may be limiting for some kinds of land use (white background)**

Dominant slope (slop)	
0	**No information**
1	**Level (0 to 8 %)**
2	Sloping (8 to 15 %)
3	Moderately steep (15 to 25 %)
4	Steep (over 25 %)
5	Sloping to moderately steep (8 to 30% **)
6	Steep to mountainous (over 30% **)

** for use with the Digital Soil Map of the World only

Drainage (drai)	Rooting depth (root)	Topsoil texture (text)
NE = Not evaluated	**8 = 120-150 cm**	**0 no information**
EX = Excessively drained	**7 = 100-120 cm**	1 coarse
W = Well drained	6 = 80-100 cm	**2 medium**
MW = Moderately drained	5 = 60-80 cm	**3 medium fine**
I = Imperfectly drained	4 = 40-60 cm	4 fine
TP = Temporarily poorly drained	3 = 20-40 cm, shallow	5 very fine
P = Poorly drained	2 = 10-20 cm, shallow	7 rocks
VP = Very poorly drained	1 = < 10 cm, lithic	8 peat
		9 no texture class

Stoniness (ston)	Salinity (sal)	Alkalinity (alk)
00 = 0% stones	**L = Low: ECse < 4 dS/m**	**L = low (ESP < 6%)**
10 = 10% stones	**M = Medium: 4 < ECse < 15 dS/m**	**M = medium (6 < ESP < 15%)**
15 = 15% stones	H = High: ECse > 15 dS/m	H = high (ESP > 15%)
20 = 20% stones		

Chemical toxicity
L = low: no toxicity for most crops
M = medium: toxicity for some crops possible
H = high: toxicity for all crops

7.2.3 The initial sets of ESCAPE and CGMS suitability rules

In the present study, the assessment of soil suitability is based on the definition of the range of unsuitable class values for each of the seven soil parameters. Note that chemical toxicity was not used by ESCAPE and was integrated in the salinity parameter of CGMS (see 4.2). Theoretically, a very large number of possible combinations of unsuitability criteria can be defined, each combination leading to a specific soil suitability map. Table 7-2 shows the classes that have been used in the application of ESCAPE and CGMS for the soil suitability assessment of crop groups in Europe. Most rules refer to a threshold value or a selection of classes for one soil parameter.

In some cases, a rule refers to two or more soil parameters, involving a conditional statement like soils with a rooting depth between 50 and 70 are only excluded if the slope is steeper than 25%. These combined criteria are not given in Table 7-2 but only as subscript, as they lack simplicity and the underlying rationale is not provided. The combined criteria have great potential to finetune suitability results, especially on a local level, but it may be complicated to estimate their impact on the suitability rating over the whole continent. It means that such refinement can have unexpected, opposite effects for other areas. Therefore the combined criteria have not been evaluated specifically in the present study.

The rules of ESCAPE and CGMS have been studied and compared between crop groups. Below some remarks following from this analysis:

- For all land uses considered (arable crops and grass) the following soil parameter values lead always to a rating of the soil as unsuitable: very shallow soils (1 and 2: less than 20 cm deep), rocky surfaces, very poorly drained soils, and soils having high salinity.
- Note that in addition to these basic unsuitability criteria for all arable crops considered (cereals, maize, root crops, oil seed crops), the following soil parameter values lead always to a rating of the soil as unsuitable: thick peat layers, very high stoniness (20%) and very steep slopes of more than 25 %.
- ESCAPE rules for maize support same wetness conditions as grass, and wetter conditions than other crops if the soil depth is deeper than 100 cm. ESCAPE rules for maize also can tolerate high alkalinity; other field crops do not tolerate high alkalinity. On the other hand, maize cannot be grown on shallow soils; 50 cm is the limit, which is the same for oilseed crops.
- For other field crops the limiting rooting depth is 30 cm; and 20 cm for grass.
- In ESCAPE all crops, for which stoniness is differentiating, have the same threshold for stoniness of above 20 percent stones by volume.
- Note that in ESCAPE chemical toxicity is not applied as a criterion for unsuitability.
- From the listed criteria, some are rather irrelevant for application to the soil map of Europe as they hardly occur on the recent version of the map: rooting depth '2' (10-20 cm) only occurs in Egypt; and slope class '5' (8-30 % slope) only occurs in Lebanon.

Table 7-2: **Soil unsuitability criteria for different crop groups as applied by INRA using ESCAPE (Le Bas et al, 1999). Dark grey and light grey indicate respectively suitable and unsuitable classes of a soil property.**

	root	root	root	text	text	text	text	text	drai	drai	drai	ston	ston	ston	slop	slop	slop	slop	slop	sal	alk
	<10	10-20	20-40	fine	very fine	rocks	peat	no text.	tmp poor	poor	very poor	>10 %	>15 %	>20 %	8 - 15	15-25	>25	8-30	>30		
Class	1	2	3	4	5	7	8	9	TP	P	VP	10	15	20	2	3	4	5	6	H	H
ESCAPE:																					
Grass (1)																					
Cereals (2)																					
Maize (3)																					
Root crops																					
Oil seeds																					
CGMS (4):																					
Cereals																					
Maize																					
Root crops																					

NB:

- Only classes of soil properties are shown that have severely limiting influence on crop growth (corresponds to cells of Table 7-1 with white background).
- Slope classes 5 and 6 are not foreseen in ESCAPE rules, ESCAPE selects on 15 and 25 percent slope limits.
- Water Regime classes have been translated into drainage classes: WR = 2 becomes 'I', WR = 3 becomes 'TP' or 'P', WR = 4 becomes 'VP'.

Some combined criteria exist that are not shown in the table above:

1) For grass a combined criterion exists: if the slope is less than 15% and the water regime is 'TP' and 'P', the soil is unsuitable.
2) For cereals a combined criterion exists: if the rooting depth is between 30 and 50 and texture is 'coarse', the soil is unsuitable.
3) For maize a combined criterion exists: if the rooting depth is between 50 and 100 and the water regime is 'TP' or 'P', the soil is unsuitable.

