Methodology and experience from the soil geographical database of Europe at 1:1,000,000 scale

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Methodology and Experience from the Soil Geographical Database of Europe at 1:1,000,000 scale

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Introduction

A large amount of work for the knowledge and conservation of soil resources have been done for many years in Europe, but without real harmonisation at the beginning. Many of these activities have been supported by the European Commission, but not sufficiently co-ordinated. This led to the creation of the European Soil Bureau (ESB) (Montanarella, 1999) a few years ago to better co-ordinate European activities on soils. The bureau's General Secretary is Dr L. Montanarella.

This short report briefly presents the organisation of the of European Soil Bureau projects, then the state of advancement of one of those projects resulting from an important and fruitful effort of international collaboration: the European Soil Geographic Database at 1:1 Million scale, within the framework of the European Soil Information System (EUSIS).

The 1:1,000,000-scale European Soil Database Working Group has already been in operation for many

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years, well before the creation of the ESB. It has been the driving force of a European joint effort by many soil scientists from different countries. The chairperson of the group is Dr. M. Jamagne (INRA - SESCPF). A more detailed presentation is done below.

It is expected that the development of this soil information system will continue well beyond 1999 with the extension of the coverage to new countries.

Other scientific Working Groups have also been formed: one on Soil Erosion Risk Assessment, Chairperson Prof. N. Yassoglou (Athens, Greece), a second on Soil Analytical Methods, Chairperson Prof. E. Van Ranst (University of Ghent, Belgium), and more recently on Heavy Metals in Soils, chaired by Dr W. Eckelmann (BGR – Hannover, Germany).

The European Soil Information System (EUSIS)

This system has been developed within the framework of the European Soil Bureau, as described above through the scope of the 1:1,000,000-scale European Soil Database Working Group. Before presenting the current state of advancement of EUSIS, the different stages which allowed reaching its present status will be quickly described.

General Historical background

European programmes of the European Communities Commission on soil information and management have been included since many years in two wide-ranging programmes:

- in the agricultural production domain (DG VI), by means of the Soil Map of the European Communities (EC) at scale 1:1,000,000 .
- in the environment domain (DG XI), by means of the CORINE programme.

Activities of FAO and EU General Directorate VI (Agriculture)

From 1952, studies were made about the different soil classification systems in Europe, with the objective of an eventual harmonisation and collaborative work among soil scientists. The first result was the publication of the FAO Soil Map of Europe at scale 1:2,500,000 in 1965 (FAO, 1965). During the seventies, work continued under the guidance of FAO on the Soil Map of Europe at scale 1:1,000,000. The soil legend was designed at the same time as that of the Soil Map of the World at scale 1:5,000,000, published in 1975 (FAO, 1975). But, due to insufficient funding, the work was stopped by FAO and the map was never published.

In 1978, the European Commission decided, in agreement with the FAO, to resume the work for the countries of the European Communities (EC). The final EC Soil Map was published at scale 1:1,000,000 in 1985 (Tavernier, 1985; CEC, 1985). In 1986, the territories of Austria and Switzerland were added to the map at the initiative of UNESCO and the International Soil Science Society (CEC – ISSS, 1986).

During this time, agronomic research was organised by DG VI in different Program Committees with precise objectives, co-ordinated by the Permanent Committee on Agronomic Research (PCAR). The Program Committee for Soil Science first was called "Land Use" and later became "Land and Water Use and Management". Between 1972 and 1985, it worked successively on the following points:

- inquiries in EC countries to define the main problems affecting land management;
- drafting of the EC Soil Map at scale 1:1,000,000;
- organisation of "Workshops" where soil conservation took an increasingly important place;
- introduction of computerisation in data processing;

- research into land evaluation, land degradation and conservation.

The publication of the 1:1,000,000-scale EC Soil Map was certainly a most powerful stimulus but we have to keep in mind that it was the fruit of more than 30 years of works and many regional and national soil survey staffs.

Activities of EU General directorate XI (Environment)

The main objective of the CORINE programme (DG XI) was the creation of a Coordinated Information System on the state of the Environment and Natural Resources of the European Communities. This implied setting up a homogeneous framework for the gathering, storage, presentation and interpretation of environmental data on the EC countries (Briggs and Martin, 1988).

The CORINE program resulted in the digitalization of the EC Soil Map in 1986, producing the first version of the geographical soil database (version 1.0). This work consisted in digitalizing the contours and indicating, for each polygon, the number of the corresponding soil association and the nature of the possible phases. No additional data were entered other than those already present on the map (Platou et al., 1989).

Thus, this database was created as a support for research on soil parameters, their storage and handling, and their use for both agricultural production and land conservation. This initial version of the database was quickly put into use for the study of two major problems requiring multiple parameter combinations: soil erosion susceptibility, and soil buffering capacity.

A first project tried to make a zoning of the southern part of the EC, in terms of susceptibility of soil to erosion, associated with another zoning dealing with land quality (Giordano et al., 1995).

The second problem requiring zoning concerned "Buffering" capacity and susceptibility to acid rain. Here, zoning was based on the primary attributes of the first version of the database, and mainly on the FAO soil name. There were other attempts to make use of this information. These were not always published and there were few studies.

