The Soils and Terrain Digital Database (SOTER) as a Basis for Development

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Abstract

A case is presented for the use of a soils database which is capable of storing and handling information at different scales of operation. Such a system, a World Soils and Terrain digital database (SOTER), has been developed at the International Soil Reference and Information Centre (ISRIC) for use at a global scale as well as for individual continents or countries. Trials of this system has been carried out in several parts of the world and it is now ready for wider application. Compilation of databases and the development of database handling systems for soil information currently are an important area of development in soil science and will help in the attempts being made to identify soils for use on a sustainable basis, especially in the developing countries. With an increasing population demanding greater agricultural production, the pressure on soils will become more intense and there is, therefore, an urgent need to recognize which soils are sufficiently resilient to stand up to the demands made upon them. Planners responsible for development need to have soil information easily available so that land use decisions can be made in the light of the best information available.

Introduction

Intense and increasing pressure on land and water resources throughout the world have been shown to lead to land degradation and pollution, as well as decreasing biological productivity and declining bio-diversity. The initial calls by soil scientists for these problems to be addressed seriously has since been taken up by many national governments and international organisations culminating in the need for an approach that:

- Strengthens the awareness of the users about the importance of soil resources, as well as informing scientists and decision makers about the dangers of inappropriate management;

- Enhances the capability of national resource institutions to collect and deliver reliable, up-to-date information on these resources in an accessible format to a wide audience;

- Encourages monitoring of changes taking place in the status of resources in order to identify, halt and remedy their deterioration. This not only applies to soils, land and water, but also to land cover and the diversity of other biological resources.

The sustainable use of the land, so strongly advocated by the United Nations Conference on Environment and Development (UNCED) held at Rio de Janeiro in 1992 in its Agenda 21, is an important but poorly defined concept. At the centre of the concept, but rarely mentioned by non-soil scientists, lies the soil which is a vital part of the intricate web of interactions between human beings and the natural environment. In order to understand these interactions and effectively to be able to use the land on a sustainable basis, it is essential that maximum use is made of existing knowledge about soils. In this contribution we limit ourselves mainly to methods of making an inventory of land and soils, leaving aside the relationship of economic, social and cultural systems with natural systems.

The role of soil science

To meet future world food needs, reduce poverty and at the same time protect the environment calls for a massive international effort, in which we see a clear role for the soil scientist to play. The dominant focus of investigations in soil science up to now has been on agricultural production. The nature of most investigations has been appropriate and the quality high; however, the research does not seem to have adequately benefited those people whom it is supposed to help, particularly in the Developing Countries. Research in soil science needs to be broadened to emphasize food security, alleviation of poverty and hunger, and the protection of natural resources. The significance of this research is that it must take place against a continually growing world population which will make ever-increasing demands upon the soil to provide food for its support (PINSTRUP-ANDERSEN and PANDYA LORCH, 1994).

At the end of the 15th World Congress of Soil Science, held in Acapulco, Mexico, in July 1994, a declaration was adopted in which it is stated that "Soil science has a crucial role to play in realizing sustainable land use systems that satisfy the needs of an evermore global society". Soil scientists should cooperate in research teams with scientists in other disciplines, such as agronomy, ecology, biology, engineering, economy and sociology. This is not only needed in pressing global issues such as those related to climatic change or global warning, but also at a national level. A holistic interdisciplinary approach that is dynamic and process-oriented is a pre-requisite for lasting results. An important issue in this approach is the contact between the natural and social sciences (ANON 1992; CATIZZONE and MUCHENA, 1994; BRIDGES and CATIZZONE, 1995).

At the 31st General Conference of the International Federation of Agricultural Producers (IFAP), held in Istanbul, Turkey in May 1994, it was stated that farmers' organisations should identify and implement achievable solutions towards a more environmentally friendly and sustainable land use for the future (ANON, 1994). However, it is stressed that the combination of sustainability and environmentally sound development is not a task which farmers can achieve alone, it will require dialogue and partnership with many different sectors of society. This will require closer working links between international and national agricultural research establishments and the farming community in order to ensure that the needs of farmers are correctly addressed. Adequate research should be undertaken, and the needs of small-scale resource-poor farmers should especially be taken into account.