Considering the CGMS rules the following remarks are important:

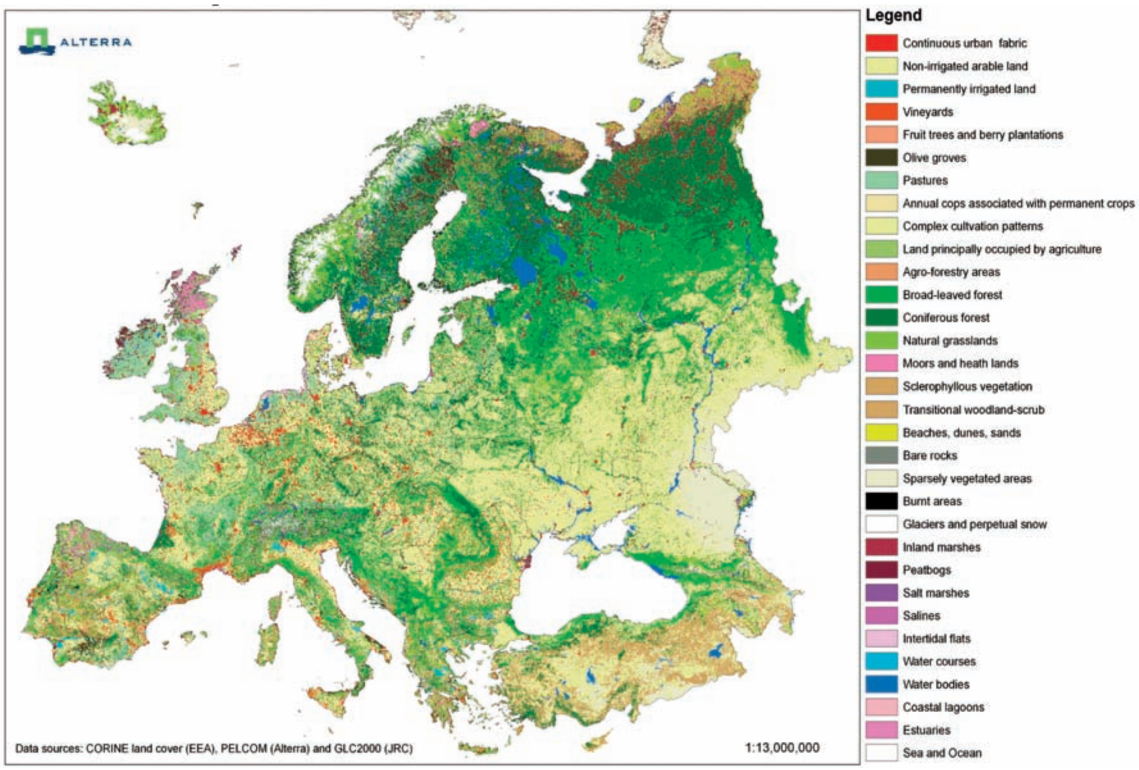
4) In addition to the criteria in the table above, the CGMS rules use a number of soil phases (AGLIM1 in SGDB) as unsuitability criteria: lithic, concretionary, petrocalcic, disturbed soils, fragic, flooded, eroded, phreatic, saline and sodic. Only the phases drained, gravelly, stony and no information are considered as suitable for cereals. The phases gravelly and stony can be linked to the classes '10' and '15' of the soil characteristic volume of stones as has been done in the table above. The CGMS rules cannot use the texture class rocks and peat because these two classes are the result of PTR which was not used the previous database. CGMS use the basic texture parameter TEXT_SRF_DOM in which rocks and peat are known as 'no texture'. Because the CGMS rules mark rocks, peat and no texture class as unsuitable this difference does not lead to different results.

In addition, the unsuitability rules of the current CGMS have been compared between crop groups and with the ESCAPE rules. Below are some remarks following this analysis:

- The CGMS rules correspond rather well with the ESCAPE rules in the sense that the unsuitability rules use largely the same set of soil parameters and the threshold values are in the same range of class values. Therefore, they are comparable. But there are differences. The CGMS rules exclude more soils as unsuitable than ESCAPE. For instance, the CGMS rules for cereals are identical to the ESCAPE rules for root crops. The CGMS rules for maize and root crops are more severe than any set of ESCAPE rules.
- According to the CGMS rules, maize can be grown on most soils which are suited for cereals, but not on gravelly or stony soils, or on very shallow soils (<20 cm).
- According to the CGMS rules, root crops can be grown on most soils suited for maize, but not on fine textured soils. In all suitability classifications, this CGMS rule for root crops is the only one which classifies fine textured soils as unsuitable.
- The current stoniness rules in CGMS are based on the rough AGLIM-classes only, while in the new SGDB more distinctions in stoniness classes have been introduced.
- The major difference between the CGMS rules for maize and root crops on the one hand and all ESCAPE rules for arable crops on the other hand is that CGMS classifies stony soils as unsuited, while ESCAPE classifies them as suited.
- Another difference between CGMS rules and ESCAPE rules is that CGMS applies a slope of 15 percent as a maximum for all arable farming, while ESCAPE sets the threshold for oil seeds at 25 percent. For maize and cereals ESCAPE applies also 15 percent slope as threshold.

In contrast with ESCAPE, CGMS classifies wet soils deeper than 100 cm and alkaline soils as unsuited for maize.

Figure 7-1: Pan-European land cover database with a spatial resolution of 250m based on CORINE and PELCOM data sources (Mucher, 2004)



7.2.4 An attempt to integrate ESCAPE and CGMS criteria

The soil unsuitability criteria listed in Table 7-2 show a sequence of increasingly severe soil requirements for the various types of land use. When the combined criteria are ignored for a moment, a sequence of nested criteria can be distinguished going from the ESCAPE rules for grass, cereals, and root crops to the CGMS rules for maize and root crops, where the ESCAPE root crop rules are identical to the CGMS cereal rules, as follows:

1. Grass-ESCAPE: unsuited are all soils which are less than 20 cm deep, or have a rocky surface, or very poor drainage, or high salinity.

1. Cereals-ESCAPE: same rules as in grass-ESCAPE, and in addition, all other soils are unsuited which have peat surface, or no texture class, or poor or temporarily poor drainage, or more stones than 20 %, or slopes steeper than 25 %, or high alkalinity.

2. Root crops-ESCAPE: (largely identical to cereals-CGMS), as cereals-ESCAPE, and in addition all other soils are unsuited which have a very fine texture, or slopes steeper than 15 %.

3. Maize-CGMS: as root crops-ESCAPE, and in addition all other soils are unsuited which have 10 % stones or more, or soils which are less than 40 cm deep.

4. Root crops-CGMS: as maize-CGMS, and in addition, all other soils which have fine texture are unsuited.

The CGMS cereal suitability rules are almost identical to the ESCAPE root crop rules, but there is a difference, which concerns the handling of soil phases. The CGMS rules made use of the soil phases, and because the original purpose of distinguishing soil phases was to label certain soil units as having serious limitations to agricultural use, most soil phases in the CGMS rules have been classified as unsuited. In the new SINFO pedotransfer rules the properties of the soil phases have been translated into rooting depth, drainage class, stoniness class, and new soil surface texture classes like peat and 'no texture'. This duplicates part of the information from the soil phases. Another complicating factor was that the new SGDBE version 4 distinguishes more phases than the older version 3.2. This indicates that in the CGMS rules more soils are excluded as unsuitable as in the corresponding ESCAPE rules. The only phases accepted in the CGMS-rules as suited are 3 (gravely; suited for cereals) and 21 (drained; suited for all crops), apart from the phases 0 (no information) and 1 (no phase), which are both considered as suited for any kind of cropping.

The maize-ESCAPE and oilseed rape-ESCAPE rules are somewhat besides the nested sequence above. According to the ESCAPE rules, maize and oilseed rape require more or less similar soils as root crops, but shallow soils of 20-40 cm deep are unsuited. On the other hand, oilseed rape can be grown on steeper slopes (up to 15 %) than root crops and maize. In contrast to root crops and oilseed rape, maize can tolerate high alkalinity, while on deep soils maize can tolerate rather wet conditions.