History of the Geographical Soil Database

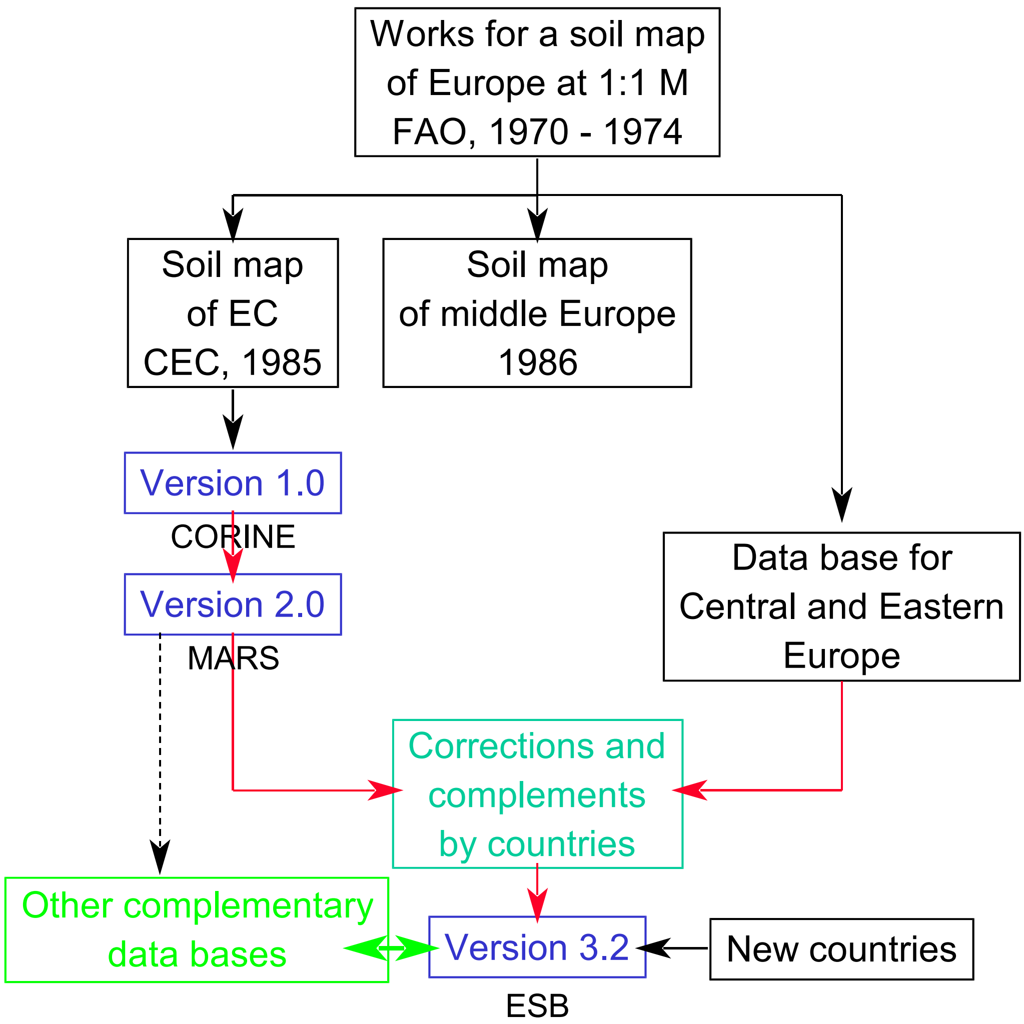

Figure 1. Diagram showing the geographical soil database history

Activities of the EU Joint Research Centre

Later on, another major programme in need for soil data was the MARS project of DG VI (Monitoring Agriculture by Remote Sensing). This programme includes different activities especially Initiative 3: creating yield forecast models (Meyer-Roux, 1987; Vossen and Meyer-Roux, 1995). To make new agrometeorological models, or improve existing ones, MARS requires databases on physical and agronomic conditions. These databases themselves depend on the use of remote-sensing data for crop monitoring and yield forecasts.

As part of the MARS project, the combination of specific soil parameters led to the first draft of a *Water Storage Capacity* Map needed for agrometeorological models. However, this work was not really satisfactory and demonstrated that the existing database was in need of improvements.

Evolution of the Database

The "Soil and GIS" EC Support Group.

The database as described above and managed by a Geographic Information System (Burrill, 1996), was progressively created by a Support Group of the CEC called "Soil and GIS", organised by the MARS project. The support group members were experts from different EC countries.

The main objectives were:

- identification of Pedological Factors that have an impact on spatial and temporal yield variations;
- discussion on Models suitability in relation with Data Precision;
- making proposals for further work to complete the available information from soil maps and associated databases (new "Attributes").

The Soil & GIS group suggested going back to the primary information sources. The method included three approaches ranked according to the ease to get the data.

The easiest method to obtain data was to consult the archives used to elaborate the EC Soil Map. Another source of information was the consultation with national experts. Finally, the last was the retrieval of basic measured data from analysed soil profiles.

Those three approaches are explained more details below.

Improvement using data from the FAO archives

To provide satisfactory answers to the problems being studied, the database had to be improved. An existing source of additional data was found in the archives (Table1), stored at Ghent University (Belgium). These archives had not been used for reasons related to map harmonisation.