Although gains in productivity and global agricultural production have been and will probably continue to rise, an increased efficiency in the use of soil and water resources is a pre-requisite for the achievement of sustainable agriculture and rural development. The global demands for food, water, housing and development will escalate if the projection that the world's population will exceed 10 billion in 2050 is correct. An improved resource management is only possible if the relevant environmental factors are known and a natural resource base is available.

International agencies such as the World Resources Institute, the World Bank, United Nations Environment Programme (UNEP), Food and Agriculture Organization of the United Nations (FAO), the Consultant Group of International Agricultural Research (CGIAR) and International Geosphere Biosphere Programme (IGBP) have expressed the need for a quantified basic information on land and soil resources. Over the last decade, significant changes have affected the collection, interpretation and dissemination of soil survey data. The most important advances resulted from the incorporation of new technologies developed for remote sensing and information handling. Also, efforts have been made by soil scientists to quantify and standardize soil information and data, but in the process, dependence on technology also has increased the degree of complexity and abstraction of soil survey operations. This increased complexity of soil information and information systems may satisfy the scientific community, but will not necessarily provide the kinds of data required by land resource managers and decision-makers. They need to have the possibility of readily accessing soil and terrain data sources through point and geo-referenced databases in order to quantify the productive capacity of soils. This is necessary at one level to obtain a better understanding about the risks and rate of soil degradation and at another level to better quantify processes of global change.

The Soils and Terrain digital database (SOTER), aims to provide such information which can be used to assess the productivity of land, to provide a basis for its sustainable use, to monitor the effects of soil degradation, and to help in the development of action plans for conservation of productive soils or rehabilitation of degraded soils at global or national levels (OLDEMAN and VAN ENGELEN, 1993).

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The Soils and Terrain digital database (SOTER)

With the support of the International Society of Soil Science (ISSS), and the collaboration of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the United Nations Education, Scientific and Cultural Organisation (UNESCO), and national soil resource institutions throughout the world, ISRIC has developed and tested SOTER. The Soil and Terrain digital database was developed for use at 1:1 M scale and was tested in five countries. Results were reported at the 14th International Congress of Soil Science in 1990. The ISSS Working Group on World Soils and Terrain Digital Database endorsed the methodology. A users manual has been jointly published by UNEP, ISSS, FAO, and ISRIC (VAN ENGELEN and WEN, 1993), accompanied by attribute input software. It is now being implemented in a series of programmes that can assist planning agencies to improve the assessment of the national environmental resources for their sustained utilization.

In SOTER, geo-referenced map units are linked with a digital database specifying the key attributes of the components of these mapping units. In short the SOTER database:

- Has a resolution equivalent to an average map scale of 1:1 M;
- Is compatible with global databases of other environmental resources;
- Is amendable to updating and purging of obsolete and/or irrelevant data;
- Is accessible to a broad array of international, regional, and national decision makers and policy makers;
- Is transferable to, and applicable by developing countries, for national database development at larger scales.

The general approach in SOTER is to review all existing soil and terrain data in a geo-referenced area — whether or not registered on official soil maps — and to supplement this information with remote sensing data for vegetation cover, where appropriate. The data are then rearranged according to the procedures of the SOTER manual. Individual facets of the land are grouped together into units showing a distinctive, and often repetitive pattern of land form, slope, parent material, and soils. Areas so obtained are delineated on the base map as *SOTER units* (Fig. 1). Each SOTER unit is geo-referenced and considered unique with respect to its constituent soil and terrain characteristics.

Areas of different lithology within similar landforms are separated as different *terrain units* which display similar patterns of surface form, slope, micro-relief and parent materials. The next step includes the delineation of *terrain components*, each of which within it a number of *soil components* (Figs. 1 and 2). These major soil components will be represented by actual soil profiles described from the area and linked into the system as shown schematically in figure 3. This enables the quantitative identification of soil attributes and their range of properties within these major soil classes. Initially, each soil component may be represented only by a small number of profiles. In the long term, the intention is to increase the number of profiles as rapidly as possible, consistent with the information becoming available.

