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Global Assessment of Land Degradation

Soil and landform properties for LADA partner countries

(Argentina, China, Cuba, Senegal and The Gambia, South Africa and Tunisia)

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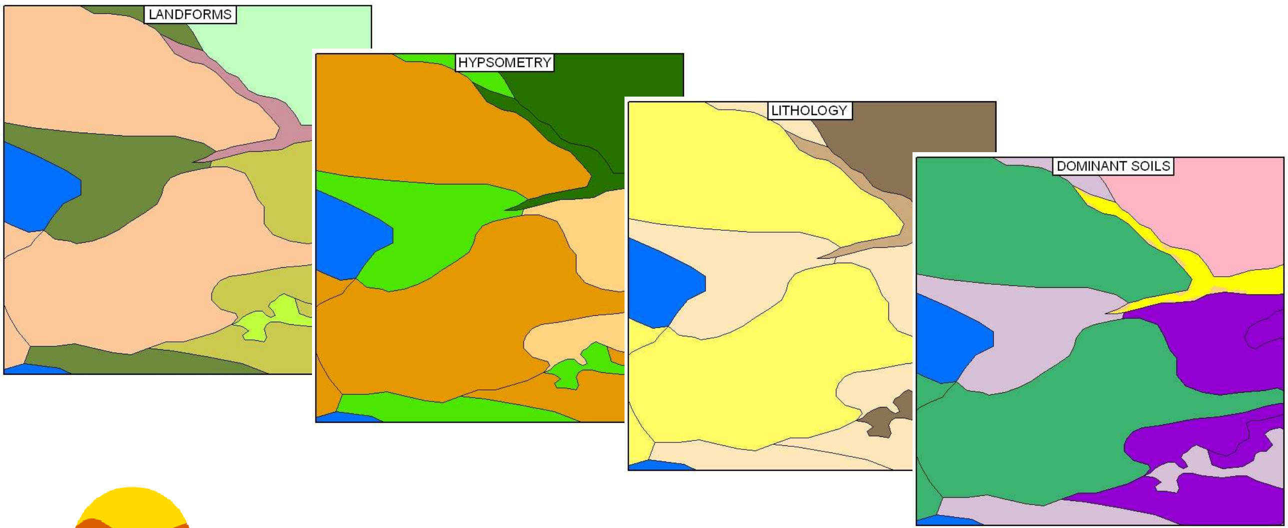

LADA

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Front cover: Thematic maps of the southern part of Santa Cruz Province (Argentina)

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SUMMARY

This report presents the activities of ISRIC – World Soil Information executed within the framework of the Global Assessment of Land Degradation (GLADA) project as a part of the FAO program Land Degradation Assessment in Drylands (LADA). It describes methods for the compilation of enhanced soil information in a soil and terrain database at scale 1:1 million for the six LADA partner countries: Argentina, China, Cuba, Senegal, South Africa and Tunisia.

The outputs are given in a Soil and Terrain (SOTER) database for each partner country. The databases will be used to sustain the analyses of the Normalized Difference Vegetation Index (NDVI) and help to assess possible causes for prevailing land degradation by correlating NDVI trends with parameters from the SOTER database.

Keywords: Soil and Terrain (SOTER) database, Global Assessment of Land Degradation (GLADA), Land Degradation Assessment in Drylands (LADA), soil data, Argentina, China, Cuba, Senegal, The Gambia, South Africa and Tunisia.

1 INTRODUCTION

This report summarises an initial activity of ISRIC – World Soil Information within the framework of the Global Assessment of Land Degradation (GLADA), which is part of the FAO program Land Degradation Assessment in Drylands (LADA).

ISRIC's activities in this program are laid down in a Letter of Agreement PR 35825 between the Food and Agriculture Organisation of the United Nations and ISRIC – World Soil Information, signed in February 2007.

A major task of the GLADA program is a quantitative and reproducible global assessment of land degradation. This global assessment has been carried out by remote sensing and measurement of deviance from local norms for the vegetation cover (Bai *et al.* 2008). In this procedure, land degradation has been assessed by the negative trends in the normalised difference vegetation index (NDVI), derived from the reflected wavebands measured by earth-observation satellites during the period 1981-2003. Degradation has been identified as 'hot spots' on the derived images. The quality indicators of these 'hot spots' will be derived from secondary remote sensing analysis and based on stratification of the land area according to Soil and Terrain (SOTER) units and land cover. Finally, these results will be validated (ISRIC - World Soil Information 2006).

ISRIC'S include two SOTER-related activities for the 6 LADA partner countries (Argentina, China, Cuba, Senegal, South Africa and Tunisia):

1) Preparation of a landform map derived from an analysis of the digital elevation model of the Shuttle Radar Topography Mission (SRTM-90 m DEM) as a first stratification of the land area (Huting *et al.* 2008).
2) Enhanced information on soils in a SOTER format that is relevant for the assessment of soil degradation.

