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A multilingual soil profile database (*SDBm Plus*) as an essential part of land resources information systems

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Abstract

The multilingual soil profile database (named *SDBm Plus*) is user-friendly software designed to store and retrieve in an efficient and systematic way the large amounts of geo-referenced soil attribute data collected in soil surveys and laboratories. The database has the following main characteristics: (i) running on Windows platforms; (ii) 'assist menus' facilitating data entry; (iii) automatic translation from English to Spanish, French and German; (iv) metadata facility to describe the methods used in laboratory analysis; (v) temporal mode to collect over time the analytical, physical and hydraulic soil properties; and (vi) interface for the automatic transfer of soil attribute data to GIS and computerised land evaluation models. The following soil attribute datasets are included in *SDBm Plus*: (i) site characteristics, information related to the identification and taxonomic classification of the soil profile; (ii) horizon description; (iii) conventional soil survey analytical results; (iv) soluble salts and most trace elements present in the soil or considered as major soil contaminants; (v) general soil physical analytical results; (vi) water retention and hydraulic conductivity at different tensions; (vii) photographs; and (viii) analytical methods and procedures used. This database can be used in soil monitoring and evaluation regardless of scale (regional, national or local), and especially to implement tools on choosing optimal land use and management decisions in sustainable agriculture development.

Keywords: Soil survey; Land evaluation system (LES); Relational database management system (RDMS); Geographic information system (GIS); Land resources information system (LRIS)

Software availability

Availability: The FAO-CSIC Multilingual Soil Profile Database (SDBm Plus) is available free of charge through the FAO/AGLL Internet site: http://www.fao.org/WAICENT/FaoInfo/Agricult/AGL/Aglhomep.htm or the CSIC/IRNAS Internet site: http://www.microleis.com (software and documentation).

1. Introduction

Soil resource surveys, as a preliminary stage of land evaluation processes, generate large quantities of data from both field description and laboratory analysis. Commonly, their potential to generate useful information, through land evaluation systems (LES), has only been exploited to a minimal extent because of the data handling limitations of manual methods of analysis.

Recently, these tasks have been facilitated and simplified by land resources information systems (LRIS), which comprise two basic components: a geometric database and an attribute database. The geometric or spatial database comprises records of the location and extent of an object represented by a point, line or surface, and is handled by Geographic Information System (GIS) software. The attribute database is geographically referenced, describes the characteristics of the object and

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enables (i) the application of standardised procedures, (ii) the extrapolation or aggregation of analyses and interpretations, and (iii) enhanced repeatability of analyses and results. A Relational Database Management System (RDBMS) is used to manipulate the attribute database. The two LRIS components are integrated to enable the development of interpretative processes including the preparation of maps.

The increase in process modelling of soil erosion, water and solute transport in soils has imposed a demand for accurate measurements of salt and metal contaminants and hydraulic properties of representative soils. An alternative to the direct and often difficult procedure of these special measurements is their estimation using pedotransfer functions. Pedotransfer functions relate special properties to more easily measured or estimated soil data such as soil texture, organic matter and other data routinely collected by soil survey. A prerequisite for deriving pedotransfer functions is the availability of databases including basic soil data and soil spatial properties from a wide range of soils (Wösten, 2000).

All of these emerging technologies in data and knowledge engineering provide excellent practical possibilities in the land resources evaluation process. It basically involves the development and linkage of integrated database which, along with pedotransfer functions, spatialisation tools and computer programs for automated land evaluation models, constitute sustainable land use and management decision support tools. Recent developments of this kind carried out in many European national institutions, along with the continental perspective of the European Soil Bureau, are described by Heineke et al. (1998).

Over the last two decades the Food and Agriculture Organization (FAO), within the framework of the Agro-Ecological Zoning (AEZ) programme, has developed computerised systems for inventory, evaluation and planning of land resources, especially for use in developing countries. The purpose of zoning, as carried out for rural land use planning, is to identify and delineate areas with similar sets of potentials and constraints for development. AEZ defines zones on the basis of soil, landform, climate and land use characteristics integrated in a GIS (Antoine, 1994). For surveys of land resources, a physiographic approach is also recommended, which integrates landforms, soils and vegetation (SOTER programme: FAO, UNEP and ISRIC, 1995). In collaboration with the United Nations Environment Programme (UNEP) and other national and international institutions, FAO has recently developed an improved framework for sustainable land resources development and management that addresses the evolving nature of integrated land management (FAO and UNEP, 1999)