Prof. Tavernier, co-ordinator of the FAO work, stored the archives of the EC soil map. Thanks to a good co-ordination of activities, it was easy to retrieve the main soil variables of interest (King et al., 1994).

The Table 1 below gives an example of those archives. Each column corresponds to an attribute describing the Soil Typological Units (STU). (Example of the data available in the FAO archives).

Table 1. Data on types of parent material and land-use were among the new attributes introduced, leading to the improved *Version 2.0* of the soil database. The main attributes were: - FAO Soil Name; topsoil texture class; slope; phase; parent material; land use; percent area of the SMU occupied by a given STU

EC Soil Mapping Unit number	Soil Typological Unit (FAO)	Composition (%)	Texture	Slop	hase	Elevation (m)	Parent material	Land use
42	Bd I Bgg	90 5 5	2	c	Stony lithic	300-600	Residual stony loam from schists	Forest, pasture, arable land
57	Lgs Lo Be I, Ge	75 10 10 5	4	c	Stony lithic	250-400	Residual loamy clay of marl	Arable land, pasture, forest
58	Ql Lo Ph	80 10 10	1	c	Stony lithic	300-450	Residual sand of sandstone	Forest, arable land
8	Lo Be	75 25	2 2	c c	Stony	250-380	Residual stony loam	Pasture arable land

Updates by national experts

However, this first step was insufficient to obtain the information needed for agrometeorological modelling. It was decided therefore, to consult with the soil scientists who had previously gathered the basic data (CEC, 1991; INRA-JRC, 1996). To do this, two approaches were suggested.

The first approach was to update the soil mapping units in order to improve the description of soil variables, because those that are stored in the archives and in version 2.0 are very old.

National input was limited to the data produced earlier by the EC countries and stored in the Ghent archives. In many countries, however, the state of knowledge on the soil landscape had made considerable progress since the original work was undertaken. National consultations were therefore needed and the relevant part of the database was sent to soil scientists in each country, for review, corrections and updates. For this, version 2.0 was sent to all national correspondents. They were asked to update of the attribute values, as well as of the drawing of soil boundaries.

In several countries this led to profound changes for large portions of the map; in other countries the changes made were less fundamental. Furthermore, new attributes were added.

The second approach was the development of a soil knowledge database with the support of the DG XI. The idea was to formalise, as an expert system, the knowledge used to estimate unknown soil parameters using soil variables already stored in the database. These estimations were called pedotransfer rules in reference to the concept of pedotransfer functions (Bouma and Van Lanen, 1986). The word «rules» means these functions are qualitative and based on estimates by experts.

Version 3.0 of the spatial soil database.

The database has thus been improved by adding new attributes allowing a better characterisation of the Soil Mapping and Soil Typological Units. This final version was called version 3.0. The *new attributes* were:

- Depth to textural change (classes from 1: 20/40 cm, to 5: No change);
- Subsurface textural class (classes from 1: Coarse, to 5: Very Fine);
- Depth to textural change;
- Obstacle to roots (classes from 1: no obstacle, to 4: between 20 and 40 cm);
- Presence of an impermeable layer (classes from 1: absent, to 4: within 40 cm);
- Water regime (classes from Dry to Very Wet);
- Water management.

Soil Information System: The Structure

The soil information system has presently four parts: (1) the metadatabase, (2) the soil geographical database at scale 1:1,000,000, (3) the soil profile database, and (4) the knowledge database.

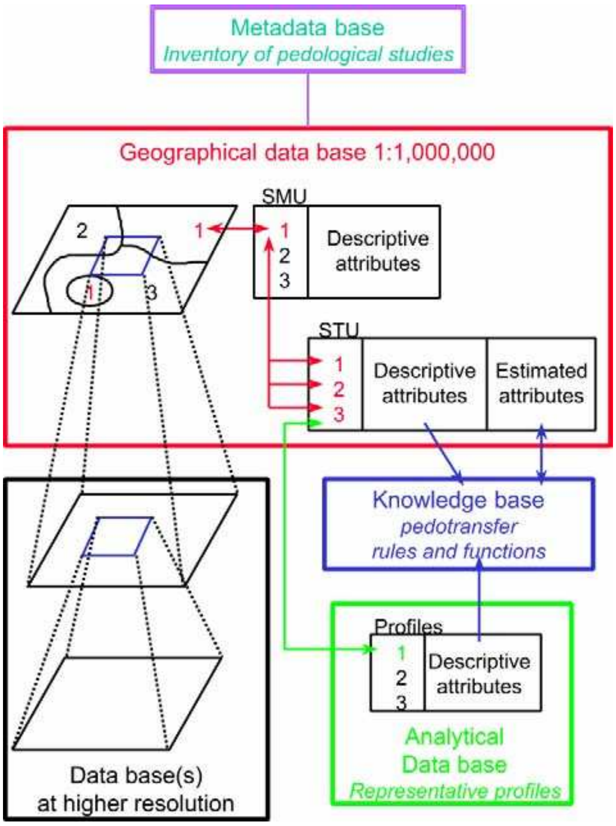

Figure 2. Relationship between the different parts of the database

The Metadatabase is chronologically the last stage and it is still in progress. The objective is to gather information on references for pedological studies in Europe. The resulting metadatabase should provide a catalogue where users could find more information about more detailed national maps. An earlier programme was carried out but has not been updated for ten years.