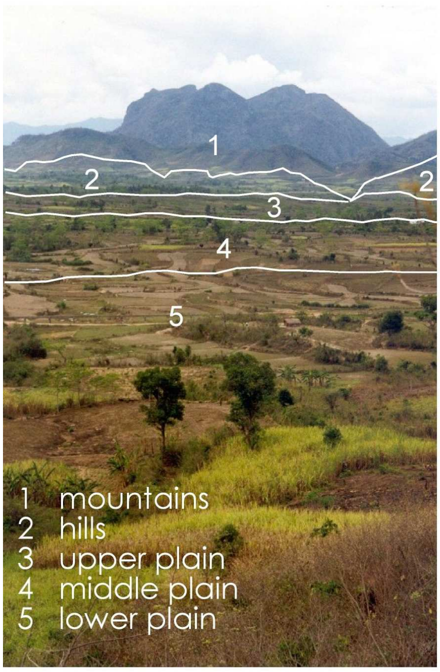
This report describes the procedures followed to compile the enhanced information on soils for each of the partner countries, at scale 1:1 million.

2 METHODS AND MATERIALS

2.1 SOTER methodology

The SOTER methodology was initially developed for a land resources information system at scale of 1:1 million (van Engelen and Wen 1995). SOTER consists of a geometric database and an attribute database. The first stores data on the SOTER units' location, extent and topology, and the later the units' soil and terrain characteristics.

The SOTER procedure is based on the relation between the physiography (landform), parent material and soils. It identifies areas of land with a distinctive and often repetitive, pattern of landform, lithology, surface form, slope, parent material and soils. The methodology uses a stepwise approach identifying major landforms, the terrain unit at its highest level of distinction, which are than subdivided on basis of differences in parent material and soil properties. The so-identified mappable units are called SOTER units (Figure 1); they represent unique combinations of terrain and soil characteristics (Dijkshoorn 2002; van Engelen and Wen 1995).



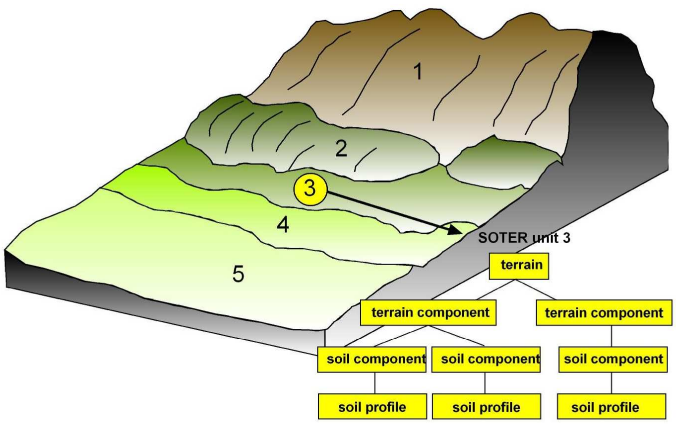


Figure 1: Representation of SOTER units and their database structure

The attribute database consists of several tables; data for terrain units, terrain components and soil components are linked by primary keys. These are unique identifiers. The characteristics of landform and parent material are described at the highest level. In the terrain unit table, one or more terrain component(s) (TCID) may be distinguished based on differences in landform and lithology that, due to the scale of delineation, cannot be shown on the SOTER map, but can be described in the attribute database. A further discrimination is made in terms of soils, the soil components (SCID), which show the proportion of each soil type within the terrain component (Figure 1). Soil components are not shown on the map, but detailed in the attribute database. They can be compared to a soil association or a compound mapping unit (Dijkshoorn 2002; van Engelen and Wen 1995).

Each soil component is characterized by a representative soil profile (Figure 1). The soil horizon characteristics of each representative profile are stored in the horizon table. Selection and characterization of the representative profiles are based on the Revised Legend of the Soil Map of the World (FAO-Unesco 1988) and the World Reference Base for Soil Resources (ISSS *et al.* 1998; IUSS 2006). Map units are characterized using (FAO-Unesco 1988), Revised Legend, to ensure consistency with earlier SOTER products.

The structure of the SOTER database, definitions of the SOTER relations, field description, content and coding conventions are detailed in the SOTER Database Structure Manual (Tempel 2002).

2.2 GIS based methodology for SOTER landform mapping

A GIS-procedure based on SOTER criteria (Dobos *et al.* 2005) was used to indentify a common topographic format for the terrain units (landform). This methodology has been slightly adapted for the use with the LADA partner countries (Huting *et al.* 2008). The methodology is based on modelling of the 90 m digital elevation data (90m DEM) of the Shuttle Radar Topography Mission (SRTM) (CGIAR-CSI 2004). This GIS based methodology discriminates on calculated pixel values of raster cells of the 90m DEM. By applying certain generalisation algorithms and vectorisation of the raster, new (temporary-terrain) units are indentified that meet set criteria. To demarcate major landforms according to the SOTER methodology, these temporary-terrain units are then grouped on basis of slope, elevation and relief intensity criteria. Several clustering procedures have been evaluated. The definition of relief intensity was modified to facilitate digital calculations[1] (see **Appendix 1**).

The 90m DEM data were processed with ArcMap's Spatial Analyst. Single parameters maps were derived for elevation, slope and relief intensity using SOTER criteria; this gives information on the terrain variability. The combination of these parameters is used to generate the 'SOTER combi-map', that shows terrain units having a defined set of slope, relief intensity and elevation. This SOTER combi-map provides the basis for a classified landform map; it is also a helpful tool in terrain analysis. However, the method has still some short falls. For instance, some combinations of slope and relief intensity do not fit well in the SOTER landform classification, in particular for plain versus dissected plain. In such cases, slope is kept as most discriminating factor for mapping the SOTER landform.

[1] Relief intensity – is defined as the median differences within one km^2 circle around the pixel in consideration.