The *SDBm Plus* database has been developed through a joint FAO–CSIC project. It draws on the initial FAO–ISRIC project (SDB database; Van Waveren, 1989) and the subsequent FAO–ISRIC–CSIC project (SDBm database; Antoine et al., 1995). These former versions were developed for MS DOS in CLIPPER language; whereas the present development, in C++ language (BORLAND C++ Builder, Version 5, Borland International, Inc., 2000) for MS Windows, focuses on the following innovative aspects: enlarged multilingual ability and automatic translation into widely used languages; use of several taxonomic classifications including conversion function; consideration of hydraulic properties, heavy metals data and photographic information; recording of temporal variability of soil properties; derived variables option by using pedotransfer functions; metadata facility for detailed description of analytical methods; high-quality reports and graphics presentations; and interface facility to generate output files to be used in the LES/GIS-based models; as summarised in Fig. 1.

In this paper, the scientific concept and software development of *SDBm Plus* are described, although the database system is an open project under continuous development.

2. Structure and configuration

2.1. Variable types

2.1.1. Stored variables

The soil profile characterisation used in the *SDBm Plus* system was basically developed according to the Guidelines for Soil Profile Description (FAO and ISRIC, 1990). Also, the system includes listings of the main soil taxonomic classifications (FAO, 1974, 1990; USDA, 1987, 1998; FAO, ISRIC and IUSS, 1998). A function that allows one to translate soil type data from one taxonomic classification system into another is being developed according to the availability of the required translation keys.

As shown in Fig. 2, the field and laboratory information on a soil profile is grouped into the following data blocks:

Block 1: *General information*. The characteristics of the soil profile site as well as its identification and classification. A total of 62 variables.
Block 2: *Soil horizon description.* Information on the soil morphological and other characteristics of each horizon. A total of 54 variables.
Block 3: *Standard analyses.* Information on the standard analytical results for sampled horizons. A total of 33 variables.
Block 4: *Soluble salts and Heavy metals*. Information on the main soluble salts in the soil and on the most important trace elements related to soil contamination. A total of 27 variables.
Block 5: *Physical data*. Information on soil physical

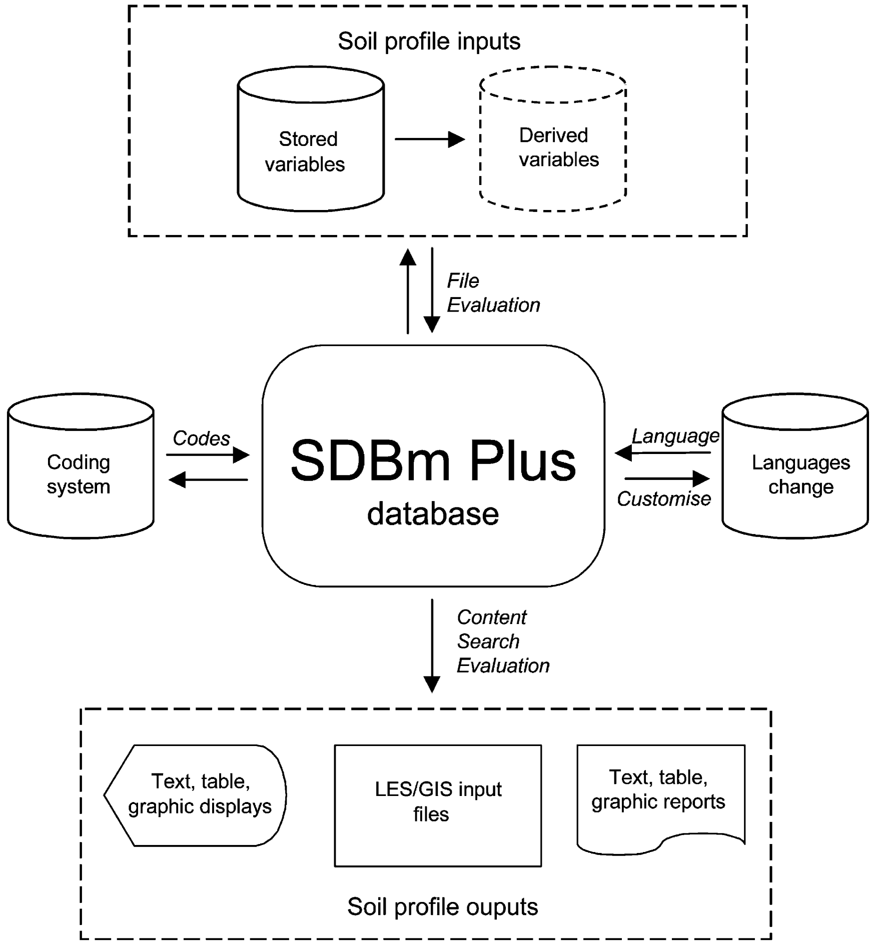

Fig. 1. General scheme of the *SDBm Plus* database.

determinations that are used as input data for crop simulation models and land evaluation systems. A total of 9 variables.

