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Harmonized Global Soil Resources Database

Letter of Agreement between FAO and ISRIC
(PR 29651)

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SUMMARY

This document presents a harmonized soil resources database for those areas of the globe were SOTER or similar database were available. For all soil components of the mapping units of these databases, a set of 18 soil parameter estimates has been generated. As most soil components seldom hold all physical and chemical attribute data required by SOTER, missing data have been filled, using a procedure that used taxo-transfer rules derived from 9600 profiles in the ISRIC-WISE database.

Parameter estimates are presented by soil unit for fixed depths intervals of 0.2 m to 1 m depth for: organic carbon, total nitrogen, pH (H_2O), CEC_{soil}, CEC_{clay}, base saturation, effective CEC, aluminium saturation, $CaCO_3$ content, gypsum content, exchangeable sodium percentage (ESP), electrical conductivity of saturated paste (EC_e), bulk density, content of sand, silt and clay, content of coarse fragments (> 2 mm), and available water capacity (-33 to -1500 kPa).

Results are presented in a rasterized version of the geometric database at 5 by 5 arcminutes and a MS Access® database. The latter contains tables with the SOTER unit composition and a SOTER summary file with the 18 soil parameter estimates for standard depths for all soil components in a SOTER unit.

Keywords: soil parameter estimates, SOTER databases, WISE database.

1. INTRODUCTION

A Letter of Agreement (PR 29651) between the Land and Water Development Division of the Food and Agriculture Organization of the United Nations (FAO-AGL) and ISRIC – World Soil Information has been signed on 17-09-2004 to establish collaboration in support of producing an updated soil resource information database and generating the data for standard depths for all existing SOTER databases. The project period was from 1-10-2004 until 31-3-2005. The deliverables were further specified in the Terms of Agreement accompanying the LoA:

A Harmonized Global Soil Resources Database with a resolution of 5 arcminutes by 5 arcminutes based on:

a) harmonizing:

- SOTER of Latin America and the Caribbean (scale 1:5 M) (FAO *et al.* 1998b)
- SOTER of Southern Africa (scale 1:1 M and 1:2 M) (FAO and ISRIC 2003)
- SOTER of Central and Eastern Europe (scale 1:2.5 M) (FAO and ISRIC 2000)
- Spatial soil databases of Northeastern Africa / North and Central Eurasia (scales 1:1 M and 1:5 M respectively) (FAO and IIASA 1999; FAO *et al.* 1998a)

The final product would maintain the scales of the source data.

b) generating soil properties for standard depths:

A total of 18 soil parameter estimates for standard soil depths was generated based on profile data from SOTER (van Engelen and Wen 1995) completed with data from WISE, applying a methodology described by (Batjes 2003).

This report describes the various project activities: in Chapter 2 the modifications to the existing databases have been described;

Chapter 3 discusses the harmonization process, Chapter 4 the rasterization process and the end products, and Chapter 5 gives conclusions and options for future improvements.

2. MODIFICATIONS OF PRIMARY DATABASES

Contrary to SOTER conventions (van Engelen and Wen 1995) not all SOTER products are based on the Digital Chart of the World - DCW (DMA 1993) as the standard topographic base map. For Latin America for example (FAO *et al.* 1998b), the topography of the Soil Map of the World (FAO-Unesco 1974) was used. During this project all SOTER databases have been harmonized to DCW boundaries (international boundaries and coastlines).

All new polygons derived from the DCW and smaller than 10 km^2 (roughly 0.3 x 0.3 cm) were removed by using an ArcView script (Jenness 2005).

New data have been added to fill blatant gaps in the attribute database and errors in the attributes have been corrected (Dijkshoorn *et al.* 2005).

To standardize the coding of non-SOTER units in all SOTER databases, e.g. lakes and inland water bodies, glaciers and land ice, or urban areas, the following has been agreed (Table 1):

For water bodies in the GIS table the label has been standardized to ISO country code and ns1 for water (e.g. RUns1 = Russia non soil 1). These polygons do not have a SOTER unit number and thus no longer occur in the SOTER attribute database.

Details of the modifications are given below for each primary database.

Table 1. Non soil units at polygon level and their new codes

SOTER code	Description
ns1	lakes, permanent inland water bodies
ns2	glacier, land ice, permanent snow fields
ns3	salt plains, salt flats
ns4	dunes, (shifting) sands
ns5	rock outcrops, crumbly rock?
ns6	urban , building areas
ns7	quarry, open air mining and other excavations
ns8	perennial swamps, inaccessible marshes
ns9	salt lakes
ns10	Badlands
ns99	no data

Source: van Engelen *et al.* (in prep.)