7.3 Analysis of CGMS and ESCAPE suitability maps

On the basis of these criteria in both ESCAPE and CGMS various suitability maps have been created on the basis of the same data set (SGDBE version 4). According to the requirements of the study, the only distinction was between suited and not suited, and no distinction was made between degrees of suitability, e.g. highly suitable and moderately suitable. The suitability is assessed for each Single Typological Unit (STU) separately. For the mapping all suitable STUs within a Soil Mapping Unit (SMU) were aggregated and the area percentage of suitable STUs per SMU has been mapped. For the sake of comparison the current suitability maps used in CGMS have been prepared in the same way. These latter maps are the result of applying the CGMS suitability rules to the version 3.2 of the Soil map of Europe.

The various suitability maps have been compared with each other and with the European Land Cover Database (Mucher, 2004), especially to check the relationship between the occurrence of suitable soils and the agricultural land cover classes, such as:
- non-irrigated arable land;
- permanently irrigated land;
- annual & permanent crops;
- complex cultivation patterns;
- pastures.

The SGDBE version 4 covers Europe completely, and all Mediterranean countries, Iceland and the Asian part of Russia all the way east to the Pacific. However, the discussion on suitability maps and their comparison with land cover maps is limited to the European areas, i.e. Europe west of the Ural, and Turkey.

7.3.1 Comparison of CGMS-rule based suitability maps from SGDBE version 3.2 with the land cover map

The cereal suitability map based on CGMS rules and SGDBE version 3.2 (see Annex 5, map 1) showed high percentages of suited land in all countries north of the Pyrenees and Alps up to the southern part of Sweden and Finland, and through Central Europe. Further in Eastern Europe, most territory of the former Soviet Union was uniformly very suitable, except in the southern parts of Ukraine and Russia, where according to the soil map a wide strip of alkaline soils stretches along the Black Sea to the northern tip of the Caspian Sea, and therefore rated as unsuited. Over most of the land between the Pyrenees and the Ural, this CGMS suitability map for cereals overestimates the cultivated lands. North of this zone, the map shows low suitability percentages in Norway, the northern parts of Sweden and Finland, and boreal Russia which corresponds with actual land use. In reality, in the Nordic zones the land use is more determined by climatic suitability than by soil suitability, but climatic factors are not discussed here. The suited area in England is relatively low compared to actual land cover. Here, the low proportion of suited land is related mainly to the wetness of the land. In southern Europe the proportion of suited land is much lower than elsewhere, due to the presence of sloping land. In CGMS it was assumed that 15 percent (as landscape characteristic) is the maximum slope for arable farming. In Spain and Italy, the pattern of suited land is still well correlated to the land cover map, but in Italy the suitability map underestimates the amount of cultivated land. The slope factor is especially important in Italy and the southern part of the Balkans (south of Sava-Donau rivers), but not Albania, according to the SGDBE 3.2.

When looking at the CGMS rule-based suitability maps of maize (see Annex 5, map 2) and root crops (see Annex 5, map 3), in many countries and regions a strong underestimation of agricultural area can be observed, and large differences between countries. This is due to the more severe criteria applied, specifically the additional requirements that suitable soils should have no gravelly or stony phase, which rule has a large impact on the extent of suited areas across Europe. Another difference is caused by the requirement that suitable soils should be at least 40 cm deep, where 20 cm was still suited for cereals. The CGMS maps for root crops and maize show much smaller suited areas than the cereal map, but not for all countries. Little or no differences between cereal and maize maps are for the former Soviet Union, Finland, Norway, England, Scotland, and Ireland. Relative large reductions in suited areas can be seen for Sweden, Wales, the southern half of Germany, Czech Republic, Austria, Italy, Albania, Spain, Portugal, and Turkey.

The difference between root crops and maize was in the requirement that root crops cannot be grown well in fine textured soils. This leads to some additional reduction in suited area for root crops as compared to maize, visible on the map for parts of Spain, France, England, Italy, Hungary and Romania, Albania, Greece and Turkey.

7.3.2 Comparison of CGMS-rule based suitability maps from SGDBE versions 3.2 and 4.0

While keeping the CGMS rules the same, the SGDBE version 3.2 has been replaced by version 4.0. Not only did the basic data change but also the PTR that derive soil properties like rooting depth, drainage conditions, salinity and alkalinity were changed. These properties are needed for the CGMS rules. As long as CGMS used SGDBE version 3.2, the derived variables were obtained using rather simple PTR, based mainly on soil name codes. In version 4.0 of SGDBE, more detailed PTR have been applied to estimate rooting depth, drainage conditions, salinity and alkalinity, e.g. taking into account data on parent material, textural profile, soil phase and depth to impermeable layers. This has influence especially on the estimates of rooting depth and drainage conditions. The SGDBE version 4.0 distinguishes more phases than before and this has influence on the results of the CGMS rules as well. As a result from differences in the derived soil parameters between SGDBE version 3.2 and 4.0, the soil suitability maps based on the same set of CGMS-rules are different.

For most countries, the position and extent of suited areas on the CGMS cereal map based on SGDBE version 4.0 (see Annex 5, map 4) has changed a bit as compared to version 3.2, and, overall, the more detailed information leads to the exclusion of more land as unsuitable, and this seems plausible. In a few cases the new map leads to a strong underestimation of the suited area for cereals: the Netherlands, Belgium, the Danish Islands, the Baltic countries. Strong decreases in suited cereal area are also found for the northern half of Russia and for

Belarus, Austria and Albania, but here the new pattern seems more realistic than the old one. The map of Algeria is completely different but this includes the Sahara desert, where soil suitability is not relevant anyway as no crops are grown. The soil suitability map of Turkey is inverted. In a few other areas in Europe the estimated extent of suited land is larger than before, and this includes the soils of southern Ukraine and Russia formerly mapped as alkaline, and small areas in Romania, north-western Germany and Portugal. The increases in suited area in northern Sweden, Finland and Russian Karelia are unexpected, but not relevant as they are north of the cereal growing areas.

Similar observations as for cereals can be made on the differences between the CGMS suitability maps version 3.2 and version 4.0 for maize (see Annex 5, map 5) and for root crops (see Annex 5, map 6). Most shifts are in the same direction as for cereals, but there are a few exceptions: On the new map Finland is entirely unsuited, while larger areas of suited soils are mapped in Austria, Wales, Portugal and south-western Spain.

The overall impression is that the CGMS rules are not good enough to estimate the extent of potentially cropped soils. The use of the new soil map leads to more plausible results in most regions, but also to new errors elsewhere. These errors could be repaired, but a systematic analytical approach must be preferred.