Block 6: *Water retention and Hydraulic conductivity*. A total of up to 25 determinations per soil sample quantifying the detailed hydraulic properties for use in mechanistic simulation modelling. A total of 5 variables.

Block 7: *Additional analytical variables*. A total of up to 10 specific soil characteristics, such as: soil cohesion, internal friction angle, preconsolidation stress, void–load relationship, etc. A total of 10 variables.

Block 8: *Photographs*. Digitised information on site, soil profile and other plates. A total of 4 photos.

Block 9: *Metadata*. Information on the procedures and methods followed in elaborating soil analysis data. A total of 78 methods.

The blocks should be seen as distinct datasets, which can be manipulated independently. For instance, for a certain soil profile, only the analytical results may be entered, updated, printed or selected.

2.1.2. Derived variables

A set of non-stored variables can be calculated using pedotransfer functions through the evaluation interface facility in the *SDBm Plus* system. Soil mechanical and hydraulic properties, the determination of which is difficult or time-consuming, can be estimated from more readily available simple data obtained during soil surveys using several approaches. This set of soil variables corresponds to:

Block 10: *Derived variables*. Information calculated using pedotransfer functions.

2.2. Data type

The soil profile data stored in the *SDBm Plus* database are of the following types:

Coded data. General and horizon information is largely stored in a coded format according to the SDB coding system. This system is flexible and is part of the data-

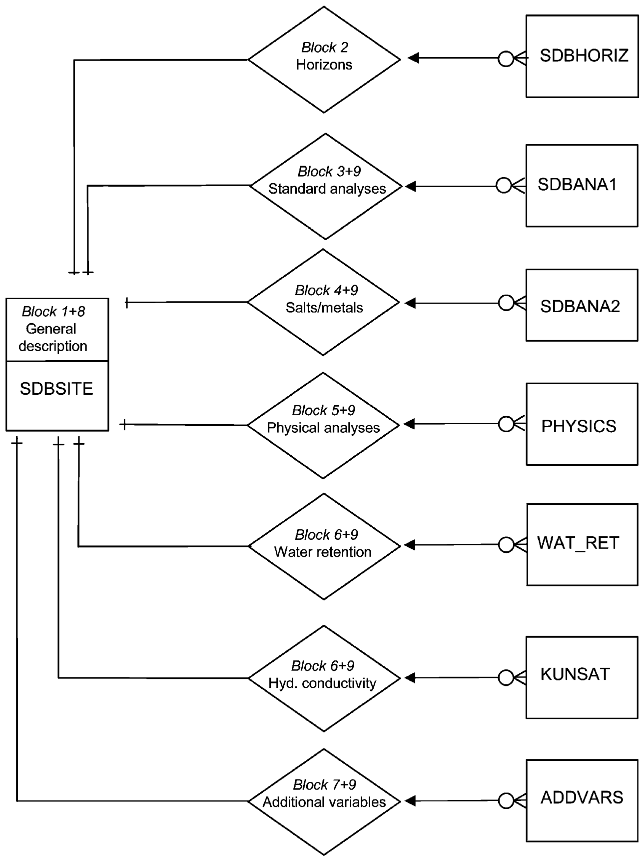

Fig. 2. Structure of the *SDBm Plus* database tables.

base. It contains a set of default classes and codes; however, changes or additions can be made.
Numerical data. Laboratory data are predominantly stored in a numerical format.
Text data. Text or descriptive data, such as comments, are stored exactly as entered.
String data. Some variables are stored as a string of characters plus digits of limited size.
Binary data. Photographs are stored in JPEG format.