The method also fails to discriminate landform on basis of morphology; e.g. plateau - higher lying, level land with a scarp -, or depression - lower lying, enclosed level land without river outlet -; these are not recognized and both are still classified as a plain. The present GIS-procedures are being refined (Huting *et al.* 2008).

Using the Zonal Statistics Module of ArcGIS© and the 90m DEM data of the identified SOTER units, median values for slope, relief intensity and values for maximum, minimum and median elevations were calculated. These values have been added to the attribute data of the terrain table in the SOTER database to substitute the data from previous assessments.

2.3 Data sources

2.3.1 Spatial data source

The geometric database for the SOTER maps have been made congruous to the Digital Chart of the World (DCW) (DMA 1993), see also (van Engelen *et al.* 2005). All maps are in geometric projection (WGS84) and use decimal degrees.

The geometric SOTER maps have been derived from: Argentina and Cuba from SOTERLAC (Dijkshoorn *et al.* 2005; FAO *et al.* 1998) and South Africa from SOTERSAF (FAO *et al.* 2003). For China, Senegal and The Gambia, and Tunisia new SOTER products were compiled in this project.

The SOTER map of Senegal and The Gambia was derived from the analogue "Carte morpho-pédologique du Sénégal" at scale 1 : 500,000 (Stancioff *et al.* 1986) and digitized by Centre de Suivi Ecologique, Senegal (CSE 1994).
For Tunisia, the SOTER map was derived from the analogue "Carte Pédologique de la Tunisie", scale 1: 500,000 (Division des Sols 1973), which was digitized and updated in 2007. The topographic base maps have been made congruous to the DCW for use as SOTER maps; polygons smaller than 10 km^2 have been eliminated.

For China, only a soil map, rasterized to 30 arc second (approximately 1 km) was available as part of the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC 2008). It is based on the Soil Map of China, at scale 1:1 million, compiled by the Institute of Soil Science Chinese Academy of Sciences (Shi *et al.* 2004). The raster map has been converted to a polygon map and generalized by dissolving all polygons smaller than 10 km^2. After overlay with the DEM-derived combimap, a basis for the new SOTER map was generated.

2.3.2 Primary soil data

Primary soil and terrain data for Argentina and Cuba were also obtained from the SOTERLAC database at scale 1:5 million (FAO *et al.* 1998), with updates for a few countries (e.g. Brazil, Peru, etc.), see (Dijkshoorn *et al.* 2005). During this exercise, no new attribute data for Argentina were added to SOTERLAC; data for Cuba were partly updated based on the available data sources..

The primary soil data for South Africa were extracted from SOTERSAF, at scale 1:2 million (FAO *et al.* 2003).

New SOTER databases were compiled for Senegal and The Gambia, in cooperation with the Institut National de Pédologie, Dakar, and for Tunisia with the Bureau des Resources en Sols, Tunis. The SOTER database for Tunisia was compiled at ISRIC, with most information coming from IRD (formerly ORSTOM) documents, including (Belkhodja *et al.* 1973) and (Mtimet 1999).

The SOTER database for China was compiled by the Institute of Soil Science, Chinese Academy of Sciences (ISSCAS) Nanjing (Zhang and Zhao 2008). In the database, map units are characterized by only one single soil. Usually, however at scale 1:1 million, soil map legends generally describe soil associations, comprising several soil units.

3 RESULTS AND DISCUSSION

3.1 General

The compilation of the SOTER databases depends on existing geometric and attributes data available for the countries. Usually, no new soil survey or soil data collection is envisaged in the procedures. As a result, large variations can occur in resolutions and data densities within and between countries.

Table 1 one gives a summary of the composition and contents of SOTER polygons, units and components of the database for the six LADA project countries.

Table 1: SOTER details per country and component

Country	Surface area in 1000 km^2	Number of polygons	SOTER units	Terrain compo-nents	Soil compo-nents	Profiles[a)]
Argentina	2791	633	203	220	564	222
China	9474	66134	5033	0	5033	1430
Cuba	110	95	30	49	73	30 + 4(s)
South Africa	1220	3349	3042	7009	11897	615 + 1938(s)
Senegal and Gambia	197	2242	149	155	274	57 + 33(s)
Tunisia	155	752	250	256	533	56 + 44(s)

a) Synthetic profiles (s) are profiles without any measured soil parameters, of which only the FAO classification is known from legacy soil maps.

3.2 Argentina

The SOTERLAC database of Argentina, scale 1:5 million (FAO *et al.* 1998); (Dijkshoorn *et al.* 2005; van Engelen *et al.* 2005), was used to extract a 1:1 million SOTER map for Argentina.

A digital elevation model (DEM) derived from SRTM data (CGIAR-CSI 2004) was compiled and has been used for the analysis of the single parameters slope, relief intensity and elevation. The results of the single parameters have been combined in a combi-map. See Chapter 2.2.

The SOTER map at scale 1:1 M was used as overlay over the SRTM- DEM derived combimap and single parameter maps. When comparing the boundary fit of these maps, it appeared that SOTER unit boundaries deviated considerably from landform boundaries on the combimap. To correct for considerable shifts and to display terrain units more accurately, the map was redrawn and re-digitized.

Most corrections of the SOTER unit boundaries are based on this combi-map and, alternatively the single parameter maps, slope, relief intensity and elevation. With the overlay of the drainage pattern (GIS Lab Penn State University 1993) and the digital soil map of Argentina (Instituto de Suelos-INTA 1995) other SOTER unit boundaries have been corrected. The use of the digital soil map of Argentina was very useful, especially where the information of the combimap was less discriminative and soil boundaries appeared to be decisive for the delineation of the SOTER units, e.g. in nearly all plain areas.