7.3.3 Comparison of ESCAPE-rule based suitability maps from SGDBE version 4.0 with land cover map

The comparison revealed that the relationship between actual land cover and suitability maps (see Annex 5, map 7-11) was weak, except in some obvious cases where the absence of intensive agricultural land use coincides with the occurrence of unsuitable soils due to the presence of steep slopes, rock- or peat-covered surfaces, or salt flats. The low proportions of suited soils found in the southern part of the Balkans, the Alps, Scotland, and Norway correspond well with the land cover information. On the other hand, more analysis is required to get an understanding of some results. When looking at the ESCAPE-based suitability maps the proportion of suited soils was relatively low in England, Spain, Latvia and Estonia. Italy as a whole is mapped as suitable for oilseeds, but largely unsuited for root crops. In Norway, Germany, Spain and Greece the shift in suited area from oilseeds to root crops goes in the same direction as in Italy, but in Sweden the shift is in the other direction, while the selection of suitable soils does not change in Finland, Denmark, Russia, Ukraine, Turkey and the countries east and south of the Mediterranean Sea. These apparently arbitrary differences can be interpreted easily on the basis of the criteria. Italy has a lot of sloping land, which is rated unsuited for root crops, but suited for oilseeds. Sweden has no sloping land (according to the soil map), but a lot of shallow soils, which are rated suited for root crops and unsuited for oilseed crops. In countries without steep slopes and without shallow soils, the suitability maps for oilseed rape and root crops are quite similar.

In summary, the existing ESCAPE-based suitability criteria for cereals and grassland lead to estimates of relatively high proportions of suited land in comparison with the land cover map. The application of more severe suitability criteria for oil seeds and root crops in ESCAPE leads to underestimation of suited land in some countries. The ESCAPE rules for root crops correspond largely with the CGMS rules for cereals, but CGMS excludes in addition all soil phases as unsuited, so that the suited area resulting from the ESCAPE rules is larger. The difference leads to clearly more plausible results than the CGMS rules in a few cases: the Netherlands, the Danish Islands, Lithuania, Russia north of the Caspian Sea, Cyprus, north-eastern Spain. In a few other cases it is more difficult to judge which result is better: northern Algeria, the whole of Sweden, southern Finland, boreal Russia and eastern Turkey.

7.3.4 *Conclusion on the applicability of CGMS and ESCAPE-rule based suitability maps*

In conclusion, we have shown that the CGMS-cereal rules and all ESCAPE rules lead to a general overestimation of the cultivated area, and the more severe CGMS-rules for maize and root crops to a general underestimation. In general there are large differences between countries, which are partly caused by lack of uniformity in the soil map and soil database. The application of new pedotransfer functions to estimate values of single soil properties per STU for use as suitability criterion is an important step to fill gaps in the database and towards more data consistency. The extension of the soil database with derived soil parameters makes it possible to formulate suitability criteria on the basis of specific parameters only, which is more precise than criteria based on lumped parameters as soil name or soil phase, which have a large internal variation. The old CGMS rules made direct use of soil names and soil phases as criteria.

The ESCAPE rules applied on the new SGDBE version 4.0 are more flexible and precise than the old CGMS rules. The refinement of the ESCAPE rules for the search of more plausible and accurate selections of suited soils calls for searching additional criteria. Because changes in suitability rules often lead to irregular responses across countries, it is important to follow a systematic approach in analyzing these differences. The necessary condition for choosing criteria is based on the matching of soil requirements of a given land use with the available soil properties. This process requires knowledge of reasonable land use specific sets of requirements, and of the available data sets in terms of geographic distribution of single soil factors and correlation between soil factors.

7.4 Analysis of distribution of limiting single soil factors

In Europe in general the major field crops are not grown on soils which have one or more of the following properties: rocky, thick peat layers, very shallow (less than 20 cm), steep slope (over 25 %), very wet (drainage class very poorly drained), highly saline or highly alkaline. This forms a set of soil unsuitability criteria. We first analyzed the individual soil properties rooting depth, texture, drainage, volume of stones and slopes to find out how an 'unsuitable' class of a soil property contributes to the overall unsuitability map. This analysis helped us to get better grip on the unsuitability criteria. The soil properties salinity and alkalinity did not require this analysis. Soils are unsuitable when the class is 'High'.

7.4.1 *Rooting depth*

As a decisive criterion for separating suitable and unsuitable soils, the criterion based on soil depth limit of 10 cm does have influence in the following countries: Iceland, Turkey, Spain, south central France and Corsica, parts of the Balkans, Scotland and Norway. The use of 20 cm as criterion has no additional effect on the selection of suitable soils. The use of 40 cm as a limit of suitability has no additional effect in Iceland, Turkey, Tunisia and Morocco, but has a big effect in Sweden, Norway, parts of Spain and of the Balkans, and some effect in France, West Germany, the United Kingdom, and the Alpine regions, but only minor effect in the other regions. Finally it has very little or no effect at all in Italy, the Benelux countries, Denmark, East Germany, Poland, the Baltic states, Finland, and few in Russia, with some exceptions.

7.4.2 *Texture (rock and peat)*

In most of Europe rock areas are absent. The regions where rocks occur on the soil map are the western half of the Iberian Peninsula, the western part of Scotland, England and Wales, Iceland, the northern half of Sweden, North West-Russia (Karelia, Kola peninsula), Greece and Albania, the Swiss and Austrian Alps. There are clear country-effects. Rocky areas are absent in France, Germany, Italy, Czech Republic, Slovakia, Poland, Baltic states, Finland, Turkey, the Middle east and the Maghreb. With a few exceptions, the occurrence of peat areas is limited to the northern half of Europe, roughly above the line London-Warsaw-Moscow. Peat soils are dominant in Scotland and parts of Russia, notably around the White Sea, and across the Ural in the plain of the Ob River. The patterns are very different between countries: large mapping units with a low proportion of peat soils, or a pattern of small mapping units where peat soils are dominant, surrounded by mapping units without or with a low percentage of peat soils. Texture 'very fine' is very rare. Some local concentrations: Hungary, Danube lower plain in Romania/ Bulgaria, Krim and just north of it in Ukraine, and a narrow strip north of the Caucasus. Very few sites are found elsewhere.

7.4.3 Drainage

Most very poorly drained soils occur in the northern half of Europe. They occur in the moors of Scotland, and hills of northern England and Wales, in Estonia, and scattered all over northern Russia, and Belarus in large concentrations. Remarkable are three SMUs with very poor drainage in Belgium. Uniform large areas with 2-40 percent of very poorly drained soils cover Sweden and Finland, and occur also in the coastal zones of Iceland. A more fragmented distribution and lower concentration of very poorly drained soils are found in Latvia, Lithuania, Poland, and northern Germany. Hardly any very poorly drained soil occurs in southern Europe - the exceptions are Hungary, and the lower Volga River.