2.3. Data organisation

In the *SDBm Plus* database system, the different datasets for a soil profile are organised according to a set of database tables (Fig. 2) and the following connectors:

Profile code. The soil profile code, containing 6 digits (e.g. SE0123), is particularly important since it identifies the information in each block of data, links the data blocks and connects them to the profile site.
Horizon number. A soil horizon in a soil profile is referenced by the horizon number (e.g. 1, 2, 3, etc.), although in the database it is referenced by the combination of profile code and horizon number. This one-to-many relationship means that several horizons belong to a single soil profile.
Sample code. A soil sample in a soil profile is referenced by the sample code (e.g. A, B, C, etc.). The analytical dataset maintains a one-to-many relationship with the general information through the profile code; a record is defined in the dataset by combining profile code and the sample code.
Date. Standard analyses, soluble salts and heavy metals, physical analyses, and water content and hydraulic conductivity data all maintain a one-to-many relationship with the general information; but also, the designation of a sample is made through the combination of the profile code and the sample code, plus the date when the sample was taken or the in situ determination was performed (e.g. 2000-01-10). With this feature, the *SDBm Plus* dataset also has a temporal reference since many soil properties change with the seasons as well as with more extended periods of time.

2.4. System requirements

The minimum software and hardware configuration required for installing *SDBm Plus* is the following: IBM compatible PC computer 486; 16 MB RAM; 10 MB free disk space; colour monitor; graphics adapter supporting 800×640 pixels screen resolution; MS mouse or other compatible pointing device; and MS Windows 95. A computer with a faster processor and more board memory is recommended if the program is expected to be used frequently. *SDBm Plus* supports the option to work on local area network.

The *SDBm Plus* system software and user manual are distributed on CD-ROM. Also, this system is available free of charge through the FAO/AGLL Internet site: http://www.fao.org/WAICENT/FaoInfo/Agricult/AGL/Aglhomep.htm or the CSIC/IRNAS, MicroLEIS Group, Internet site: http://www.microleis.com. It is intended to publish the user manual in English and Spanish as a FAO World Soil Resources Report.

3. Key features and outputs

3.1. Main menu

The *SDBm Plus* database is a standard Windows application using the regular control functions. Upon entering the database, a start-up window with a main menu appears on the top of the screen with the following main options: File, Codes, Content, Search, Customise, Language, Evaluation and Help.

3.2. Main option: file

This *SDBm Plus* main option enables the database operations related to the entry and exit of soil data.

3.2.1. *Input/edit/delete*

This sub-option is used to enter new soil profile descriptions and laboratory data into the database. An example of an input data screen is shown in Fig. 3.

The coded general and horizon information is entered according to the coding system (Main option: Codes) and making use of the pop-up windows. In order to facilitate data entry tasks, normally tedious and slow, these pop-up tables, which are arranged alphabetically by definition, can be displayed for each coded variable.

The edit screens are identical to the input data screens and work in the same way. The only difference between them is that the edit screens contain the actual information of the site, horizon or sample to be changed, whereas the input data screens are empty.

The delete sub-option is used to remove all information stored under a particular soil profile code from the database, or any input data screen from a particular soil profile.

In the *SDBm Plus* system, special attention is given to the harmonisation of soil analytical techniques among the different institutions; thus, it is possible to specify the corresponding metadata or method used for each analytical data item.

3.2.2. *Import/export*

Available data on a single soil profile or a series of profiles may be imported into the *SDBm Plus* database. The import file formats accepted are: Paradox from SDBm Plus databases, and dBase from SDBm databases.

In the export sub-option, a series of stored soil profiles can be transferred from the *SDBm Plus* system to other general or soil-specific databases such as MS Access, ARCVIEW or MicroLEIS models. Two formats are supported: Paradox and ASCII.

3.3. *Main option: codes*

This *SDBm Plus* main option facilitates effective database management of most of the descriptive field data to be stored in a coded format. Storage of coded data and metadata reduces the size of the database and, what is equally important, it standardises the descriptive data and thus allows for selection, comparison and validity checking.

The coding system includes the class codes and definitions of all the generalisation levels of each coded variable. It follows the Guidelines for Soil Profile Descriptions (FAO and ISRIC, 1990), although the classifications of the variables are not fixed. Each conversion table can be edited interactively. This means that codes can be added, definition terms can be changed, and codes and definitions can be removed from the classification of each variable. Consequently, the default *SDBm Plus* coding system for the site and horizon description, and for the metadata references, can be enhanced and updated by the user.