The 1:1,000,000-scale Soil Geographical Database is the central component of the system (Jamagne et al., 1994). It includes the list of the Soil Typological Units (STU) i.e. all soil types within the European Union which were mainly identified using the FAO-UNESCO legend (1974), revised by the CEC (1985), and later on using the FAO 90 revised legend.

From a semantic point of view, STUs are described by soil attributes already presented above, using harmonised coding: FAO soil name, parent material, slope, phase, topsoil texture class, textural differentiation, subsoil texture, depth to an obstacle to roots, presence of an impermeable layer, water regime, water management.

From a geometric point of view, STUs are generally too small to be drawn on a map at 1:1,000,000 scale. They are grouped within Soil Mapping Units (SMU), defined by contour lines and polygons. The classic concept of soil association is therefore used but the basic data are present for all STUs forming a SMU, and not for predominant soil units only.

Organization of Information

The figure below shows how the data about the soilscapes are introduced into the Database. The data are organised into 2 sets: a Geographic Dataset and a Semantic Dataset.

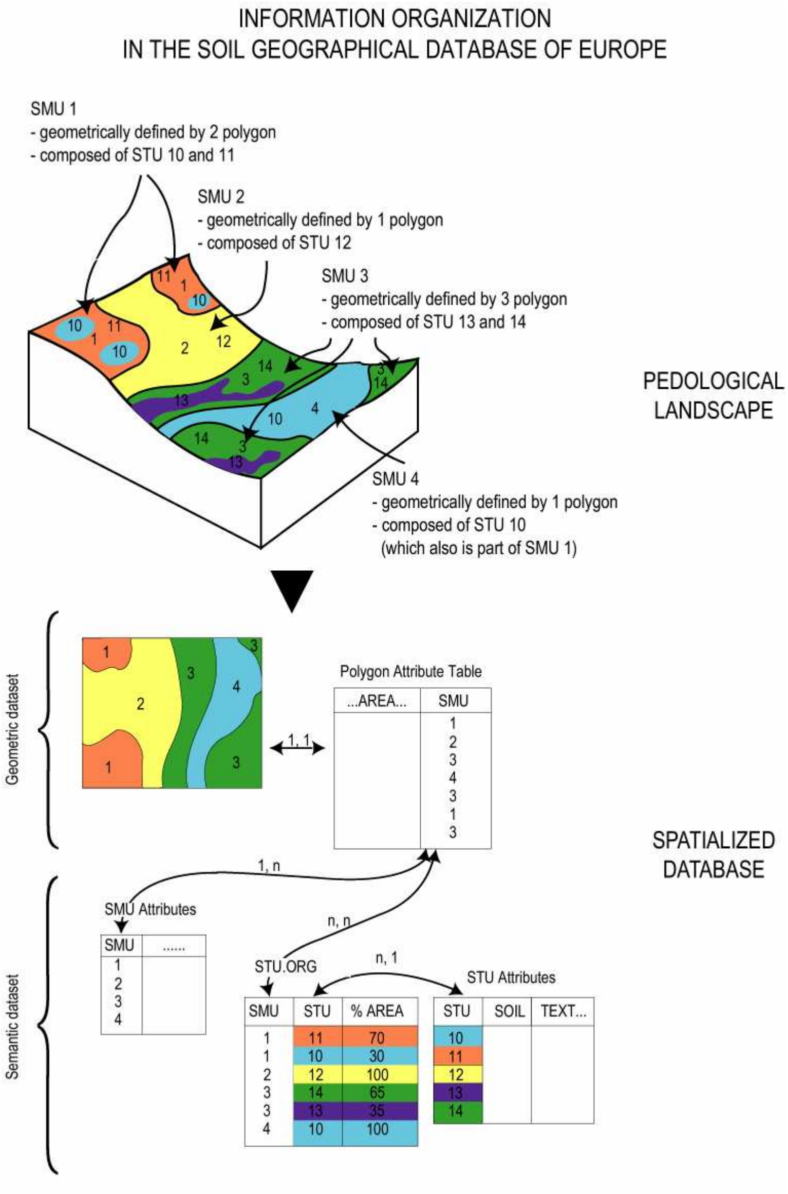

Figure 3. Soilscape information organisation in the database

STU Attributes

The different attributes are listed hereafter. Each variable coding is described in a soil data dictionary, found in the Instructions Guide (INRA, 1997).

SOIL WRB	WRB reference soil name.
SOIL90	Full 1990 FAO-Unesco legend soil name.
TEXT1	Dominant surface textural class.
TEXT2	Secondary surface textural class.
SLOPE1	Dominant slope class.

