A Proposal for the Compilation of a Soil Profile Analytical Database for West Africa

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Abstract

The digital map of West Africa at scale 1:5 million makes regional modelling using various pedo-transfer functions possible. The establishment of West African soil profile analytical database linked to an update of this soil map containing various soil properties, analysed according to standard methodologies, will strengthen the knowledge base on the physical environment in the region significantly. Based on the experience gained from the establishment of a similar database for Europe, a proposed methodology for a West African soil analytical database is outlined. Such database can prove an invaluable source of information for a wide range of agricultural and environmental interpretations.

Key words: Soil database, West Africa

Introduction

During the second half of this century, national or regional soil surveys have been carried out in many countries throughout the world including countries in West Africa. Only a few countries have produced national soil maps at medium to large scales (1:50,000 or larger.) However, in many countries minor parts have been mapped and published at large scales as 1:5,000, 1:10,000 and 1:25,000. The development of information technology during the last two decades has led to the computerisation of some national soil maps and, in the years to come, it is expected that most of the other national soil survey maps will be digitised.

Because of the incompatibility of different national soil classification systems around the world, an international soil legend was developed in the 1960s and 1970s by FAO (FAO-Unesco, 1974). As a result, soil map of the world at scale 1:5,000,000 was constructed according to this system (FAO-Unesco 1971-1980). The system has since been revised following various lessons learned form national and regional surveys such as the EC soil map at scale 1:1,000,000 (Commission of the European Communities, 1985). In 1988, a revised legend was published (FAO-Unesco-ISRIC 1988), but the soil map of the world at scale 1:5,000,000 was not revised in accordance with the new legend. A world soil resources map at 1:25 million scales was published instead (FAO, 1993a). In 1998, at the last ISSS congress, the world reference base for soil resources, WRB-systems, was launched (FAO-ISRIC-ISSS, 1998).

For West Africa, the FAO-Unesco soil map of 1974 at scale 1:5,000,000 is still the most comprehensive representation of the soils of the whole sub-region. A digital version of the

1974 soil map of the world is available (FAO, 1995) and contains various taxo-transfer[1] functions that allow the transformation of the soil map into various thematic maps such as those for soil suitability for specific crops, or the extent of soil erosion risk. For optimal use of the FAO Soil Map, particularly from an agro-ecological and environmental perspective, it will be necessary to build a soil profile analytical database containing geo-referenced information on texture, organic matter content, cation exchange capacity (CEC), electrical conductivity (EC), soil water retention and other important soil parameters. The development of such soil profile database is required to refine and adapt the pedo-transfer and taxo-transfer functions to regional conditions, and to allow the modelling of water movement in soils, nutrient circulation, fixation of heavy metals or transport of agro-chemicals, e.g. of pesticides.

Storage medium of soil databases

Few international soil databases have been compiled in digital form. The format and content may differ considerably between the various databases. For instance, the ISRIC-ISIS database (Van Waveren 1987; Van Waveren & Bos, 1988) and the multilingual SDB database (FAO-ISRIC, 1996) allow the storage of morphological as well as analytical properties. Proposals for a systematic collection of soil and terrain data have been developed at the International Soil Reference and Information Centre, ISRIC (Van Engelen & Wen, 1993), also published simultaneously as World Soil Resource Report 74 (FAO, 1993b). The system allows the storage of geographic (mapping units) as well as point information (analytical soil profile information).

In addition, a global soil analytical database has been compiled at ISRIC for the geographical quantification of soil factors and processes that control fluxes of greenhouse gases, under the title of World Inventory of Soil Emission potentials (WISE) (Batjes & Bridges, 1994). These data were then further supplemented by those collected by FAO and by the USDA-NCSC and after extensive filtering on reliability, a subset was released as the IGBP international Soil Profile dataset (IGBP-DIS, 2000), containing about 900 soil profiles. The whole dataset of more than 4000 soil profiles was also statistically analysed and average results published for each FAO soil unit-topsoil texture combination (Batjes *et. al.*, 1997).

Another system of database storage developed in French is called STIPA, and in West Africa, several countries such as Mali and Burkina Faso have stored a significant number of soil profile information in this format. Last but not least, the European Union developed an analytical soil database which contains physical and chemical properties as estimated data (Profoma I database) and as measured data (Proforma II database) as discussed by Madsen & Jones (1995). An overview of the main systems used to store the various soil profile information are given in Tables 1 and 2.