2.1 Latin America and the Caribbean (SOTERLAC)

Geometry

The topographic base used for SOTER Latin America and the Caribbean (FAO *et al.* 1998b) is similar to that of the 1:5 M FAO-Unesco Soil Map of the World (FAO-Unesco 1974). The DCW international boundaries and coastlines – with a scale of 1:1 M - have now been incorporated into SOTERLAC. This resulted in numerous additions of small islands in the Caribbean and along the Chilean coast. Such new polygons smaller than 10 km^2 have been removed using GIS to obtain a topographic background with a similar detail for all harmonized databases.

A total of 70 polygons in the GIS file refer to non-soil or miscellaneous units. They were given special codes (Table 2) and they were removed from the attribute database.

Table 2. Non soil units at polygon level and their codes in SOTERLAC

Description	Number of polygons	Code
Water bodies and lakes	63	ns1
Glaciers	6	ns2
Urban areas	1	ns6

The mapping units of Puerto Rico and the Colombian Amazon were revised (Dijkshoorn *et al.* 2005).

SOTER attributes
Data of about 70 soil profiles for Peru, Belize and Puerto Rico have been added (Dijkshoorn *et al.* 2005).

The SOTERLAC database (version 1.0) (FAO *et al.* 1998b) only considered a limited number of profile horizon attributes. SOTERLAC, version 2.0, follows the structure of the 1:1 M SOTER (van Engelen and Wen 1995). New data, for example exchangeable bases, have already been entered for all Brazilian profiles.

2.2 Southern Africa (SOTERSAF)

Geometry
No geometric corrections were made to SOTERSAF (FAO and ISRIC 2003) as the coverage already used the coastline and boundaries of the Digital Chart of the World (DMA 1993), in accordance with SOTER conventions.

SOTER attributes
The South African part of SOTERSAF contained numerous profiles for which only the soil classification was known. The number of these virtual profiles – every soil component lacking a measured profile was allowed a virtual profile with a classification name – has been reduced by grouping similarly classified soils.

A total of 130 polygons in the GIS file represent non-soil units. There were no data for 4 polygons. All were given special codes (Table 3) and have been removed from the attributes database.

Table 3. Non soil units at polygon level and their codes in SOTERSAF

Description	**Number of polygons**	**Code**
Water bodies and lakes	129	ns1
Perennial swamps	1	ns8
No data	4	ns99

2.3 Central and Eastern Europe (SOVEUR)

Geometry

Various corrections have been made to the SOTER database of Central and East Europe at scale 1:2.5 M (FAO and ISRIC 2000). The geometric part of SOVEUR has been corrected according to the Digital Chart of the World (DMA 1993). This included mainly the correction of national boundaries and coastlines. New polygons smaller than 10 km^2 have been removed.

Profile locations

Profiles from Hungary and Ukraine had incorrect locations when plotted: errors were corrected.

SOTER attributes

Table 4 shows the non-soil units that are now excluded from the attribute database in SOVEUR (342 polygons), but occur on the map.

Table 4. Non soil units at polygon level and their codes in SOVEUR

Description	Number of polygons	Code
Water bodies and lakes	323	ns1
Urban areas	7	ns6
Glaciers and land ice	11	ns2
Quarries	1	ns7

In the soil component table some features can be classified as non soil. These form a part of the polygon and are also part of the landform such as dunes, rock outcrop, perennial swamps, salt plains, badlands, etc.

Non-soil units are flagged in the field 'Profile ID' of the soil component table by the ISO country code followed by the non-soil (ns) code (Table 5).

Table 5. Non soil units within soil components and their codes in SOVEUR

Description	Number of polygons	Code
Dunes and shifting sands	70	ns4
Rock outcrops	287	ns5

1.4 Northeastern Africa (IGAD)

The Soils of northeastern Africa database (SNEA) (FAO *et al.* 1998a), which follows the DCW boundaries, has been restructured according to the SOTER format to allow generation of soil attributes for standard depths as explained in Chapter 2. The new tables for the soil component only hold the soil unit description according to the Revised Legend (FAO *et al.* 1988). The Kenyan part of the SNEA database has been replaced with data from the revised KenSOTER database (Batjes and Gicheru 2004).