The other classes in the order of decreasing wetness are poorly drained, temporarily poorly drained and imperfectly drained. Considering all these wet soils together, we observe that in the Nordic countries, Finland, Sweden, Norway and Iceland, the overall pattern of soils with impeded drainage does not change in comparison with the map of very poorly drained soils, as there are few soils in these classes. In Norway the occurrence of class poorly drained is important. In the UK every class occurs, and the total area with imperfectly drained and wetter is considerable. In Ireland the major drainage class is imperfectly drained. A high percentage of wet soils is found for the Baltic states and Poland, about 50 to 80 percent of the total land area falls in the wet drainage classes, it increases across the countries when moving from Poland to the north. The northern half of Russia has extensive areas with drainage limitations of all degrees, especially behind the Ural Mountains. In southern Russia and Ukraine drainage problems hardly occur, only the major river floodplains are mapped as drainage class imperfectly drained. The exception is the lower Volga River and coastal plains of the Caspian Sea, and some areas in the Caucasus. Turkey has some soils with drainage class poorly drained, but no soils in the other drainage classes. Northern Algeria has a high proportion of soils in the drainage class temporarily poorly drained, and Morocco has them in three classes: poorly drained, temporarily poorly drained and imperfectly drained. Greece and Bulgaria have low proportions of wet soils. On the Iberian Peninsula, wet soils are found in the south-western quarter of the area, but their proportion of area occupied is low.

In the remaining countries the areas of wet soils are scattered and their proportion is usually less than 40 percent, while the classes imperfectly drained and temporarily poorly drained are the most widespread. Some areas with a relatively high proportion of wet soils are Brittany - Normandy, Massif Central in France, west Belgium, east and southern Netherlands, the Danube plain of Hungary-Croatia, Serbia, the Po Valley in Northern Italy.

As a summary, when the limit of suitability is set at drainage class imperfectly drained, in some regions a part of the cultivated soils will be classified as unsuitable. This is the case in England, Northern Ireland, Netherlands, Estonia and coastal Algeria. The shift to less severe rules leads to increasingly higher proportions of suited soils, but some imbalance between the regions will remain. The other extreme is to classify only the very poorly drained soils as unsuited for agriculture. The latter rule has influence on the selection of soils in Northern Europe only.

7.4.4 Volume of stones

Soils having a volume of stones larger than 20 percent occur in Spain and Estonia only, and outside Europe in Syria and inland Algeria. Soils having volumes of stones larger than 15 percent are found in many more countries but show an irregular distribution over Europe. The stony area in Spain has increased, and Portugal appears on the map. There are considerable concentrations of stone-rich areas in southern France, and in the eastern Po Valley in Italy. A very large concentration of these soils is found in the central and southern parts of Germany, in the Czech and Slovak Republics, the Carpathian Mountains, in the Baltic countries, and the three Nordic countries, Finland, Sweden and Norway. In the Alps they occur in a very fine distribution pattern. In addition, they are scattered all over Northern Russia. A remarkable feature is a belt in Russia along the border with Georgia and Azerbaijan. Stony soils cover large parts of Armenia, Turkey, Greece, Bulgaria, Syria, Jordan, and northern Algeria. Countries with very few stony soils (15 % stones and more) on the map are Iceland, Poland, Denmark, the Netherlands, northern Belgium and Ireland, Morocco, Tunisia, the former Yugoslavia, Ukraine. When the class limit for 'volume of stones' is put at 10 percent an enlargement of areas of stony soils can be seen for eastern Spain, France, the Alps, the Balkan coast and Greece, central and eastern Turkey and northern Algeria.

In the practice of farming, the presence of stones in the topsoil has a large effect on the use potential of the land, as they hamper ploughing and especially the stones make the harvesting of tuber crops very difficult. This pleads for using the volume of stones as a criterion for distinguishing good arable soils from soils unsuited for arable farming. However the distribution of the stony soils when applying 'volume of stones above 10 percent' as a criterion leads to the labelling as 'unsuitable for cropping' of most of Germany, the Czech and Slovak Republics, and the Lower Po Valley, and of large parts of Spain, the Baltic countries, Sweden, Greece, Turkey, eastern Mediterranean countries and Algeria. Shifting the criterion to 'above 15 %' has the same consequence. But relaxing the rule to exclude only the soils with a volume of stones above 20 % is meaningless as such soils are mapped only in Spain. For these reasons we decided to exclude this criterion from the set of suitability rules.

7.4.5 Slopes

Most steeply sloping land (>25%) occurs in the former Yugoslavia south of the Sava and Danube River and Greece. Other areas with a small proportion of steep slopes are the western half of the Iberian peninsula and the Pyrenees, Scotland, Norway, the Alps, the southern half of Germany, the Carpathian mountains and Transylvanian Alps, Eastern Turkey, Middle east, and Maghreb countries. The pattern is determined by the mapping detail, which is different across countries. Countries with important mountainous districts but yet with very few steep slopes are France, England and Poland, while steep slopes do not occur at all in Iceland, Sweden, Russia, and Ukraine.

Changing the criterion into 'slopes larger than 15%' leads to a large increase in the proportion of sloping land in most of these regions, large areas with more than 60 percent sloping land especially Spain, Italy, the South Balkan Peninsula and Norway. The changes in the other areas are less dramatic. New regions with sloping land in the 15-25 percent class appear in France, Southern Belgium, Wales, Finland (in particular the north and the coastal strip) and Lithuania. No changes in Turkey, Cyprus and Morocco. No slopes in Sweden, Iceland, Ukraine, and Russia. Changing the criterion into 'slopes larger than 8%' leads to very high proportions of sloping land in all Mediterranean countries, especially a large increase in Turkey and the Maghreb countries. A high proportion of sloping land appears now in Iceland, Ireland, Sweden and Finland, and a relatively low proportion in France, Belgium, England, and Poland. Very few slopes above 8 percent occur in the Netherlands, Denmark and Estonia, and they are completely absent in Russia, Ukraine, Belarus.

7.5 Application of a sequence of decreasingly severe sets of suitability rules

The function of soils in agriculture is to provide a favourable growing environment for the plant roots and a good working environment for the farmer. The plant roots require that the soil provides them space, foothold, water, oxygen, nutrients and absence of toxicity and diseases, the farmer requires that the soil allows mechanization and is easy to till. According to cropping handbooks, the best soils for most arable crops are deep, well drained, medium textured soils in level topography. It could be added that the soil should be not saline, alkaline, rocky, peaty, and stony. In this way, the soils are defined by the presence of favourable properties and the absence of bad properties. It is more practical to define a selection of suitable soils by a set of exclusion criteria, the unsuitability rules.

We have applied very simple single rules, and in a first step to exclude only the soils with extremely unfavourable soil conditions. This leads to a selection of soils from which only the soils of the lowest production potential have been excluded. In a second step, the selection of more or less suitable soils is reduced further by applying additional unsuitability criteria. In each next step of the procedure one criterion is added in order to identify step by step a smaller selection of increasingly better soils. The resulting series of suitability maps are evaluated by comparing them countrywise with the land cover map.