SLOPE2 Secondary slope class.
AGLIM1 Dominant limitation to agricultural use.
AGLIM2 Secondary limitation to agricultural use.
MAT1 Dominant parent material code.
MAT2 Secondary parent material code.
ZMIN Minimum above sea level altitude (in metres).
ZMAX Maximum above sea level altitude (in metres).
USE1 Dominant land use.
USE2 Secondary land use.
DT Depth class to textural change.
TD1 Dominant sub-surface textural class.
TD2 Secondary sub-surface textural class.
ROO Depth class of an obstacle to roots.
IL Presence of an impermeable layer within the soil pro file.
WR Dominant annual average soil water regime class of the soil profile.
WM1 Normal presence of a water management system in agricultural land (> 50% STU).
WM2 Purpose of the water management system.
WM3 Evident type of water management system.
CFL Global confidence level of the Soil Typological Unit attributes description.

Table of attributes

Table 2 gives an example of STU attributes included in the different SMUs.

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Following is an example of a thematic map output that was realised using directly the geographical soil database. It represents the dominant soil type for each SMU. The 1974 FAO legend was used, with some modifications by CEC for the soil map published in 1985. Soil names are listed at the second level of precision.

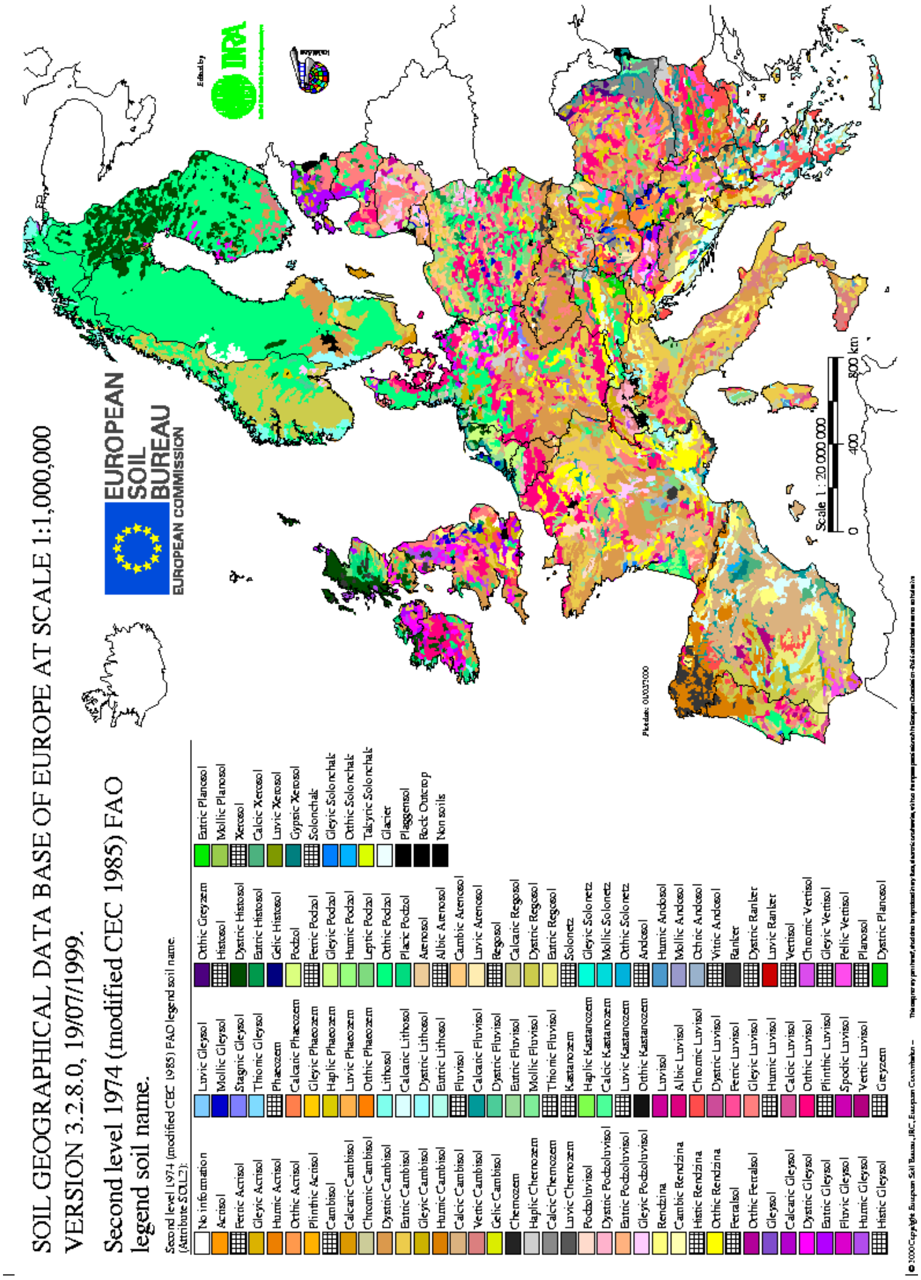


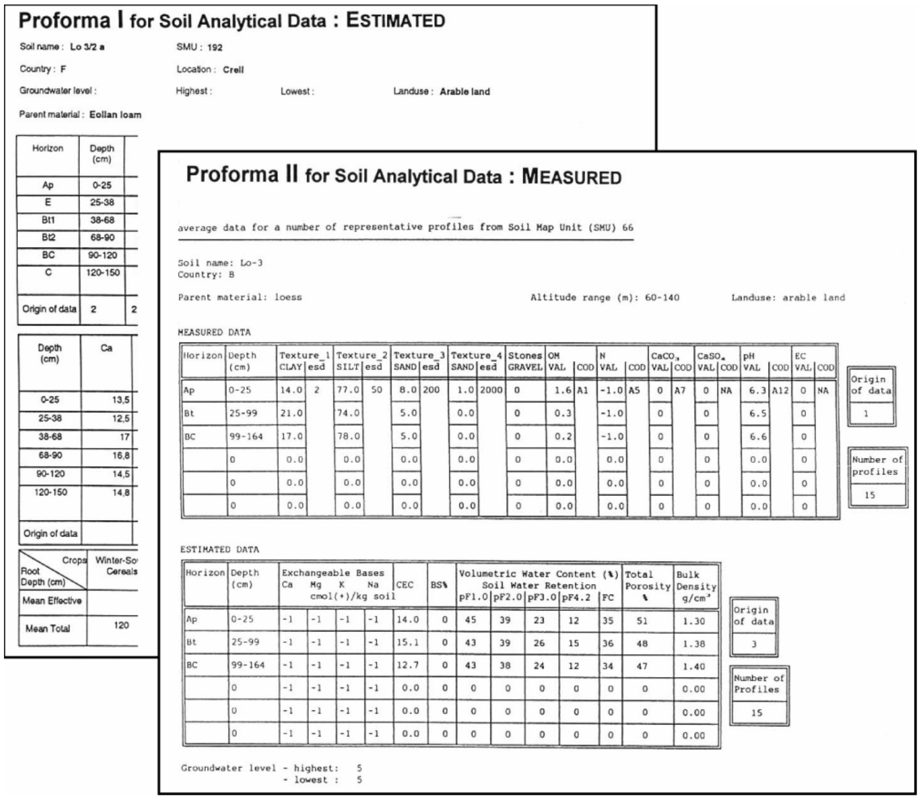
Figure 5. Second level 1974 (modified CEC 1985) FAO legend soil name

The Soil profile database

In order to obtain reliable data, the database was further improved using basic soil profile data (Madsen and Jones, 1996). For each dominant soil unit, a representative soil profile was collected with its relevant analytical data. Standard formats were developed to facilitate the harmonisation of data obtained through different analytical methods used in different European countries.