FAO Soil Map of the World.

The FAO Legend used in the soil map of the world (FAO-Unesco, 1974) is based on 26 major soils groups that are subdivided into 106 soil units. The definition of the soil types is based on the presence or absence of diagnostic horizons. Each map unit, occurring

[1] *A taxo-transfer function is the estimation of soil parameters based on modal soil characteristics of soil units, as derived from a combination of their classification name (taxon), expert knowledge, empirical rules and the analysis of a large number of profiles belonging to the same taxon*

with the limits of a discrete physiographic entity is described as an association of soil units. Each association is composed of a dominant soil unit and of subdominant associated soils, each of the latter covering at least 10% but less than 50% of the area. Important soils, that cover less than 10% of the area, are noted as inclusions. The percentage share of the dominant soil types, the associated soil types and the inclusions are derived as a function of the number of dominant, associated and included soils (FAO,1978). The topsoil textural class of the dominant soil and its slope class are given for each association according to the definitions in FAO-Unesco (1974). Slope and textural classes for the associated soils and the inclusions are derived from known

TABLE 1
Major Databases for storing soil information:

Name of database	*Reference*	*Language*	*Capabilities*
STIPA		French	Morphology and analytical
SDB	FAO-ISRIC	English, French, Spanish	Morphology and analytical
USDA-NCRS	USDA	English	Morphology and analytical
ISIS	ISRIC	English	Morphology and analytical
SOTER	UNEP-ISRIC-		
FAO-ISSS		English, French, Spanish	Geographical and analytical
WISE	ISRIC		Analytical (measured)
EU	ESB		Analytical (measured + estimated)

TABLE 2
Examples of soil information stored at national and international level

Country/Region	*Database system*	*Number of profiles*
Global WISE dataset	WISE	4700
International Pedon dataset	WISE	1100
USA + rest of the world	NCSR	15000(USA) + 5000 (rest of world)
Botswana	SDB	2500
Mali	STIPA	600
Europe	SPADE	Appr. 1000

relationships between specific soil types and the general landscape in which they occur and the example, Table 3, shows the description of the mapping units present in Liberia.

The map unit description Bg2-2a indicates that Bg (gleyic Cambisol) is the dominant soil type, while the figure '2' after Bg refers to the associated soils and inclusions. These are written on the back of the map, in this case Gd (dystric Gleysol) and Jd (dystric Fluvisol) as associated soils and Qc (cambic Arenosol) and Od (dystric Histosol) as inclusions. The figure to the right of the hyphen indicates the textural class: class 1 includes coarse textures with less than 18% clay and more than 65% sand; class 2 textures have less than 35% clay but does not belong to class 1: these are medium textured topsoils; whereas texture class 3 stands for topsoils having more than 35% clay (fine textured). Finally the slope class is given according to the following definition: a: less than 8%, b: 8-30% and c: more than 30%. In the example given the gleyic cambisol has a medium texture and is situated in a relative flat terrain.

An example that illustrates the composition and texture/slope rules for associated and included soils is as follows: Fo45-2b is composed of a dominant soil Fo with texture class 2 (medium); and slope class b (undulating, 8-30%) is indicated. As there are 2 soils associated and 1 soil included, the dominant unit is considered to occupy 50% of the mapping unit. Each of the associated soil units (Fx and Gh) will occupy 20% and the included soil (I) is considered to be medium textured by default, while Fx is

TABLE 3
Composition of the mapping units in Liberia

Mapping unit name	*Dominant soil unit*	*Associated soil units*	*Included soil units*
Fo45 – 2b	Fo-2b	Fx, Gh	I
Fo46 – 3bc	Fo – 3bc	Fr, Gh	Be, Jc, Nd
Fx7 – 3b	Fx – 3b	Ao and Fo	Ap
Fx12 – 2ab	Fx-2ab	Ao, Fp and Gh	Gd, I
Fh7 – 3b	Fh-3b	Fx and Gh	Fo, I
Fp6 – 2b	Fp – 2b	Fx	Gd, I, Nd
I-Fx-1ab	I-1ab and Fx-1ab		
I- Fo – 2bc	I-2bc and Fo-2bc		
Bf3	Bf		I
Bf3-2b	Bf-2b		I
Bf7-2b	Bf-2b	Bh, Fh	
Bg2-2a	Bg-2a	Gd, Jd	Qc, Od
Af5 – 1/2a	Af-1a and Af-2a	Ao, Nd	
Rd17 – 1a	Rd – 1a	Bf	I