7.5.1 Suitability class A7 of arable soils

The soil unsuitability criteria consist of rooting depth, texture, drainage, slope, salinity and alkalinity. Normally the criteria refer to a specific kind of land use, or group of crops, but in the present study we have inverted the way of reasoning: we try to define a set of criteria which allows the generation of a geographic representation of the major agricultural areas in Europe. The selection of soils resulting from this first set of rules is not known a priori and cannot be related to a specific crop. Therefore we call this first set of rules A7, short for Arable 7 (see Table 7-3). The A7 set of rules refers to crops with very low requirements for mechanization and supply of moisture and oxygen to the roots. Application of these criteria separates the soils with low productive potential from the soils with higher potential. We may expect that agriculture takes place within the suitable areas. Exceptions exists, for instance, in a few regions where crops are grown on reclaimed peat soils, but most peat soils are not used for field cropping. Our aim is to identify a set of rules for selecting a grouping of soils which corresponds largely with the major crop cultivation areas. Exceptions to the rules are acceptable as long as they do not lead to strong over- and underestimations of the cultivated areas across Europe.

The use of this first set of unsuitability rules results in the selection 'A7' of suitable soils, which shows a strong overestimation of the suitable area in comparison with the agriculturally utilized land over most of Europe (see Annex 5, map 12). This overestimation could stem either from a choice of the wrong set of parameters, from too soft criteria, or errors on the soil map. On the other hand, for some countries the selection A7 corresponds rather well with the land use map, e.g. Scotland and the United Kingdom, while for a few areas the agricultural area is underestimated, notably Estonia and parts of Belgium. Apparently in these latter cases one or more unsuitability criteria are too severe, the soil map is erroneous or other factors like climatic or socio-economic factors explain the differences.

In Northern Europe the unsuitability of soils outside the A7 selection is related mainly to the occurrence of peat and very poorly drained soils. In a few countries other soil parameters play a role, notably shallow soils (Iceland and Norway), and steep slopes (Norway only). Note that steep slopes do not occur in Sweden, Iceland and Russia.

The Very Poorly drained soils occur only in the northern half of Europe, and are very common especially in Estonia, Finland and Scotland, and, to a lesser degree, in Northern Russia, Sweden, Norway, England and Hungary. The occurrence of Very Poorly drained class in Belgium is probably an inconsistency in the mapping of drainage classes. In many cases, the Very Poorly drained soils are associated with peat soils, so in these cases two unsuitability criteria apply to the same soil unit. This linkage of Very Poorly drained class to peat is much less in Estonia, Hungary, Belgium and England. In these countries many mineral soils are mapped as Very Poorly drained, and part of these soils are in reality used for agriculture, so the unsuitability criterion is too severe for our purpose. A solution could be to skip Very Poorly drained as unsuitability criterion and to apply 'peat texture' only. The disadvantage is that many correctly excluded mineral soils with very poor drainage will then appear as suitable on the map.

Table 7-3: **Successive soil suitability classes defined with decreasingly severe criteria, but presence of stones accepted in all classes. Dark grey and light grey indicate respectively suitable and unsuitable classes of a soil property.**

	root	root	root	text	text	text	text	text	drai	drai	drai	drai	ston	ston	ston	slop	slop	slop	slop	slop	sal	alk
	<10	10-20	20-40	fine	very fine	rocks	peat	no text.	imperfect	tmp poor	poor	very poor	>10 %	>15 %	>20 %	8 - 15	15-25	>25	8-30	>30		
Class	**1**	**2**	**3**	**4**	**5**	**7**	**8**	**9**	**I**	**TP**	**P**	**VP**	**10**	**15**	**20**	**2**	**3**	**4**	**5**	**6**	**H**	**H**
Arable 1																						
Arable 2																						
Arable 3																						
Arable 4																						
Arable 5																						
Arable 6																						
Arable 7																						
Grass 1																						
Grass 2																						

In the southern half of Europe the unsuitable soils (according to the set of rules A7) are related mainly to steep slopes or very shallow soils. Small areas with rocks are associated to these soils. In a few well defined regions highly saline and alkaline soils occur, which are classified as unsuitable according to A7. The largest proportion of unsuited soils according to the A7 set of criteria is found for Spain and Portugal (steep and shallow soils), the Alpine region (steep), the former Yugoslavia (steep or shallow), Greece, Turkey and the Caucasian countries - but not the Russian Caucasus – and the countries of the Maghreb and Middle East. Very few unsuitable soils according to the A7-criteria are found in Italy, Albania, France and all countries north of the Alps and north of the Sava-Danube rivers and the Ukraine. Southern Russia is also suitable, except for two large concentrations of saline and alkaline soils. The areas with highly saline and alkaline soils are in practice little used for cropping. Highly saline soils are limited to some very tiny (at the scale of Europe) coastal strips, and small areas in Portugal, Hungary, Cyprus, Turkey, southeast Russia, and in the countries east and south of the Mediterranean Sea.

Highly alkaline soils are found in small areas in Hungary, Albania, Cyprus, and are more widespread in the Ukraine, and in south east Russia near the Caspian Sea and the border with Kazakhstan.

7.5.2 Suitability class A6 of arable soils

The selection of suitable soils can be narrowed by applying more severe criteria. The candidate criteria for a sharper selection are rooting depth, texture, drainage, and slope. Let us assume that arable crops require soils with a rooting depth deeper than 40 cm (rooting depth class 3 is excluded as unsuitable). This has a visible effect on the area of suitable soils in most countries (see Annex 5, map 13).

It has a very strong effect in a few countries, often associated with mountain soils or glacial and desert landscapes: Spain, Switzerland, Austria and Slovenia, Sweden and Norway, northern Russia, the Russian Caucasus, Albania, Syria and the Algerian Sahara, but it has no effect at all in the Netherlands, Denmark, Italy, Iceland, Finland, the Baltic states and Poland, Romania, Cyprus, Turkey, Jordan, Egypt, Tunisia and Morocco, Ukraine, Georgia, Armenia and Azerbaijan. In a few countries in central Europe, the effect is less strong but still clearly visible: southern and central Germany, the Czech Republic, the Slovak Republic and Hungary, and the former Yugoslavia. It has a small effect in the remaining countries all situated in Western Europe: Ireland, United Kingdom, Belgium, France and Portugal.

The resulting suitability map A6 is a better representation of agricultural land than the former A7 map, but it still overestimates the agricultural area in most countries. A reasonable correspondence (in addition to Scotland and the United Kingdom) with the land use map is found for Spain, Greece, Switzerland and the Baltic states except Estonia.

7.5.3 Suitability classes A5 and A4 of arable soils

Another candidate for a refinement of the unsuitability criteria is drainage. The criterion that very poorly drained soils are unsuitable can be extended to poorly drained soils (A5) and further to temporarily poorly drained soils (A4). Compared to A6, the application of stronger drainage criteria leads to mixed results: more plausible selections in some countries, worse results in other countries, and little or no effect in many other countries (see Annex 5, map 14). Of course no effect is observed in countries where the involved drainage classes are lacking. This is in Iceland, Finland, Bulgaria, Greece, Moldova, and Ukraine, the southern half of Russia, Cyprus, Syria, Jordan, and Tunisia.