The coding system, which forms an integral part of the *SDBm Plus* system and is stored in a number of conversion tables, is also used to develop the multilingual dimension of this database system. As shown in Fig. 4, the first field of the conversion table contains the code item, whereas the following four contain the definition

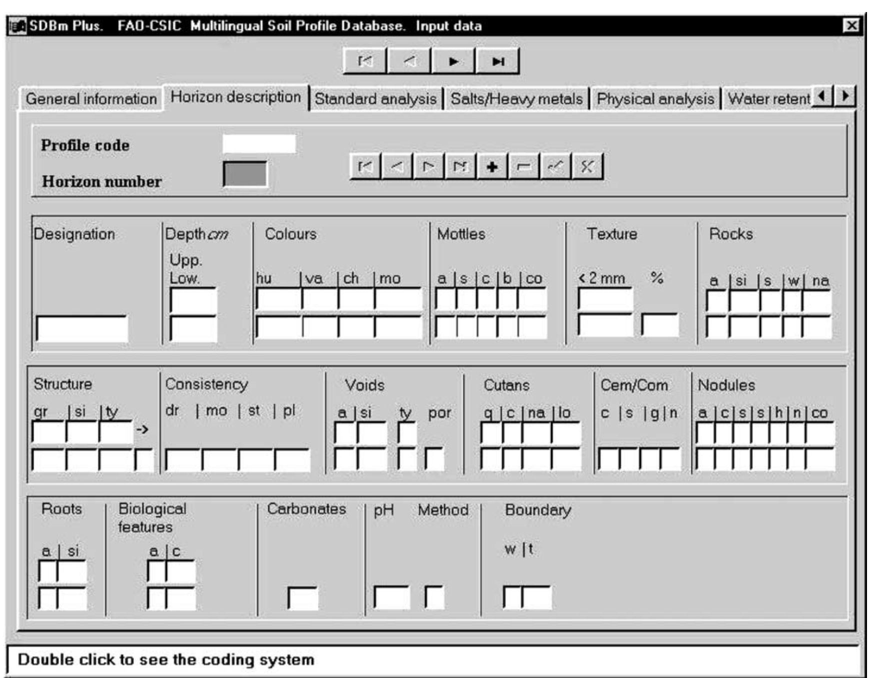

Fig. 3. Example of an input data screen.

CODE	LANDFORM	GEOMORFOLOGIA	GEOMORPHOLOGIE	GEOMORPHOLOGIE
PL	plain	llano	plaine	Ebene
AP	alluvial plain	llano aluvial	plaine alluviale	alluviale Ebene
LP	lacustrine plain	llano lacustre	plaine lacustre	Ebene aus Seesedimenten
CP	coastal plain	llano costero	plaine côtière	Küstenebene
UP	upland	sierra	chaîne de montagne	Hochland
GP	glacial plain	llano glacial	plaine glaciaire	glaziale Ebene
DU	dunefield	campo de dunas	champ de dunes	Dünenfeld
PN	peneplane	penillanura	pénéplaine	Fastebene, Penepläne
PT	plateau	meseta	plateau	Plateau, Hochebene
PE	pediment	piedemonte	pédiment	Bergfußniederung
HI	hill	colina	colline	Hügel
VA	valley	valle	vallée	Tal
MO	mountain	montaña	montagne	Berg
VO	volcano	volcán	volcan	Vulkan
LA	lava plain	llano de lava	plaine de lave	Lavafeld
DT	delta	delta	delta	Delta
BA	basin	cuenca	bassin	Becken
TF	tidal flat	llanura mareal	slikke	Watt
PY	beach	playa	plage	Strand
FG	fluvio-glacial plain	llano fluvio-glacial	plaine fluvio-glaciale	fluvio-glaziale Ebene
SP	sand plain	llano de arena	plaine de sable	Sandebene

Fig. 4. Example of a conversion table in English, Spanish, French and German for the coded variables.

terms in the working languages: English, Spanish, French and German.

3.4. Main option: content

All the database content can be visualised or printed in different formats (text, photographic, tabular and graphic) using this *SDBm Plus* main option, which represents the database results on screen or printout.

3.4.1. Soil profile characterisation

The list of soil profiles stored in the database can be displayed and printed along with the total number of stored profiles. Selecting from this list of stored soil profiles, this sub-option allows users to view individual soil profiles on screen or to obtain printouts of standard morphological description and analytical data tables. The soil profile description report responds to the internationally accepted conventional format (Fig. 5), and can also be supplemented with photographs of site and soil profile.

3.4.2. Graphical presentations

This function calculates and displays the following graphics from the analytical data tables: vertical distribution of the analytical variables, and tension vs. water content or hydraulic conductivity (Fig. 6a, b). In the vertical distribution, the x-axis shows the values of the variable examined and the y-axis the depth of the samples. In the tension vs. hydraulic properties, up to 25 entries can be displayed.

This application, as screen display or printout, helps in the characterisation of a soil profile and facilitates comparison with other soils.