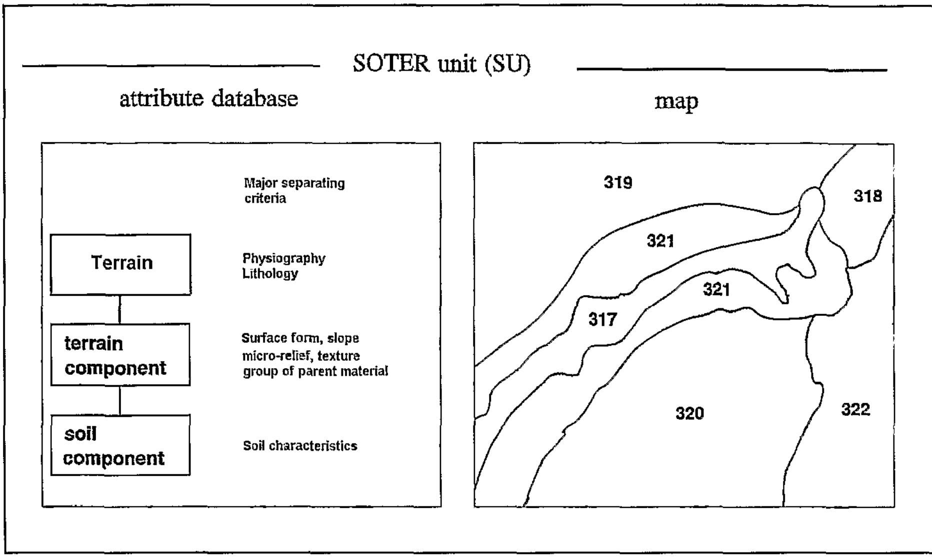

Figure 1. Example of a SOTER unit, as represented on a map and its legend, and its constituent terrain units, terrain components (TC) and soil components (SC) as specified in the database.

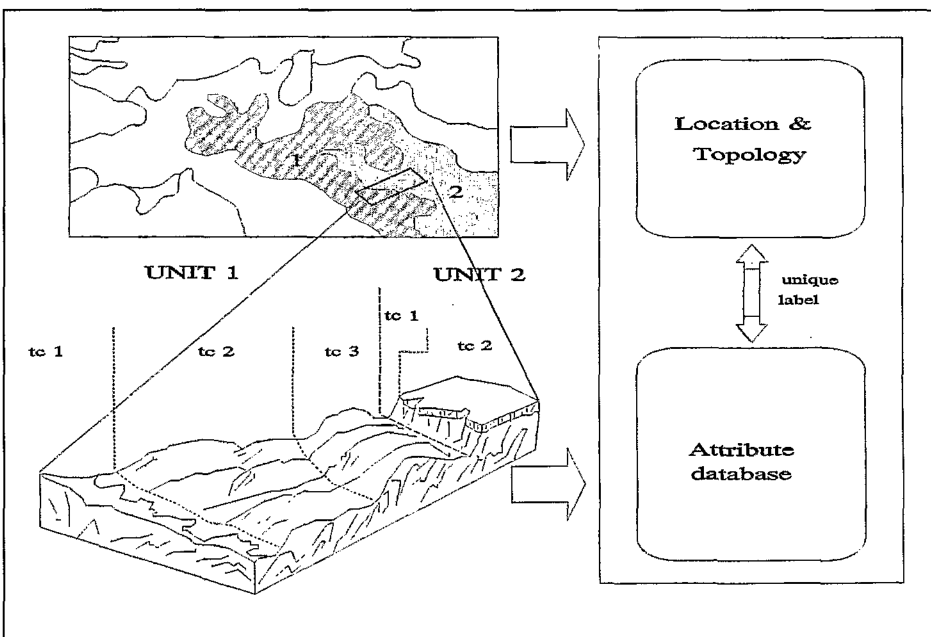

Figure 2. Schematic representation of a terrain unit and its terrain and soil components.