Redrawing and corrections of the SOTER map resulted in more polygons and SOTER units. Because of the larger scale needed for LADA, some polygons were split and boundaries redrawn, while in other cases new SOTER units have been created on basis of the soil map and combi-map. The present 1:1 million SOTER map has 203 mapping (SOTER) units, compared to 108 on the original SOTER map for Argentina at scale 1:5 million. See Table 1.

For each SOTER unit the median values of slope, relief intensity, and maximum, minimum and median elevation were calculated, using the Zonal Statistics Module (ZSM) of ArcGIS© and SRTM-DEM derived data. The calculated results were incorporated in the terrain table of the SOTER database. Comparison with the original data showed that large deviations occurred in place for the actual values of the parameters, but that most cases the given landform classification was similar.

The attribute data for the representative profiles of the 1:1 million-scale SOTER database were extracted from the SOTERLAC database. No new representative profiles have been added. These attribute data are restricted to those available in the reduced SOTERLAC dataset (FAO *et al.* 1997).

3.3 China

The digital Soil Map of China used here, has a raster format of 30 arc seconds (approximately 1 km) and forms a part of the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC 2008). It was compiled in 1995 by the Institute of Soil Science, Chinese Academy of Sciences (ISSCAS) from data of the Office for the Second National Soil Survey of China (Shi *et al.* 2004). The mapping units are based on the genetic soil classification of China (GSCC) and converted and correlated to the FAO Revised Legend (FAO-Unesco 1988).

The raster map contains over 67,000 polygons (FAO/IIASA/ISRIC/ISSCAS/JRC 2008). The ISSCAS team created links between the polygons and reference profiles, representing the dominant soil of the mapping unit, respectively a miscellaneous unit, such as lakes, glaciers, rock outcrop (Zhang and Zhao 2008). The parent material/lithology of the reference profiles were given in the original profile table. This information has been used to list the SOTER unit's dominant parent material, as this was not given; this appears not correct for all SOTER units.

The landform was determined using the SRTM 90m DEM in a GIS based procedure (Huting *et al.* 2008).

The database consisted of two attribute tables, profile and horizon table, with a key to the geometric database. The original dataset was reorganized. The data set is composed of 5 tables, maintaining the SOTER structure. Many attribute data are lacking in the dataset, such as information on rock outcrop, stoniness, drainage class. The one to one relation of the SOTER unit to the soil component in this database restricts storage of only one dominant profile. The database contains data for 1430 representative profiles.

Initially, many polygons had identical landform, lithology and soil classification (FAO-Unesco 1988). These polygons have been aggregated to create the SOTER units, taking into account the different profile-ID for similarly classified soils. In total 5040 SOTER units have been created out of the initial 67,209 polygons.

The terrain information on median slope, relief intensity and elevation for the SOTER units was derived from the 90m DEM data using the Zonal Statistics Module (ZSM) of ArcGIS©, following the SOTER criteria for landform, maintaining the SOTER landform as classified during the mapping of SOTER landform according to GIS procedures (Huting *et al.* 2008). Comparing this landform and the relief index and/or slope it appeared that in a few cases landform and slope do not correspond, e.g. too low slope for landform medium-gradient mountain, or to high relief index for plain. These discrepancies occurred for very small SOTER units, often composed of one or two polygons, in contrasting landscapes on the islands Taiwan and Hainan. Probably this has to do with the different pixel map of the islands as they were processed separately.

3.4 Cuba

A similar procedure as for Argentina was followed for Cuba. The SOTER database of Cuba was extracted from the SOTERLAC (FAO *et al.* 1998). The SOTER unit map of Cuba was enlarged to scale 1:1 million and put as an overlay over the combi-map and the derived single parameter maps of slope, relief intensity and elevation. See also Chapter 2.2.

The combimap showed many terrain units and more detail in landform than observed in the original SOTERLAC map at scale 1:5 million. Similar shifts occurred for Cuba as for Argentina. However, the deviations observed for Cuba were much smaller, but still the SOTER unit boundaries were not sufficient precise for scale 1:1 million and differed in their location compared to the units of the combi-map. Therefore, the SOTER unit boundaries were adjusted, using the combi- and the single parameter maps, for those cases where landform contrasted too strongly on both maps, e.g. hilly on the combi-map and flat on the original SOTER map.
This has resulted in a better fit of the present SOTER unit boundaries with the terrain units derived from the DEM analysis and has improved the accuracy of the geometric location of the units. The followed procedure was based on SRTM-DEM derived data. The procedure may be improved by the use of satellite imagery and national atlases as suggested by Reyes (Ramiro Reyes 2004).

No new SOTER units were delineated, because no new soil information was available. The main changes are thus a few new polygons that were split from larger SOTER units on basis of strong contrasting terrain features shown on the combi-map. It formed part of the adjustments made to the SOTER map. See Table 1. For a number of profiles supplementary attribute data have been added to complete the attribute data conform the requirements of a 1:1 million SOTER database.

Median values for slope, relief intensity and elevation were calculated with ArcGIS© Zonal Statistics Module (see Argentina) and the results inserted into the terrain-table of the SOTER database for Cuba.