B Cambisol; J Fluvisol; G Gleysol; I Lithosol; F Ferralsol; A Acrisol; Q Arenosol; N Nitisol; O Histosol; R Regosol.

considered to be coarser and has a "1" topsoil texture by default. However, the default slope class for each of them is different (FAO 1978): Fx is considered to have an "a/b" slope by default, Gh would have an "a" slope class while soil unit I would have a "b/c" slope. Note that when two slope classes are indicated (a/b,b/c), half of the soil unit is considered to fall in one slope class and the other half in the other. The full composition of soil mapping unit Fo45-2b is as follows: Fo –2 – b: 50%; Fx – 1 – a: 10%; Fx – 1 – b: 10%; Gh – 2 – a: 20%; I – 2 –b: 5%; I – 2 – C: 5%. This information if fully contained in a database that accompanies the digital version of the soil map of the world and rules are considered adequate for the scale at which they are applied.

The digitization of the FAO Soil Map and the application of the rules for composition and texture and slope distribution have resulted in several advantages. First and foremost, it has become relatively easy to make area calculations and reproduce maps at different scales. It is possible to make interpretations of the soil map on various themes, for example land suitability and environmental risk assessment (Lee, 1984, Jones & Biagi, 1989, van Lanen & Bregt, 1989). Furthermore it is possible to update the soil map very easily when new knowledge becomes available. For example in Europe a revised EU Soil Map for Denmark has been constructed (Madsen & Jensen, 1995), a new soil map for Germany, including the former German Democratic Republic (East Germany), has been constructed by Eckelmann & Adler (1994) and Hartwich *et al.* (1995), and King *et al.* (1995) have expanded the soil attributes to the EU-Soil Map based on archival studies and data from national representatives.

The FAO Soil Map is outdated for may countries as it was first published more than 25 years ago and is based on information mainly collected during soil surveys that took place in the nineteen sixties or before. An international effort, started in 1995 with support from various international organizations (FAO, UNEP, IIASA, ESB, ISSS, etc.), is under way to prepare a significant update of the global soil map by the next World Congress for Soil Science in 2002 (Nachtergaele, 1996), using the SOTER method. An overview of the present status and the operational plan is given in table 4.

The compilation of the soil profile analytical database.

The guidelines for the compilation of such database for West Africa could be similar to those adopted for the establishment of the and the operation; plan is given in Table 4. European soil profile analytical database (Madsen & Jones, 1995), which contains data from about 30 countries (Madsen & Jones, 1998). The database should be exclusively related to the FAO Soil Map of West Africa and the compilation should be based on the following principles:

The database should be compiled in phases, first a simple one (phase 1) which later can be expanded

West Africa should be divided into several regions: In phase 1, this could be the countries

In phase 1 a database containing one dataset from each soil type represented on the FAO Soil Map within the regions should be compiled

The compilation of the soil profile and analytical data by each West African country should be carried out according to a standard methodology.

The analytical data should be collected by local experts from national soil survey bodies or soil data centres.

TABLE 4
Operational plan for the world SOTER-shell: 1995-2002

Region	*Status*	*Main agencies involved*	*Publication*
Latin America and the Caribbean	Finalized	ISRIC, UNEP, FAO, CIATT, National Soil Institutes	Dec. 98
Eastern Africa	Finalized	FAO/IGAD	June 98
West Africa	Proposal	ISRIC, GTZ, IITA	?
Southern Africa	Ongoing	FAO/ISRIC/UNEP	Dec 2002
North and Central Asia	Ongoing	IIASA-FAO	Dec 1999
Southeast Asia	Project submitted, ongoing, awaits funding		?
Near East	Ongoing	FAO (Saudi Arabia, Yemen, Lebanon, Morocco, Mauret)	Dec 2001
Europe / FAO	Proposal Dec 2001	European Soils Bureau	
USA and Canada	Requested	NCSR	?
Australia	Requested	CSIRO	?