3.4.3. Statistical summary

This function, applied to a selected set of soil profiles and analytical variables, presents a table with the following preliminary statistical indicators: number of samples, average, maximum and minimum values, standard deviation and coefficient of variation.

3.4.4. Metadata report

From the analytical data tables, it is possible to view the analytical method used for each determination. Also, a metadata report can be printed containing all the laboratory methods used in the analytical characterisation of any soil profile.

3.5. Main option: search

This *SDBm Plus* main option is used to select soil profiles based on the presence of one or more variables with specified values.

3.5.1. Fast search

This procedure should be used if a search is made using one, or a combination of two, of the following key soil variables: profile code, taxonomic classification, soil unit, profile status, administrative unit and geographic coordinates.

3.5.2. Detailed search

This procedure is used to select by any field or laboratory characteristic, or combination of these. Firstly, the appropriate datasets or block(s), and the key variable required must be activated. A second key variable of the same block may be selected. Then the search code or numerical value must be entered, along with the selected comparison operator.

SDBm Plus. FAO-CSIC Multilingual Soil Profile Database.

SOIL PROFILE DESCRIPTION

Profile code : SE0305	**Date :** 1976-06-01
Sheet / grid : 1020 /	**Coordinates :** N370700 / W 054720
Survey area :	**Elevation :** 18 m
Location : Finca El Pinganillo. Utrera.	**Administrative unit :** La Campiña
Authors : J. L. Mudarra, J.L. Arrue	
FAO 90 classification : Calcic Vertisol	**Soil climate :** Xeric thermic
USDA 87 classification : Typic Pelloxerert	**Local soil classification (serie) :** Tierra Negra
Land use : Annual field cropping	**Topography :** Flat
Human influence : Ploughing	**Land form :** Plain
Crops : Wheat	**Land element :** Depression
Vegetation : No vegetation	**Position :** Intermediate part
Species :	**Slope :** 2 - 8%
Grass cover :	**Micro topography :** Gilgai
Parent material : Marine deposits	**Drainage :** Imperfect
Effective soil depth: >150 cm	**Water table :** Not observed
Rock outcrops : Nil	**Flood :** Rare
Surface stoniness : Nil	**Moisture conditions :** Dry
Erosion : Sheet erosion	
Sealing / crusts : Nil	

Remarks : ARRUE UGARTE, J.L., 1976. Factores químicos, fisico-químicos y físicos determinantes de los caracteres, propiedades y dinámica de la porosidad de los suelos. Tesis Doctoral. Universidad de Sevilla.

Horizon	Depth, cm	Morphological description
A p	0-30	Very dark gray (10YR 3/1) (moist) and Light gray to gray (10YR 6/1) (dry); clay; weak medium subangular prismatic parting into fine structure; hard in dry and friable in moist, sticky and plastic in wet; high porosity, many Voids fine, many voids very fine; common nodules calcareous white hard; strongly calcareous; common biological activity; abundant fine roots and abundant medium roots; clear smooth boundary.
B 21	30-48	Dark gray (10YR 4/1) (moist) and Light gray to gray (10YR 6/1) (dry); clay; weak medium structure; very hard in dry and firm in moist, very sticky and very plastic in wet; few slickensides on pedfaces Cutans; high porosity, common Voids fine, common voids very fine; common nodules calcareous white hard; strongly calcareous; many biological activity; abundant fine roots and abundant medium roots; diffuse smooth boundary.
B 22	48-82	Dark gray (10YR 4/1) (moist) and Light gray to gray (10YR 6/1) (dry); clay; moderate medium structure; very hard in dry and firm in moist, very sticky and very plastic in wet; common distinct slickensides on pedfaces Cutans; few Voids fine, common voids very fine; strongly calcareous; common biological activity; common fine roots; diffuse smooth boundary.
C 1	82-	Very dark gray (10YR 3/1) (moist) and Light gray to gray (10YR 6/1) (dry); clay; strong medium structure; very hard in dry and very firm in moist, very sticky and very plastic in wet; low porosity, few Voids fine; strongly calcareous; very few biological activity; few fine roots and few very fine roots.

Fig. 5. Example of a soil profile morphological description printout: Standard description.

3.6. Main option: customise

This *SDBm Plus* main option is used to tailor the database to meet the user's needs. Up to ten blank additional variables may be defined (Block 7: Additional analytical variables). This allows for the description of special soil features that are not covered by the basic variable blocks, such as soil cohesion, internal friction angle, pre-consolidation stress, etc. These additional variables contain only numeric data, and once the variables are activated they can be used just like any other basic variable. They may be printed, shown on data screens or used for selections.