3.5 South Africa

The SOTER database for South Africa was extracted from the SOTERSAF database, which covers the region of Southern Africa (FAO *et al.* 2003). The South African part of this database has a resolution higher than 1:1 million, as the original SOTER map for South Africa was derived from the Land Type database that was based on a 1:250,000 scale soil map, compiled by the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC-LNR 2004). For more details on the database see (Dijkshoorn 2003).

The SOTER map for South Africa is very detailed compared to the SOTER maps of other countries in SOTERSAF. Especially for the sloping and steep areas, the map resembles strong similarity to the combimap (see Chapter 2.2). In flat areas, more differences are observed; here the SOTER map shows more polygons and SOTER units than indicated on the combimap, reflecting the different soil patterns and soil composition of the flat areas. The map has about an equal number of polygons and SOTER units and sufficient resolution for a 1:1 million scale. See Table 1. No further subdivision of SOTER units was made, except a few minor corrections and modifications most of them to harmonize units bordering Lesotho.

The original SOTERSAF database for South Africa contained more than 7200 entrees for representative profiles, of which only 615 profiles are actually described and analyzed. The majority of profiles is thus synthetic or virtual and have only a profile ID-coding, referring to the terrain type, the soil type and a sequencial number to keep a link to the South African Land Type database. Leptosols, for instance, with an identical position in the landscape, and on similar lithological parent material but in different SOTER units were given a different profile identification number (ID) and appeared as different synthetic soil profiles in the database. This is not according to the SOTER procedures. In the present version of the SOTER database for South Africa, the number of identical profiles has been reduced in a systematic way following SOTER procedures (van Engelen and Wen 1995).

Synthetic profiles in the original SOTERSAF database, with a similar classification, depth, parent material and position in the landscape are selected and given an equal soil profile ID number. This new synthetic profile replaces all selected profiles and has a direct reference to the soil classification of the Revised Legend (FAO-Unesco 1988), and contains also a link to landform and parent material/lithology of the SOTER unit. However, it has lost now the direct link to the Land Type database. This adaption of the database has reduced the number of synthetic profiles to less than 2000; e.g. for the Leptosols from more than 1500 profiles to less than 250 entrees in the present database.

Median values for slope, relief intensity and elevation for the South Africa database were calculated with ArcGIS© Zonal Statistics Module (see Argentina) and the results inserted into the terrain-table of the SOTER database.

3.6 Senegal and The Gambia

The digital soil map of Senegal and The Gambia was obtained through FAO/AGLL. It is based on the '*Carte morpho-pédologique de Sénegal*' at scale 1:500,000, which used earlier work of (Stancioff *et al.* 1986). The map was digitized by the Eros Data Centre in cooperation with the Centre de Suivi Ecologique, Dakar, (CSE and PNAT/USAID 1994), and slightly modified. The legend gives information on soils, on landform (elements) and lithology. This information is very useful for discriminating and delineating SOTER units, when combined with information obtained from the SRTM-DEM analysis. The morpho-pedologic soil map was used as a topographic basis for the SOTER map. SOTER units were delineated from overlaying this soil map with the combi-map and landform assigned to the units on basis of the combi-code (see chapter 2.2). About 150 different SOTER units have been distinguished. All SOTER units smaller than 10 km^2 have been dissolved. They were allotted to neighboring polygons with which they had the longest common boundary.

The current SOTER landform criteria are too broad to discriminate the small, but agricultural important, landscape differences, e.g. in the northern inland dune landscape, small differences in elevation. Often only a few meters, make already a difference in its suitability for agriculture.

River and rivulet valley bottom areas are often small, but important landforms in (semi) arid land areas. To discriminate these landforms the methodological framework approach for rapid characterization of agricultural land-use (George and Petri 2006) has been used as overlay over the combined landform and soil map. With this map the delimitation of the valley bottoms on the SOTER map have been adjusted.

The SOTER attribute data has been compiled by the '*Institut National de Pedologie*', Dakar, Senegal. The database contains 149 SOTER units, subdivided into 274 soil components represented by 57 reference profiles. A major problem is to find reference profiles well distributed over the territory of Senegal. This was not possible; most of the eastern part of the country lacks representative profiles. The missing cases are substituted by 33 different synthetic profiles based on the FAO'88 Revised Legend classification. A synthetic profile is used, only when the mapping unit is known and no representative profile is found for that unit. They are coded using the FAO'88 classification. See also Table 1.

The soil legend, which describes the soils according to the French classification system (CPCS 1967), had to be converted into the Revised Legend of the Soil Map of the World (FAO-Unesco 1988). This posed problems, because of incomplete profile information. Due to these incomplete descriptions, the classification according to the World Reference Base for Soil Resources (IUSS 2006) was not feasible in many cases. A preliminary correlation was made between the Revised Legend of the Soil Map of the World and the French classification system; see **Appendix 3** and **Appendix 4**.

Median values for slope, relief intensity and elevation were calculated with ArcGIS© Zonal Statistics Module (see Argentina) and the results inserted into the terrain-table of the SOTER database for Senegal and The Gambia.

3.7 Tunisia

A SOTER attribute database for Tunisia was compiled, using the standard SOTER procedures. This was supplemented with SRTM-DEM analysis and derived maps to delineate and define landforms (Huting *et al.* 2008). See also Chapter 2.2.