In the northern half of Europe, A5 and A4 show successive improvements in the representation of the overall actual land use pattern in France, Ireland, Belarus and the northern half of Russia. Some improvement can be observed for the A5 selection in Germany, Denmark, Sweden, Norway, Poland, Lithuania and Latvia, while A4 is identical to A5, because the temporarily poorly drained soils are not distinguished in these countries. Worse correspondence is found for England, Wales and Estonia where in reality drainage problems are less widespread than suggested. Remarkably, this holds also for the coastal region of Algeria, where large parts are mapped as having class temporarily poorly drained.

The results are rather difficult to interpret, as the poorly drained soils may be artificially drained and in reality very suitable for agriculture. So even if the addition of the poor drainage as unsuitability factor leads to maps which show a better correspondence, it is not necessarily that in reality it is the drainage factor which is responsible for excluding these areas. This holds even more in southern Europe, where the river valleys belong to the best agricultural soils of the region, and here part of these soils are now excluded on the basis of poor drainage conditions, which may in reality not be problematic for cropping.

The effects of the stronger drainage criteria are clearly visible in Hungary and Romania. In many countries of southern Europe already considerable proportions of soils are excluded from the A6 selection, especially in Spain, the southern part of the Balkans and Turkey.

In short, the mapping of the drainage classes on the soil map is not consistent across countries in Europe, which makes it difficult to assess the extent and severity of soils with drainage problems in Europe. In addition, the use possibilities of the soils vary across Europe, because the way that the farming practice can cope with poor drainage conditions depends also on other soil qualities, type of landscape, water management measures, the cropping calendar and climate. These two reasons, the inadequate knowledge of actual drainage conditions and the variation in coping possibilities by farming, do not allow a uniform application of drainage rules for the purpose of selecting suitable soils at a European scale. It may be possible for some countries to apply drainage classes as unsuitability rules in combination with rules for other soil factors. This would require a more careful study at country level.

In the A4 rules, the texture very fine is excluded from the suitable soils as well. Texture very fine is very rare. Some local concentrations: Hungary, Danube lower plain in Rumania/Bulgaria, Krim and just north of it in Ukraine, and a narrow strip north of the Caucasus. Very few sites are found elsewhere. So the geographical effect of this additional criterion is very small.

7.5.4 Suitability classes A3 of arable soils

Another option to narrow the selection of suitable soils is by removing all soils with slopes of more than 15 %. Note that slope class 8-30 % (class 5) does not occur on the current soil map of Europe. The addition of slope class 15-25% slope as unsuitability criterion leads to varying results. The difference between the A3 and A4 class is determined positively by the extent of the slope class 15-25%, and negatively by the degree that these areas are already excluded by the other soil factors excluded in the A4 through A7 selections. The sloping land may be related with shallow soils, rocks and stoniness.

The slope class 15-25% occurs in mountainous regions, especially Spain, Italy, South Balkan Peninsula and Norway. Other regions with this slope class appear in France, Southern Belgium, Wales, Germany, the Alpine regions, southern Poland, the Czech and Slovak Republics, Romania, Finland (in particular the north and the coastal strip) and Lithuania. Very few areas with slope class 15-25% are found in England and in Ireland. It does not occur in Turkey, Cyprus and Morocco, where steeper slopes are mapped. No slopes of this class 3 or steeper are mapped in Sweden, Iceland, Ukraine, and Russia, Denmark and the Netherlands. The A3 selection shows a rather good correspondence with actual land use in the following countries: Norway, Spain, France, Germany, Poland, the Czech Republic, Hungary, Romania, Bulgaria. Somewhat too much land is probably excluded as unsuitable for Italy, the Slovak Republic, Austria, the southern Balkans and Greece. In short, the overall pattern of suitable land from which the slope class 3 is excluded is plausible in all these countries, with both under- and overestimations of suitable areas. Of course the A3 rule has no effect at all in countries where the slope class is not mapped, either because it does not occur, or its occurrence was ignored on the map.

7.5.5 Suitability classes A1 and A2 of arable soils

The application of additional exclusion criteria at the European scale is not very useful as the A3 set of rules leads already to some underestimation of the suitable areas. Yet the evaluation of the effect of additional criteria may be useful for a number of reasons.

1. The sets evaluated so far have mixed results over countries in terms of over- and underestimations of suitable areas. When country-specific rules would be acceptable, it is possible that some other soil factors are effective as selection criteria in some countries, simply because they fit better to the soil distinguishing criteria applied in the original national soil classification.

2. For many applications other than CGMS it may be desirable to make a further distinction of soils by degree of suitability, or to identify the very best soils.

For these reasons a further refinement of unsuitability criteria has been evaluated, consisting of removing all land with more than 8 percent slopes from the selection of suitable soils (A2), and removing all imperfectly drained soils (A1). Note that these rules do not yet take into account the exclusion of the heavy textured soils (texture class 4) or the coarse textured soils (texture class 1).

For the purpose of generating a proxy-map of arable land, the A2 rule could be applied successfully only in France, United Kingdom, Poland and Lithuania. In some countries no slope classes have been mapped: Iceland, Russia, Belarus, Moldova, and Ukraine. In other countries with large valleys the sloping areas are rare: Netherlands, Northern Germany, Denmark, Po valley, Hungarian plain, lower Danube plain in Romania. In most other countries, outside the large plains, the area above 8 percent slope would include a large part of the actual arable lands, and should therefore not be labelled as unsuitable. However, the criterion could be used to make a distinction by degree of suitability, or risk of erosion.

The use of imperfect drained soils as unsuitability criteria has a relatively small but still visible effect on the selection of suitable soils in the plains of Europe, especially in the United Kingdom, Ireland, France, Belgium, the Netherlands, Germany, Poland, the Baltic states, Italy and most central European countries. In southern Russia and Ukraine the major river valleys are mapped as imperfectly drained. In a few countries the imperfect drainage is not distinguished: Spain, Iceland, Norway, Sweden, Northern Russia, Belarus, the Caucasian countries, Turkey and the Eastern Mediterranean countries.

7.6 Implementation of the unsuitability criteria

The overall impression of the SGDBE is one of large variation across countries in geographical detail and it lacks consistency in the classification of original soil parameters, and consequently also in derived soil parameters (see 7.4). In general, the possibility to distinguish differences in soils on the basis of suitability criteria is greatest for France. Considerable possibilities for discriminating soil differences exist also for Spain, United Kingdom, Germany, Austria, Switzerland and the Central European countries, Lithuania, Poland, Hungary and Romania. But it is not possible to apply uniform criteria across those countries. Another group of countries have applied very specific national standards for the preparation of their part of the soil maps, leading to systematic differences with other countries: Ireland, Denmark, Netherlands, Belgium, Italy, Greece, Estonia, and Latvia. The Nordic countries show large differences among themselves and mapping has been less refined, especially Sweden and Iceland, that are very coarsely mapped. Russia, Belarus, Ukraine and Moldova have been mapped uniformly, and show consistent geographical detail over large areas, but lack data on some soil parameters, or apply other subdivisions. Turkey, the Caucasian countries, the eastern Mediterranean countries and the Maghreb countries show a coarse mapping pattern and coarse class subdivisions. An exception is the northern part of Algeria, Egypt, Lebanon and Palestine which show much more geographical detail (scale 1 to 1 million). The level of detail of soil information on the southern Balkan countries is situated between the central European countries and Turkey c.s.