The Soil Profile Database contains soil profiles characterisations with physical and chemical analyses. For each dominant STU, a representative soil profile with its analytical data was selected. Standard formats were developed to harmonise the data obtained from various analytical methods in Europe.

Difficulties encountered during the attempt to harmonise those data led to the adoption of two different forms for each STU being characterised. The first is used for measured data taken directly from real georeferenced profiles. A code indicates which analytical methods were used and missing values are permitted. A second form stores estimated data. The analytical methods are selected to allow comparisons of the values between the various European countries. On this second form, all attributes fields must be fully filled, using expert estimates if needed. More than 600 soil profiles have been entered in the database, and more are expected in the near future.



Proforma I for Soil Analytical Data : ESTIMATED

Soil name : Lo 3/2 a　　SMU : 192

Country : F　　Location : Creil

Groundwater level :　　Highest :　　Lowest :　　Landuse : Arable land

Parent material : Eolian loam

Horizon	Depth (cm)
Ap	0-25
E	25-38
Bt1	38-68
Bt2	68-90
BC	90-120
C	120-150
Origin of data	2

Depth (cm)	Ca
0-25	13,5
25-38	12,5
38-68	17
68-90	16,8
90-120	14,5
120-150	14,8
Origin of data	

Root Depth (cm) / Crops	Winter-So[illegible] Cereals
Mean Effective	
Mean Total	120

Proforma II for Soil Analytical Data : MEASURED

average data for a number of representative profiles from Soil Map Unit (SMU) 66

Soil name: Lo-3
Country: B

Parent material: loess　　Altitude range (m): 60-140　　Landuse: arable land

MEASURED DATA

Horizon	Depth (cm)	Texture_1 CLAY	esd	Texture_2 SILT	esd	Texture_3 SAND	esd	Texture_4 SAND	esd	Stones GRAVEL	OM VAL	COD	N VAL	COD	$CaCO_3$ VAL	COD	$CaSO_4$ VAL	COD	pH VAL	COD	EC VAL	COD
Ap	0-25	14.0	2	77.0	50	8.0	200	1.0	2000	0	1.6	A1	-1.0	A5	0	A7	0	NA	6.3	A12	0	NA
Bt	25-99	21.0		74.0		5.0		0.0		0	0.3		-1.0		0		0		6.5		0	
BC	99-164	17.0		78.0		5.0		0.0		0	0.2		-1.0		0		0		6.6		0	
	0	0.0		0.0		0.0		0.0		0	0.0		0.0		0		0		0.0		0	
	0	0.0		0.0		0.0		0.0		0	0.0		0.0		0		0		0.0		0	
	0	0.0		0.0		0.0		0.0		0	0.0		0.0		0		0		0.0		0	