The geometric SOTER database of Tunisia, has been derived from the '*Carte Pédologique de la Tunisie*' at scale 1:500,000. This map was digitized in 2007 (Division des Sols 1973) and obtained, through FAO/AGLS, from the '*Direction des Sols*'[2], Ministry of Agriculture, Tunis. The digital map showed several inconsistencies compared to the analogue version. Differences have been observed in delineation of the mapping units, even some units had disappeared, errors were noted in assigning attribute data to the mapping units, etc. Assuming a higher reliability for the analogue map, soil attribute data, in particular the information from the legend has been used to create the SOTER database.

A pragmatic approach has been followed to compile the database and the SOTER map. An overlay of the digital soil map with the SOTER combimap was made, while also the lithology map of Tunisia ('*Carte des Roches-mères des Sols*') at scale 1:1 million was also imported as an overlay (Dimanche 1971). The SOTER units were indicated on basis of the combination of these three maps. The mapping units of the digital soil map were kept as geometric basis and adapted when the combi-map and/or lithology map showed sufficient evidence of difference in terrain characteristics or in lithology. When necessary the delineation of the soil units to create a SOTER unit has been adapted.

A primary SOTER attribute database for Tunisia was compiled. Information to describe the terrain attributes of the SOTER unit was extracted from the above mentioned maps. The legend of the soil map followed the French classification system (CPCS 1967). This legend was interpreted and converted into the Revised Legend units of the Soil Map of the World (FAO-Unesco 1988) creating soil mapping units. See **Appendix 2**. The legend of the soil map served also to determine the number of soil components of the SOTER unit. Aided by profile

[2] Formerly Division des Sols

descriptions, often from various sources, representative profiles were assigned to the soil components to characterize each soil of the SOTER unit.

The Direction de Sols, Tunis, aimed to improve the present version of the soil map, especially the subdivision in '*classe*' (and *sous-classe*) and '*groupe*' (and *sous-groupe*) of the legend, in order to improve the legend's link to the soil components. However, this was unfortunately not feasible. As a result, not in all cases could the database be verified with actual data and only tentatively correlated with the FAO's Revised Legend (FAO-Unesco 1988). This resulted in a database in which units are unequally subdivided in soil components and classification and correlation to the Revised Legend still can be improved.

Errors may occur in the conversion of the original legend into the Revised Legend (FAO-Unesco 1988), but also in the proportional composition of soil components in the SOTER units as extracted from the original legend. Information on proportional composition was not found in any document. The composition was estimated, based on the unit description in the legend or on interpreted information in reports, maps and satellite images (ESRI 2006).

Geo-referenced, representative profiles are needed for correlation of the CPCS system with the FAO's Revised Legend. However, fully described and analyzed soil profiles, were limited in number. Most profile descriptions and analyses were made to support a soil-genetic interpretation of soil maps, rather than morphometric approaches. There are only a few profiles descriptions that follow methods complying with the data requirements for the SOTER database.

Not all profiles were geo-referenced, e.g. - *Atlas des Sols Tunisiens* - (Mtimet 1999). Soil horizons were generally well described, but often class descriptions deviate from present-day standards and soil analyses are limited to texture, pH and electrical conductivity (EC), and organic carbon determinations. An exception is a group of 15 profiles, sampled and described by the National Resources Conservation Service, USA (NRCS-SSL 1987), which give fully described and analyzed soil profiles.

The database for Tunisia contains 56 reference profiles and 44 synthetic profiles.
Median values for slope, relief intensity and elevation were calculated similarly as for the other LADA partner countries (see Argentina).

4 CONCLUSIONS

SOTER databases for the six GLADA partner countries (Argentina, China, Cuba, Senegal and The Gambia, South Africa and Tunisia) are presented at scale 1:1,000,000. Although having the same scale, the databases differ in resolution, in terms of the number of SOTER units per defined unit area, and differences in data density.

The spatial and soil attribute information, as presented here, should be improved when new materials become available in particular for the SOTER for Tunisia and Senegal and The Gambia.

Transformation of the French Classification System (CPCS 1967), as used in Senegal and The Gambia and Tunisia, into the Revised Legend of FAO posed difficulties. Additional, well described and analyzed soil profiles would be of great help for correlation and to fill gaps in the present databases.

SRTM-DEM data were useful to correct delineations of SOTER units for Argentina and Cuba.

The number of SOTER units for China can probably be reduced by aggregating units e.g. related soil components into one SOTER unit. However, such a comprehensive update needs local expert knowledge to group SOTER units together and create a new SOTER unit composed of the old ones.

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APPENDICES

Appendix 1: Hierarchy of major landforms

1st level	2nd level	gradient (%)	relief intensity ($m.km^{-2}$)
L level land	**LP** plain	<10	<50
	LL plateau	<10	<50
	LD depression	<10	<50
	LF low gradient footslope	<10	<50
	LV valley floor	<10	<50
S sloping land	**SE** medium-gradient escarpment zone	10-30	100-150
	SH medium-gradient hill	10-30	100-250
	SM medium-gradient mountain	15-30	150-300
	SP dissected plain	10-30	50-100
	SV medium-gradient valley	10-30	100-150
T steep land	**TE** high-gradient escarpment zone	>30	150-300
	TH high-gradient hill	>30	150-300
	TM high-gradient mountain	>30	>300
	TV high-gradient valley	>30	>150

Adapted from SOTER manual (van Engelen and Wen 1995); revised, not published

Appendix 2: Correlation of CPCS classification (CPCS 1967), Revised Legend (FAO-Unesco 1988), and a tentative WRB Reference Soil Group (IUSS 2006) for Tunisia.