On the contrary, if not all of the soil information available in *SDBm Plus* is to be entered, this function allows users to deactivate unnecessary fields, which will then disappear from the 'Input/Edit/Delete' screens. This makes data entry faster and easier.

3.7. Main option: language

This *SDBm Plus* main option enables the user to select or create a new working language. The default language used is English, and currently the database can also be used in Spanish, French and German. It is foreseen that the future software expansion will include other languages.

In order to establish the grammatical rules for the sentences, especially in the horizon description, the language group: Romance (Spanish, French, etc.) or Germanic

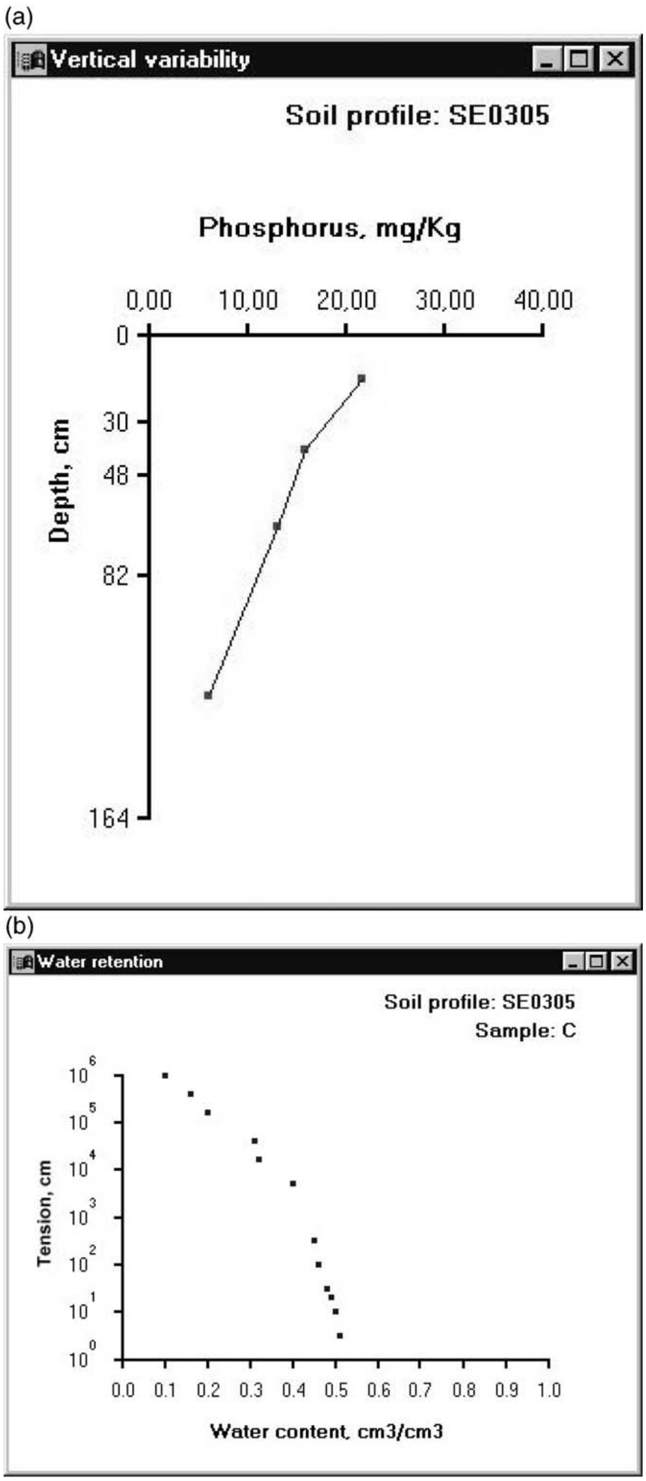

Fig. 6. (a) Example of a soil profile graphical presentation printout: vertical variability. (b) Example of a soil profile graphical presentation printout: tension vs. water content.

(English, German, etc.) must be specified for each new language. Upon selecting a different language, the program changes the memory variables to those of the new language selected.

3.8. Main option: evaluation

In order to develop computerised land resources information systems (Fig. 7), this main function of *SDBm Plus* facilitates the user to formulate and apply pedotransfer functions and generate LES/GIS input data files.