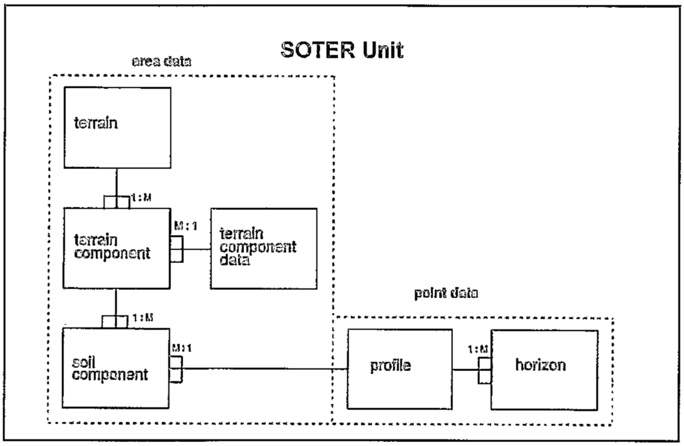

Figure 3. Structure of the SOTER database (1:M indicates one to many relations, M:1 for many to one relation).

The key attributes of profiles can readily be incorporated in a relational database management system which implies a clear gain in resolution as compared with traditional methods of small scale soil cartography (e.g. FAO-UNESCO 1971-1981). Additionally, the SOTER procedures allow knowledge of the spatial distribution and attributes of world soils to be updated and refined using uniform procedures. This is necessary because much of the information presented on the Soil Map of the World (FAO-UNESCO 1971-1981) was collected prior to the 1970s and is now out of date in many parts (SOMBROEK, 1990).

Individual terrain components are characterized in the database in terms of their major soils but these cannot be displayed on a 1:1 M scale map. The chemical, physical and morphological attributes of these representative profiles, for instance horizonation, organic carbon, cation exchange capacity, texture, structure, stoniness and moisture holding capacity, of necessity, are considered to be representative for the whole area represented by the major soil under consideration. Differences in highly variable soil properties alone, such as the content of exchangeable potassium, do not suffice to delineate a new major soil. The respective attribute data, listed in table 1, are specified using either descriptive terms or numerical values, as appropriate. Mandatory attributes required for soil horizon characterization are indicated by an asterisk.

Conclusions and future activities

World-wide coverage by SOTER at 1:1 M scale will require from 10 to 20 years to complete. Meanwhile, at the global level, there remains an urgent need for generating rapid, accurate and reliable information to help solve a multitude of soil-related environmental problems. The response to this situation is to begin work on a broad framework of data in what has been described as a SOTER "shell" or skeleton.

Table 1. Attributes of a SOTER unit.

TERRAIN		
1 SOTER unit_ID	6 slope gradient	11 dissection
2 year of data collection	7 relief intensity	12 general lithology
3 map_ID	8 major landform	13 permanent water surface
4 minimum elevation	9 regional slope	
5 maximum elevation	10 hypsometry	
TERRAIN COMPONENT	**TERRAIN COMPONENT DATA**	
14 SOTER unit_ID	18 terrain component data_ID	26 texture group non-consolidated parent material
15 terrain component number	19 dominant slope	
16 proportion of SOTER unit	20 length of slope	27 depth to bedrock
17 terrain component data_ID	21 form of slope	28 surface drainage
	22 local surface form	29 depth to ground water
	23 average height	30 frequency of flooding
	24 coverage	31 duration of flooding
	25 surface lithology	32 start of flooding
SOIL COMPONENT	56 infiltration rate	83 silt*
33 SOTER unit_ID	57 surface organic matter	84 clay*
34 terrain component number	58 classification FAO	85 particle size class tensions
35 soil component number	59 classification version	86 bulk density*
36 proportion of SOTER unit	60 national classification	87 moisture content at various
37 profile_ID	61 Soil Taxonomy	88 hydraulic conductivity
38 number of reference profiles	62 phase	89 infiltration rate
39 position in terrain component	**HORIZON (* = mandatory)**	90 pH H_2O*
40 surface rockiness	63 profile_ID*	91 pH KCl
41 surface stoniness	64 horizon number*	92 electrical conductivity
42 types of erosion/deposition	65 diagnostic horizon*	93 exchangeable Ca^{++}
43 area affected	66 diagnostic property*	94 exchangeable Mg^{++}
44 degree of erosion	67 horizon designation	95 exchangeable Na^{+}
45 sensitivity to capping	68 lower depth*	96 exchangeable K^{+}
46 rootable depth	69 distinctness of transition	97 exchangeable Al^{+++}
47 relation with other soil components	70 moist colour*	98 exchangeable acidity
	71 dry colour	99 CEC soil*
PROFILE	72 grade of structure	100 total carbonate equivalent
48 profile_ID	73 size of structure elements	101 gypsum
49 profile database_ID	74 type of structure*	102 total carbon*
50 latitude	75 abundance of coarse fragments*	103 total nitrogen
51 longitude	76 size of coarse fragments	104 P_2O_5
52 elevation	77 very coarse sand	105 phosphate retention
53 sampling date	78 coarse sand	106 Fe dithionite
54 lab_ID	79 medium sand	107 Al dithionite
55 drainage	80 fine sand	108 Fe pyrophosphate
	81 very fine sand	109 Al pyrophosphate
	82 total sand*	110 clay mineralogy