Soil profile classification Carte Pédologique de la Tunisie	FAO'88[3]	Phase	WRB (tentative)
Calcimorphe sur accumulation gypseuse	GYh	LI	Hypergypsi-Leptic Gypsisols
Régosol	RGc	LI	Calcari-Leptic Regosols
Rendzine	CMc	LI	Calcari-Leptic Cambisols
Rendzine brune sur croute et encroutement calcaire	CLp	PC	Hypercalci-Epipetric Calcisols
Rendzine brunifiée	CMc	LI	Calcari-Leptic Cambisols
Rendzine sur croute	CLp	PC	Hypercalci-Petric Calcisols
Sol à Mull - Sol brun forestier	LXh		Haplic Lixisols
Sol à Mull - Sol brun lessivé	LXh		Haplic Lixisols
Sol à mull, sol lessivé hydromorphe	PLd		Dystri-Albic Planosols
Sol à mull; sols bruns faiblement lessivés	ALh		Profondic Alisols
Sol à mull; sols lessivés hydromorphes	LVj		Endodystri-Stagnic Luvisols
Sol à mull; sols lessivés podzoliques	PZh		Skeleti-Albic Podzols
Sol brun calcaire	CMc		Calcaric Cambisols
Sol brun calcaire sur encroûtment calcaire, humifié	CLp		Hypercalci-Epipetric Calcisols
Sol brun calcaire sur marne	CLp		Hypercalci-Petric Calcisols
Sol brun humifère	CMu		Haplic Umbrisols
Sol brun isohumique	CLl		Chromi-Luvic Calcisols
Sol calcimorphe à encroûtement gypseux	GYp		Petric Gypsisols
Sol calcomagnesimorphe rendzine	LPk		Rendzic Leptosols
Sol calcomagnesimorphes rendzine	CLp		Hypercalci-Epipetric Calcisols
Sol d'apport modal sur d'apport fluviatile	FLc		Calcari-Gypsiric Fluvisol
Sol de croûte ou encroûtement gypseux	CLp	LI	Lepti-Petric Calcisols
Sol fersialitique à réserve calcique	CLl		Chromi-Luvic Calcisols
Sol isohumique subtropical brun modal	CMc		Chromi-Calcaric Cambisols
Sol isohumique subtropical châtain modal	LVk		Chromi-Calcaric Luvisols
Sol isohumique subtropical-châtain	KSk		Luvi-Calcic Kastanozems (Sodic)
Sol iso-humique, sierozem modal (subdesert soil)	CLl		Luvic Calcisols
Sol mineral brut d'érosion	RGc		Calcaric Regosols
Sol mineral brut d'apport fluviatile	FLe		Eutri-Skeletic Fluvisols
Sol mineral brut, erg, dunes	ARc		Calcari-Gypsiric Arenosols
Sol peu évolué	CMv		Calcari-Vertic Cambisols
Sol peu évolué	FLc		Hyposodi-Calcaric Fluvisols
Sol peu évolué d'apport éolien	RGe		Eutric Regosol
Sol peu évolué d'apport éolien	ARh		Haplic Arenosols
Sol peu évolué, non-climatique, d'érosion	RGc		Calcaric Regosols
Sol rouge méditeranée	LVk		Sodi-Calcic Luvisols (Rhodic)
Sol rouge méditeranée dans karst calcaire	PHl		Calcari-Luvic Phaeozems

[3] Classification of FAO'88 Revised Legend.

Soil profile classification Carte Pédologique de la Tunisie	**FAO'88[3]**	**Phase**	**WRB (tentative)**
érodé			
Sol rouge méditerranéen non lessivé modal	CMx		Chromic Cambisols
Sol salé à alcalis sur alluvion fluviatile	SCn	PH	Sodi-Gleyic Solonchaks (Calcaric)
Sol salé sur alluvion fluviatile	SNk		Calci-Salic Solonetz
Sol vertique	VRe		Sodi-Hyposalic Vertisols (Gypsiric)
Vertisol lithomorph e modal á caractère accentué	VRk		Hyposodi-Calcic Vertisols

Appendix 3: Correlation of CPCS classification (CPCS 1967), Revised Legend (FAO-Unesco 1988), and a tentative WRB Reference Soil Group (IUSS 2006) for Senegal and The Gambia.