The conclusion is that the application of uniform soil unsuitability criteria across Europe is possible only for the broad selection of the least productive soils on the basis of extreme adverse soil conditions. Any refinement in criteria in order to focus on the soils of the most important centres of agricultural production leads to inconsistent selections of soils across Europe, due to a lack of uniformity in the soil map of Europe between the countries. It is particularly unjustified to apply crop group-specific or even crop-specific sets of unsuitability criteria, as the differences in criteria are rather small, while the precision of the soil indicators derived from the soil map is rather low.

In addition, other factors like climate, socio-economic and historical factors play a role as well in explaining where the major crops are grown. So even if it would have been possible to distinguish the suitable soils per crop group in a consistent and European-wide applicable way, a mismatch between the actual crop group distribution would still exist because of these other factors. It was expected to have more precise, or better crop group-specific information on where the major crops are located using soil data and suitability rules instead of European land cover maps.

But unfortunately, it appears that using the SGDBE version 4.0 database this is not the case. The maximum goal that can be reached is a rough distinction between arable and non arable land.

For CGMS the actual land use information is mainly important for a correct spatial aggregation from the elementary mapping unit (EMU) to the most detailed administrative region level (NUTS level 2). Spatial aggregation from NUTS level 2 to level 1 and 0 is based on area statistics of EUROSTAT. Based on the above presented analysis of the soil suitability rules and the SGDBE version 4.0, it is concluded that the use of European land cover data like CLC2000 and/or GLC2000 will be a more precise source of information than the results of soil suitability rules within the aggregation from EMU to NUTS level 2.

One should remember that soil suitability rules within CGMS are still needed to aggregate from STU to SMU level. So soil suitability cannot be substituted by land cover data. Both data sources are needed. For the aggregation from STU to SMU level, a set of very basic and robust unsuitability criteria (rule A6) could be applied, leading to the separation of low potential soils from soils which are more or less suitable for arable farming. In case of permanent forage, a rule similar to the ESCAPE rule of grass (rule grass 2, see Annex 5, map 17) could be applied.

Table 7-4: **Crop groups identified in the soil suitability rules**

Crop number	Crop name	Crop group interim	Crop group final
1	wheat	Cereals	Arable
7	potato	Root crops	Arable
3	barley	Cereals	Arable
8	field beans	Cereals	Arable
2	grain maize	Maize crops	Arable
10	oil seed rape	Cereals	Arable
11	sunflower	Cereals	Arable
6	sugar beet	Root crops	Arable
9	soy bean	Cereals	Arable
12	green maize	Maize crops	Arable
50	forage permanent	Forage extensive	Permanent forage
51	forage temporary	Forage intensive	Arable
5	rice	Cereals	Arable

8 Summary

The resulting databases serve as the new soil information for the Mars Crop Yield Forecasting System. Due to the new SGDBE version and required better geographical coverage, soil information used within the CGMS had to be updated. The work consisted in:

- generation of soil parameters with FAO soil map;
- rewriting the Pedotransfer Rules for salinity, alkalinity, chemical toxicity and drainage according to the new nomenclature;
- redefinition of new Soil Physical Groups and their parameters;
- redefinition of new Rooting Depth classes;
- re-evaluation of CGMS Suitability Criteria;
- new evaluation of Soil Suitability Criteria.

New soil parameters with the FAO soil map have been generated for specific countries. This was necessary as not all countries are covered by the SGDBE, but information is needed in the frame of the MCYFS. The attributes SOIL, SLOPE, TEXT and PHASE/AGLIM were generated using additional databases such as the 1:5 mil Soil Map of World.

The pedotransfer rules for salinity, alkalinity, chemical toxicity and drainage have been adapted to the WRB standard and were applied to the SMU database to retrieve the information. These attributes are needed amongst others to determine the soil suitability for the crop growth simulation. Also a new rule for estimating rooting depth has been established by using the values taken by the different attributes and the correlations established within the soil name and the ROO attribute.

The redefinition of new soil physical groups and their parameters was performed as well. In the CGMS, soil physical groups were introduced per STU to determine the available water capacity (AWC) of a soil. Adaptation and extension of the existing rules was necessary because of the other soil classifications in the database. Rules have been defined now in a more general way so that they can handle all possible values that occur for the different attributes. Adaptation of the rules led to different available water capacity values than previously used within the CGMS and to a larger spatial differentiation. Overall the AWC value has increased. The largest differences are due to the recognition that organic soils have very high AWC values. The second largest effect is that in subsoils of secondary chalk and loess, the sponge effect of the subsoil, leading to capillary rise of moisture during the growing season, has been translated into a much higher AWC value (an additional amount of about 100 mm of water). The soil physical group is defined by the volumetric soil moisture content at wilting point, field capacity and saturation. To link the AWC values produced by the CERU32 program to soil physical groups the volumetric soil moisture content of wilting point given by the HYPRES rules (see 5.2.3) was used. The volumetric soil moisture content at field capacity was calculated by adding up the AWC value. This procedure led to 743 unique soil physical groups instead of the former 7 groups.

Based on the re-written PTRs and the application of the former suitability criteria to the SGDBE v.4 the suitability criteria have been evaluated and were re-defined. The assessment of yield level at national and sub national scale with CGMS requires information on locations and soils where the major crops are grown. This information is especially important for the spatial aggregation from simulated crop indicators from simulation units to administrative regions. Most logically this information could be obtained by combining a European land use map and the European soil map. However the main constraint for application of this procedure is formed by the lack of a harmonized land use map at the level of major crops. The solution found to overcome these constraints was to derive from the soil map a new map of plausible land use based on soil suitability rules. A rule is defined by listing the unsuited classes of soil parameters, or by specifying a threshold value for a given soil parameter. The parameters used to assess the soil suitability were rooting depth, slope, and volume of stones, texture, drainage, salinity and sodicity (alkalinity). The selection criteria are defined for each parameter as the range of unsuitable classes.

It was the aim to define a set of soil suitability rules for each major crop group, but the analysis revealed that this is not realistic when using the SGDBE v4. The conclusion is that the application of uniform soil unsuitability criteria across Europe is possible only for the broad selection of the least productive soils on the basis of extreme adverse soil conditions. Any refinement in criteria in order to focus on the soils of the most important centres of agricultural production leads to inconsistent selections of soils across Europe, due to a lack of uniformity in the soil map of Europe between the countries. It is in particular not justified to apply crop group specific or even crop specific sets of unsuitability criteria, as the differences in criteria are rather small, while the precision of the soil indicators derived from the soil map is rather low. It is concluded that the use of European land cover data like CLC2000 and/or GLC2000 will be a more precise source of information than the results of soil suitability rules within the aggregation from EMU to NUTS level 2.

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