Such an outline database will enable representative soil information to be made available in a digital format at least for studies at the global scale. Recently, ISRIC staff have completed the compilation of a global digital soil database, called World Inventory of Soil Emissions (WISE), containing over 4000 soil profiles, representative of the units shown on the Soil Map of the World (BATJES and BRIDGES, 1994).

At present national SOTER programmes are being implemented in several countries (Argentina, Kenya, Hungary, Uruguay) at 1:1,000,000 scale. Many countries of South America are collaborating to produce a 1:5,000,000 scale database for a continental-scale SOTER, to be used for up-dating the FAO-Unesco Soil Map of the World. Some "windows" at a scale of 1:100,000 have also been prepared.

A SOTER-based methodology for an assessment of water erosion risk has been developed, as well as a method for Automated Land Evaluation. Both programmes are developed for use with small-scale databases like SOTER. The SOTER Water Erosion Assessment Programme (SWEAP) allows for a rapid appraisal of the effects of different types of land use on soil loss through erosion (VAN DEN BERG, 1992). It provides options for the use of either the Universal Soil Loss Equation (USLE) or the Soil Loss Estimation Model of South Africa (SLEMSA). SWEAP also can assist in identifying appropriate management options for the same land use type and it facilitates the comparison between different types of land use and land management options with regard to environmental degradation. Hence, SWEAP will prove to be a useful tool, particularly in national and regional use planning.

The Automated Land Evaluation System (ALES) will permit the identification of the suitability of terrain units for broadly defined land uses as put forward by planners. A procedure was developed for physical land evaluation in accordance with FAO's Framework for Land Evaluation, applying ALES, and using SOTER data at 1:1 M. The system was tested in West Kenya, but validation with SOTER in other areas, or with other data is needed. In future two more technology levels and more land utilization types will be incorporated into the evaluation model. The results of the evaluation are to provide relative suitabilities of SOTER units for the defined land utilization types, based on evaluator's judgement. As a follow-up, a quantified land evaluation of potentially suitable terrain units will be attempted using a crop growth simulation model. With the resulting quantitative information on expected production and the inputs needed, the economic suitability can be evaluated by ALES.

A project to develop a methodology for the assessment of wind erosion risk has been drawn up and awaits implementation. With specific regard to Africa, an increased food production through the development of small-scale irrigation schemes could be planned with the use of an inventory such as SOTER. Methods for Sustainable Agriculture and Rural Development (SARD) have recently been put forward. Together with the International Scheme for the Conservation and Rehabilitation of African Lands (ISCRAL), adopted by FAO in 1990, these worthwhile activities should be based on reliable inventories of natural resources.

The number of requests for SOTER schemes at a national level from countries in Africa, Latin America, Asia and Central and Eastern Europe is indicative of the demand for, and importance attached to having a land resource database which contains reliable quantitative data for land evaluation and land use planning system. It will not only be an important tool at the national level, but will also be of interest to international organisations such as International Geosphere-Biosphere Programme (IGBP) in their monitoring activities and organisations like as FAO, UNEP, and other agencies which are responsible for funding research and development.

Finally, recommendations that soil scientists should adopt a more holistic approach to their studies and approach to the sustainable use of the soil can be helped in part by the adoption of data handling methodologies, which will interface with geographic information systems. GIS technology can permit many different layers of information to be superimposed in the analysis of the many complex problems involved with soil management. Some of the reasons why the results of soil science research have not been transmitted successfully in the past to the users of the land have been that insufficient attention has been given to the interacting social, legal and economic influences which govern soil and land use in development programmes. A database such as SOTER can help fulfil many of these aspirations.

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