Origin of data: 1

Number of profiles: 15

ESTIMATED DATA

Horizon	Depth (cm)	Exchangeable Bases cmol(+)/kg soil Ca	Mg	K	Na	CEC	BS%	Volumetric Water Content (%) Soil Water Retention pF1.0	pF2.0	pF3.0	pF4.2	FC	Total Porosity %	Bulk Density g/cm^3
Ap	0-25	-1	-1	-1	-1	14.0	0	45	39	23	12	35	51	1.30
Bt	25-99	-1	-1	-1	-1	15.1	0	43	39	26	15	36	48	1.38
BC	99-164	-1	-1	-1	-1	12.7	0	43	38	24	12	34	47	1.40
	0	-1	-1	-1	-1	0.0	0	0	0	0	0	0	0	0.00
	0	-1	-1	-1	-1	0.0	0	0	0	0	0	0	0	0.00
	0	-1	-1	-1	-1	0.0	0	0	0	0	0	0	0	0.00

Origin of data: 3

Number of Profiles: 15

Groundwater level - highest: 5
　　　　　　　　　- lowest : 5

Figure 6. Example of Proforma I and II: soil profile information forms

The knowledge database

A method has been designed for transforming the data stored in the database into data that can be used for specific purposes (Van Ranst *et al.*, 1995; Jones and Lollis, 1996). This method is directly derived from the concept of pedotransfer function (Bouma and Van Lanen, 1986). Because of the often-qualitative nature of the data, such functions are simple tables and we call them "pedotransfer rules". The combination of pedotransfer rules creates an expert system that allows an easier interpretation of the soil map and its associated database. An advantage of this method is that interpretations are explicit and can them be entered in a database, which has been labelled a *knowledge database*. The pedotransfer rules can be updated when necessary, either by addition of new data in the future, or based on the identification of particular features of some regions.

The aim of the Knowledge Database is to provide interpretative variables for agricultural or environmental purposes, for helping non-expert users, or for providing analytical parameters used for modelling. Interpretation is done using pedotransfer rules, elaborated by a group of experts, who estimate the required parameters by identifying logical relationships. The method used to construct the rules is an attempt to formalise how soil expert interprets the soil data stored in the Geographical Data Base. The rules can also use data from other sources e.g. climatic, land use or elevation data.

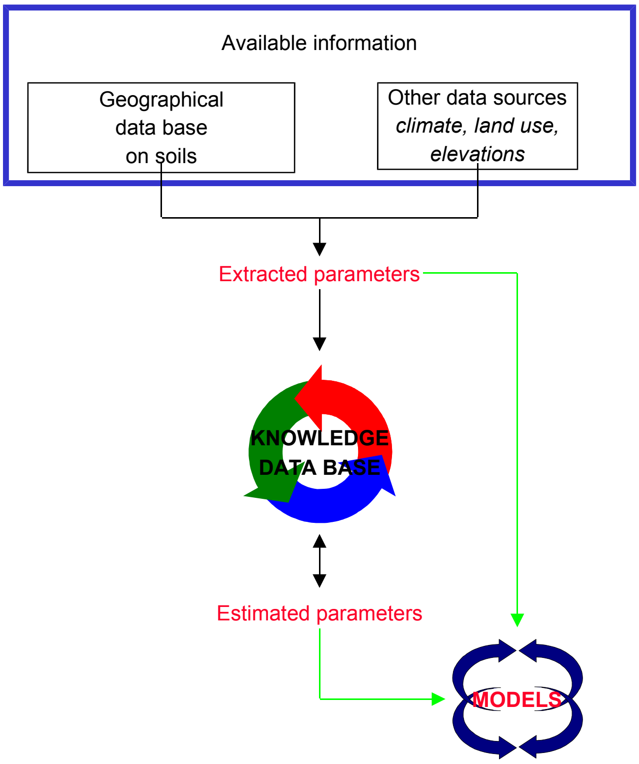


Figure 7. Diagram showing the steps for the elaboration of pedotransfer rules

More detailed databases

The 1:250,000-scale Working Group represents the future of ESB activities. The group is working on the design and elaboration of a new European soil database at scale 1:250,000. The Chairperson of the group is Dr. P. Finke (ALTERRA, Wageningen, the Netherlands).

The 1:250,000 Georeferenced Soil database of Europe project started following a feasibility study by the Directorate General XI (Environment) (R. Dudal *et al.*, 1993). This study was commissioned to meet the growing demand for soil parameters in the context of environmental studies - for which assessment at regional or watershed levels seems the most appropriate - and to support databases already developed for the CORINE program, on land cover and bio types, at scale 1:100,000. Direct contacts with national soil survey offices and land research centres of the initial 12 EU Member States showed that national soil mapping coverage at more detailed scales ranged from 10% to 100%.

However in all the countries, some areas where found that have sufficient detailed soil mapping coverage. These areas could be integrated into a 1:250,000-scale soil map through generalisation perhaps supported by some additional fieldwork. Special attention was paid to soil and terrain attributes of greater interest for environmental protection.

Given the low availability of soil data suitable for preparing a more detailed soil map of Europe, it was determined that the goal of having " a wall to wall 1:250,000 soil map" or soil database could only be achieved in the long term. Therefore, a recommendation was made to carry out studies in small pilot areas with a high data coverage, with the aim to develop a methodology, a common legend and a common database structure for the final database at scale 1:250,000.