3.8.1. Pedotransfer functions

This option allows the formulation of regression pedotransfer functions in order to calculate dependent variables (Block 10: Derived variables), which will be used in the input file generator along with the stored basic variables . It uses the following variable groups as independent variables: Block 3: Standard analyses, Block 5: Physical data and Block 7: Additional variables. Therefore, any kind of statistical model can be used in order to estimate target variables such as soil hydraulic properties (e.g. Van Genuchten parameters; Simota and Mayr, 1996).

3.8.2. LES/GIS input file generator

This function generates LES/GIS input data files bearing the following aspects: range of profiles; list of the

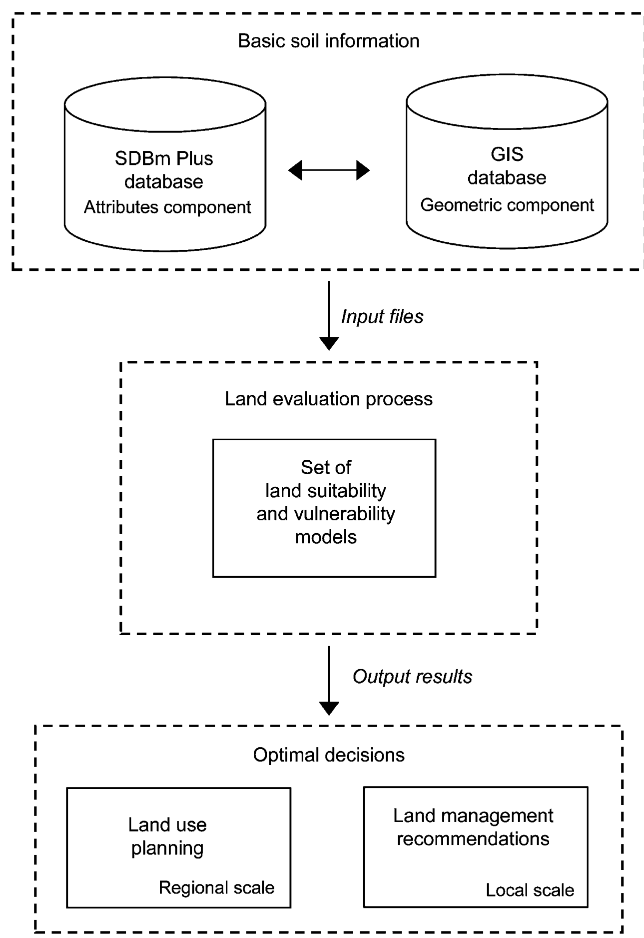

Fig. 7. General scheme of a land resources information system as decision support tool in agricultural development and planning.

soil profiles to be included in this analysis; soil characteristics, basic and derived variables to be analysed; control section, layer thickness or the control section to be analysed within the vertical soil profile; form of calculation, type of calculation, such as weighted average or dominant value; type of export file (ASCII format or dBASE format) which can be produced.

The main data file result is a matrix having as many rows as the number of selected soil profiles and as many columns as the selected soil variables. Also, a set of descriptive files is generated which explain the codes used in each coded variable selected, along with the corresponding analytical metadata. These generated data files facilitates the linkage of basic soil data to land evaluation/geographic information systems as considered, for example, in the MicroLEIS system (De la Rosa et al., 1992; De la Rosa, 2002).

3.9. Main option: help

This main function is used to display the *SDBm Plus* information included in the user manual in HTML format (HTML Report, Version 3.1, ProGa, Inc., 2000; English and Spanish versions) with a total of about 160 pages, and 37 figures of the most representative database screens and printouts. Five appendices contain the list of variables, the complete coding system in English, Spanish, French and German, a large list of soil analytical methods, a set of database labels in the four languages, and detailed technical information.

4. Concluding comments

The *SDBm Plus* Relational Database Management System for Windows described above represents a useful tool for soil characterisation and in connection to land use planning.

SDBm Plus has been developed to enable detailed characterisation of any geo-referenced soil profile, in any part of the world and in any of several languages. The coding system includes most of the generalisation levels for every input soil variable, including the taxonomic soil classification most frequently used. However, it is possible to enlarge the codes to any local generalisation level, to define new input variables and to translate the system into a new language. Presently, the database can be operated in English, Spanish, French and German.

SDBm Plus facilitates the use of the stored soil data in the application of pedotransfer functions and land evaluation systems in order to predict soil quality and soil degradation. It allows the design and implementation of environmental decision support systems. This database also takes into account most of the soil properties with temporal variability to be analysed through monitoring systems.

SDBm Plus remains open for future development and improvement, including translation to other languages, interfaces with innovative soil information systems, or adaptation to the Linux operating system and the development of on-line Internet versions.

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