- The soil profile analytical database should contain mean values according to the standard methodology for typical soil profiles.
- Because the database proposed will be used for comparative studies in West Africa as a whole, a database should be completed in full, that means no missing data.
- The database should be completed by transforming measured data according to a methodology given in the guidelines or by using expert judgement where appropriate
- In the first phase, data from farmland soils should be compiled wherever possible.
- In Phase 2 the countries in West Africa could be subdivided according to geology, geomorphology, agro-ecological regions, land use and so on, with a separate data set for each subdivision.

Number of soils present at different levels
The number of soil profiles that will be needed to build up the database should include at least the dominant soil types present in each country. However, it would be desirable eventually if analytical data also were present for soil types that occur only as associated or included soils. Following the European experience, a database comprising information from the dominant soil types only is called a level 1 database while at level 2 the database would also incorporate associated or included soils. A level 2 database would enable regional modelling of the kind described by Jensen *et al* (1998), who calculated the irrigation-need based on data from level 1 and 2 databases for

Denmark. Discrepancies of up to 50% were shown. Therefore, according to the European experience it is not advisable to compile a level 1 database but immediately to compile a level 2 database, which should be the phase 1 database for West Africa. For comparison the profiles included in level 1 and 2 database according to the European methodology for Liberia will be as follows:

Level 1 database:
Fo-2,Fo-3,Fx-2,Fx-3,Fh-3,Fp-2,I-1,I-2,Bf-2,Bg-2,Af-1,Af-2,Rd-1

Level 2 database:
Fo-2,Fo-3,Fx-2,Fx-3,Fh-3,Fp-2,I-1,I-2,Bf-2,Bg-2,Af-1,Af-2,Rd-1.
Gh-2,Fr-2,Be-2,Je-2,Nd-2,Ao-2,Ap-2,Gd-2,Bh-2,Fh-2,Jd-2,Qc-1,Od,Bf-2.

The number of level 1 profiles normally differs from the number of mapping units because two mapping units might for example have Bf-2 as the dominant soil type and it is not necessary to give more than one analytical data set. On the other hand, the dominant soil type Af-1/2 needs two analytical data sets, one for textural class 1 and the other for class two. Building up a level 2 database will increase the number of profiles significantly. At a later stage a level 3 database might be compiled. West Africa could be divided into several regions according to differences in parent material, climate, geomorphology, vegetation and topography. Each region could have its own set of soil analytical data, though some data might be identical for more than one region.

Guidelines and proformas

Guidelines and proformas for compiling the soil profile analytical database should be drawn up by a committee of experts from the different countries involved. This committee would need to decide on the following:

1) The analytical data which should be included in the database;
2) The details of the analytical methods to be used in producing the data;
3) Whether the database should include estimated data and/or measured data;
4) The format that should be used;
5) The organisation of the data collection process;
6) The ownership of the data.

Furthermore, the committee members should also adjust the FAO Soil Map so that each soil type present in a mapping unit has a texture class and the proportion of each soil type within a mapping unit is defined more correctly than the expert rule now applied. Harmonization exercises should be organized to correlate soil units and mapping units across national borders. Another important aspect is to adapt the classical soil map to the possibilities offered by GIS systems and relational databases, which allow to represent soils in their landscape context. Adoption of an internationally endorsed methodology such as the one undertaken in SOTER or the closely related European mapping approach is strongly recommended.

For the West African database, the following analyses could be included for the soil horizons:

Texture, organic matter content, structure, total nitrogen content, pH, ESP or SAR, Calcium carbonate content, calcium sulphate content, electrical conductivity, CEC and exchangeable bases, soil water retention, bulk density, root depth, groundwater level, parent material, hydraulic conductivity, KCl-soluble Al, phosphorus, and oxalate-extractable Al and Fe.

At a latter stage, other types of analyses such as X-ray determined mineralogical content could be added.

National experts would be responsible for collecting the information for the soils from their respective countries and completing the proformas in full, by transforming measured data according to the methodology in the guidelines. It may be necessary for them to use expert judgement to produce complete data sets in some cases. The soil profile data recorded on the proformas would be from actual profiles as well as modal ones. Therefore, the origin of the data must be indicated as follows:

- Averages from a number of profiles;
- Data from a single representative profile;
- Predictions derived from mathematical functions (pedotransfer functions);
- Predictions derived from class functions (pedotransfer rules);
- Expert judgement.