Soil profile classification Carte Pédologique de Sénégal	FAO'88	PHAS	WRB (tentative)
Sol brun subaride	ARl		Bruni-Hypoluvic Arenosol (Eutric)
Sol brun subaride	RGe		Haplic Regosol (Eutric)
Sol brun-rouge subaride	ARb		
Sol faiblement ferrallitique	ACf		
Sol ferralitique à réserve calcique, à caractère hydromorphe	LXf		
Sol ferrugineux tropical faiblement lessivé	ARl		Hypoluvic Arenosol (Eutric)
Sol ferrugineux tropical faiblement lessivé sur sable	ARa		
Sol ferrugineux tropical lessivé	ACh		
Sol ferrugineux tropical lessivé	ACf		Haplic Acrisol (Ferric, Epieutric, Arenic)
Sol ferrugineux tropical lessivé	ACf		Vetic Acrisol (Abruptic, Hyperdystric)
Sol ferrugineux tropical lessivé	ACh		Haplic Acrisol (Ferric, Abruptic, Arenic)
Sol ferrugineux tropical lessivé	ARh		
Sol ferrugineux tropical lessivé	ARl		
Sol ferrugineux tropical lessivé	ARl		Rubi-Hypoluvic Arenosol (Dystric)
Sol ferrugineux tropical lessivé	LXh		Haplic Lixisol (Epiarenic, Chromic)
Sol ferrugineux tropical lessivé	LXg		Gleyic Lixisols (Ferric)
Sol ferrugineux tropical lessivé à taches diffuses	ACf		Hapli-Ferric Acrisol (Abruptic, Chromic)
Sol ferrugineux tropical lessivé sur grès sablo-argileux	LXf		
Sol ferrugineux tropical lessivé, induré	ACp	PF	Pisoplinthic Acrisols (Chromic)
Sol ferrugineux tropical peu lessivé	ARo		
Sol ferrugineux tropical peu lessivé	LXf		
Sol gravillonnaire	RGe		
Sol halomorphe	SCh		
Sol hydromorphe	GLd		
Sol hydromorphe à pseudogley	FLe		Gleyic Fluvisol (Eutric)
Sol hydromorphe à pseudogley de surface	GLe		
Sol hydromorphe minéraux argileux à pseudogley	GLe		
Sol hydromorphe peu humifère	GLe		
Sol hydromorphe sur argile de décantation	GLe		
Sol peu évolué d'apport alluvial	FLe		Haplic Arenosols (Eutric, Arenic)
Sol peu évolué d'apport, hydromorphe	RGd		Endogleyic Regosol (Dystric)
Sol peu évolué d'érosion	RGe	LI	Hapli-Leptic Regosol (Eutric, Skeletic)
Sol peu évolué humifère sur matériaux très sableux de dunes aplanies	ARh		
Sol peu évolué non climatique d'apport hydromorphe sur alluvions lacustrines de texture fine	FLe		Gleyic Fluvisol (Eutric,Clayic)
Sol peu évolué non climatique d'apport	GLe		

Soil profile classification Carte Pédologique de Sénégal	FAO'88	PHAS	WRB (tentative)
alluvial, hydromorphe			
Sol sulfaté acide	FLt		Sali-Gleyic Fluvisol (Thionic, Sodic)
Sol sulfaté acide maturé à jarosite à moyenne profondeur	FLt		
Sols gravillonnaire sur niveau d'alteration argileuse de roche basique	RGe	LI	
Vertisol	VRe		
Vertisol lithomorphe à surface de structure massive (sol modal sur marnes)	VRe		
Vertisol lithomorphe à surface massive	VRk	TK	Mazic Vertisol (Calcaric)

Appendix 4: Correlation of Senegal profiles, according to the national system, Revised Legend (FAO-Unesco 1988), and the French system (CPCS 1967)

National Classification of Senegal	FAO'88	Classification (CPCS)
Bane	GLe	
Deck Dior de dépression	ACf	
Deck Dior de plaine	ACf	
Deck Dior de plaine	LXf	
Deck Dior de plaine	LXg	
Dior	LXf	
Dior Deck de vallée sèche	ARc	
Dior de basse plaine	FLe	Sol peu évolué d'apport alluvial
Dior de glacis de raccordement	LXf	Sol ferrugineux tropical lessivé
Dior de plaine	LXf	
Dior de plaine dunaire	ARh	
Dior de plaine dunaire	ARo	
Dior de plaine résiduelle	LXf	
Dior de terrasse	ARh	
Dior Deck de glacis de raccordement	ACf	
Dior Deck de vallée	ARl	
Dior Deck de vallée secondaire	CMd	
Dior Deck sur de bas plateaux	LXf	
Dior des dunes aplanies	ARo	Sol ferrugineux tropical peu lessivé
Dior-deck de dépression	ARh	
Salisol sulfaté	SCg	
Sulfatosol à jarosite	FLt	

Appendix 5: Technical information datasets

- Availability

The datasets of the 1:1M SOTER for the GLADA partner countries Argentina, China, Cuba, South Africa, Senegal and The Gambia, and Tunisia will be available (on CD/DVD) through FAO, Rome, in the Land and Water Digital media series (http://www.fao.org/ag/agl/lwdms.stm).

The SOTER datasets can also be downloaded from ISRIC – World Soil Information's website: http://www.isric.org/ .

- Formats

The SOTER datasets have been compiled using MS Office-Access®, version 2004.
The SOTER input software for the input of attribute data in the SOTER database is version 3.40 (Tempel 2002). All older versions are compatible.

The GIS files are created using ArcGIS9/ArcMap9.2®, the shape files may also be imported/ viewed in ArcView3.3®.

- Projection

The 'projection' of all SOTER maps is geographic WGS 1984 with coordinates given in decimal degrees.

- Size of files

Dataset	zipped (Mb)	unzipped (Mb)
Argentina	0.75	3.41
China	51.4	100.0
Cuba	1.02	5.23
Senegal and The Gambia	9.62	30.4
South Africa	17.2	58.0
Tunisia	0.86	4.25

World Soil Information

ISRIC - World Soil Information is an independent foundation with a global mandate, funded by the Netherlands Government. We have a strategic association with Wageningen University and Research Centre.

Our aims:

- *To inform and educate - through the World Soil Museum, public information, discussion and publication*
- *As ICSU World Data Centre for Soils, to serve the scientific community as custodian of global soil information*
- *To undertake applied research on land and water resources*