In order to initiate the project, a working group was created within the ESB. Its task was to prepare and write the Manual of Procedures (Finke *et al.*, 1999), to delineate the pilot areas and to provide overall scientific supervision of the project. From an operational viewpoint, the database will be created in selected pilot areas, each with a regional co-ordinator in charge of the territorial correlation for the project. Work has already started in different pilot areas. In the case of Italy, much of the whole country is scheduled to be covered using that methodology.

For this database at a more detailed scale, new concepts have been introduced. For example, the notions of:

- "soil body", which forms a portion of the soil cover, defined by soil attributes, and with "soil horizons" as components;

- "soilscape" that record spatial variability and form the basic map components;

- "soil regions", defined by associations of climate and parent materials.

The ultimate goal is to obtain a nested geographic soil database, going from the more detailed data that can be obtained at the individual farm level to the policy makers levels at European or world scale.

The figure below illustrates the «nested» database structure.

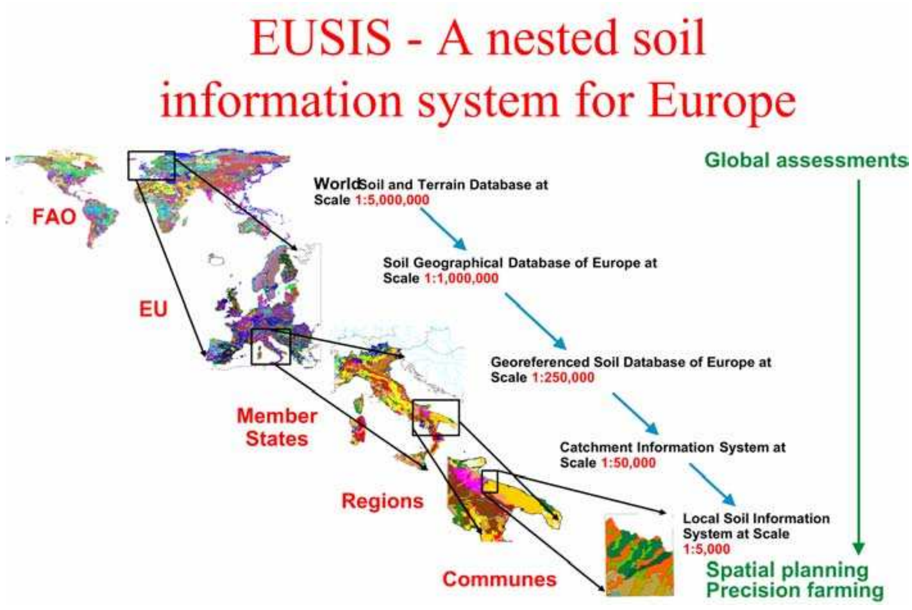


Figure 8. EUSIS nested structure

State of Progress

For the European Union countries the geographical database version 3.2 has been completed. The knowledge database and the analytical database are being updated. For the Central European countries, the geographical database is nearly complete and an analytical database is being developed. For some other countries, work on the geographical database has started. More countries will contribute in the future.

Concerning the PHARE countries, the current state of progress shows that work still remains to be done on border harmonisation. The principal efforts must bear on the «buffer zones», 50 km wide around each country. The main difficulties encountered concern the harmonisation with FAO soil name, but there are also problems with other attributes.

Figure 9. State of completion and projected extension of the 1:1 M database

Recently, in the profile database, nearly two hundred profiles were added, coming essentially from Bulgaria, the Czech Republic, Rumania and Slovakia. A new standard form has been created using MS Excel 5, accompanied by a data dictionary in order to facilitate a harmonised data entry.

Direct contacts have been established with Slovenia and Croatia to update the old data that came from the archives. The work is completed with Albania while with Kaliningrad territory is moving ahead nicely. Contacts have also been taken with Iceland.

On the basis of these accomplishments, the Commission has now decided to propose the extension of EUSIS to the NIS countries and to all the countries bordering the Mediterranean Sea.

Conclusions

A useful Soil Geographical Database at scale 1:1,000,000 is now available at the EU level and several projects have been asking to use it. Information in such a database is regularly updated when new information becomes available or when new territories are added. The European Soil Bureau is responsible for the management of this information. It ensures quality control of the updates and delivers user's licenses.

The 1:1,000,000-scale Soil Map, and then the several versions of the 1:1,000,000-scale Geographical Database made available harmonised data for diverse European projects, such an erosion risks study, monitoring of agricultural production monitoring, or water holding capacity mapping, heavy metals, Carbon storage, etc, (JRC, 1995; SAI-JRC, 1999). But considering the increasingly precise demands, quantitative information at more detailed scales is needed. One of the priorities is to elaborate a 1:250,000-scale soil database. This project is not only an improvement of the 1:1,000,000-scale database. It should also make use of new methods in order to develop more flexible and reliable information.

Moreover there is a need to go from collecting basic information to developing the necessary indicators for sustainable management of rural areas and, more generally, for protecting natural resources (water, air, landscape). Thus, development of methodological research on those indicators is an important objective, which require: data combinations, remote sensing use, natural process modelling, and linkage with monitoring networks.

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