The elaboration of the proformas, the analytical data to be included and agreement on the common analytical procedures are tasks that are the responsibility of the expert group and must be resolved before compilation of the database can begin. Compilation of the European Soil Profile Analytical Database could be an example, but the guidelines for the European database will need to be modified for use in West Africa because of differences in soil forming processes and the resulting soil types. West Africa contains e.g. a range of climatic zones from the wet tropics with old strongly leached Ferralsols to deserts with halomorphic soils.

Example of an international soil analytical database for Europe

At the end of the 1980's, a 10-year research project MARS- Monitoring Agriculture with Remote Sensing (Meyer-Roux & Montanarella, 1998) was initiated. One of the research activities was the establishment of a system for forecasting the yields of the agricultural crops in the countries of the EC. Under this specific action, a Soil and Geographical Information Systems (GIS) Support Group was established with the objective of studying the pedological parameters that, when combined with other environmental data at a scale of 1:1,000,000, would enable the yield forecasting models to operate at EU-scale. The basic data for the project included the EC Soil Map at scales 1:1,000,000. In addition, MARS required precise estimates of the water holding capacities of soils and these were not directly available from the map. The Soil and GIS Support Group evaluated the archives used in preparation of the EC Soil Map and proposed work plan for updating the description of the cartographic units such that other parameters could be derived. Under an EC research contract, a number of pedotransfer functions or rules were established (Van Ranst *et al.,* 1995) for mapping the available water content in the root zone, modelling the water balance and estimating other soil attributes.

The proposal for the establishment of a soil profile analytical database emerged during the early meetings of the Support Group in Ispra and Ghent in 1991. The experts attending these meetings agreed that two analytical databases should be compiled; one based on estimated data for modal soils (Proforma I) and one on existing (measured) data, (Proforma II) from representative profiles. The parameters proposed for inclusion was texture, organic matter, C/N, lime content, pH, electric conductivity, exchangeable bases, CEC, sodium percentage (ESP), SAR and soil water retention. Some parameters were excluded because of lack of data e.g. hydraulic conductivity and heavy metals. Guidelines for compiling the necessary data were drafted in 1992 and proformas were constructed as spreadsheets in Microsoft Excel.

The system was tested in 1992 and implemented at the end of February 1993. Initially 12 EU- countries were involved. National representatives completed the proformas some being retuned on paper others on diskette. The data on paper had to be key punched for storage on computer. Today some data are still missing but efforts are under way to fill the gaps. In March 1995, a 2-year project extension of the European Union Soil Profile Database started. The aim was to collect profile data for the following European countries: Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria, Switzerland, Austria, Norway, Sweden, Finland, Estonia, Latvia, Lithuania, Slovenia, Croatia and Albania (Jamagne *et al.,* 1995, and Madsen & Jones, 1998)

Some soil characteristics, which are of great importance for the agriculture or the environment are not currently included in the soil profile analytical database. The presence of plinthite (depth, thickness, etc.) and other types of cementation, stoniness, fragipans, etc. are information of great value when assessing land suitability. Thus, the establishment of a soil profile description (morphological) database would strengthen the system significantly. Such a database connected to the European soil map has never been developed and compiled.

Final remarks

The paper outlines a method for elaboration of a comprehensive soil profile analytical database for West Africa connected exclusively to the update to be made for the FAO-soil map at scale 1:5.000.000. The principles proposed for its compilation follow those adopted for the European soil profile analytical database. Such a database system will be of great importance for regional modelling of agricultural and ecological problems. The compilation of the database cannot be carried out without adequate funding It also needs a strong and firm management. It is important that all participants follow the common rules and complete the proformas according to the guidelines. Data storage must be standardised for all countries.

The establishment of this comprehensive soil database system will be a big challenge for the soil scientists in West Africa. It will encourage cooperation at an organisational as well as a scientific level. It will facilitate exchange of views on edaphological and pedological problems within the region and bring about agreement on common methodologies for characterising soil profiles. Furthermore, it will enhance the state of soil knowledge among soil scientist in West Africa.

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