In the attribute database (SOIL COMPONENT), 545 entries were indicated as WATER BODIES (ID = 9997) These have been deleted from the attribute file. This has been done also for non-soil entries as SWAMP (ID = 9995), and for NO DATA (ID = 9996) when covering 100% of a polygon or SOTER unit. This information is no longer available in the attribute database, but maintained in the GIS file (Table 6).

Table 6. Non soil units at polygon level and their codes in SNEA

Description	Number of polygons	Code
Water bodies and lakes	127	ns1
Swamps	16	ns8
No data	14	ns99

1.5 North and Central Eurasia

Geometry

No corrections were made for the database of Northern and Central Eurasia (FAO and IIASA 1999) as the coverage included already the coastline and boundaries of the Digital Chart of the World (DMA 1993).

SOTER attributes

The database has a SOTER structure but lacks profile and horizon data. Only soil classifications are given. All soil attribute data have thus been derived through taxotransfer rules.

2. HARMONIZATION PROCESS

2.1 Missing data

The revised SOTER databases described in Chapter 1 contain profile data, selected by national soil surveyors as being representative for the various map units, with analytical data derived from the soil survey reports, except for SNEA and North and Central Eurasia. These profile descriptions seldom hold all physical and chemical attribute data required by SOTER.

Missing data in these profiles have been filled using taxo-transfer rules derived from 9600 soil profiles in the ISRIC-WISE database. The procedure is detailed by Batjes (2003).

Details on the gap filling procedures for the SOTER databases of Southern Africa, Latin America and the Caribbean and Central and Eastern Europe can be found in separate publications (Batjes 2004, 2005a, c; Batjes and Gicheru 2004).

The databases of Northeastern Africa (FAO *et al.* 1998a) and North and Central Eurasia (FAO and IIASA 1999) do not contain profile data. Therefore, all soil parameters were derived via taxotransfer (Batjes 2005b, d).

2.2 Soil parameter estimates

Eighteen soil parameter estimates are given for each soil unit for fixed depth intervals of 0.2 m to 1 m depth. These parameters are commonly required for studies on global change (Table 7).

Table 7. List of soil parameters in secondary SOTER data sets (Batjes 2003)

Organic carbon
Total nitrogen
Soil reaction (pH_{H2O})
Cation exchange capacity (CEC_{soil})
Cation exchange capacity of clay size fraction (CEC_{clay}) • ‡
Base saturation (as % of CEC_{soil}) ‡
Effective cation exchange capacity (ECEC) † ‡
Aluminium saturation (as % of ECEC) ‡
$CaCO_3$ content
Gypsum content
Exchangeable sodium percentage (ESP) ‡
Electrical conductivity of saturated paste (ECe)
Bulk density
Coarse fragments (volume %)
Sand (mass %)
Silt (mass %)
Clay (mass %)
Available water capacity (AWC; cm to specified depth, from -33 to -1500 kPa)□

‡ Calculated from other measured soil properties.

† ECEC is defined as exchangeable (Ca^{++}+Mg^{++}+K^{+}+Na^{+}) + exchangeable (H^{+}+Al^{+++}) (van Reeuwijk 2002).

• CEC_{clay} was calculated from CEC_{soil} by assuming a mean contribution of 350 $cmol_c$ kg^{-1} OC, the common range being from 150 to over 750 $cmol_c$ kg^{-1} (Klamt and Sombroek 1988a).

□ The soil water potential limits for AWC conform to USDA standards (Soil Survey Staff 1983).

2.3 Results

An MS Access® database has been generated that contains tables showing the full composition of each SOTER unit, the soil parameter estimates for all profiles and the rules applied to fill missing data.

SOTER unit composition

The full composition of each SOTER unit is given in terms of its dominant soils – each one characterized by a typical profile – and their relative extent. The relative extent has been expressed in five classes: 1 – from 80 to 100% , 2 - from 60 to 80%, 3 – from 40 to 60% , 4 – from 20 to 40%, and 5 – less than 20%. A description of the table *SOTERunitComposition* is given in Appendix 1.

Soil parameter estimates
The depth-weighted primary and taxotransfer rule-based data as defined by Batjes (2003), have been stored, layer by layer, in a secondary SOTER data set: table *SOTERparameterEstimates* (see Appendix 2).

Taxotransfer rules
The type of taxotransfer rule used has been flagged by profile and depth layer in table *SOTERflagTTRrules* (see Appendix 3). These flags provide an indication for the inferred confidence, or uncertainty, of the various parameter estimates presented here.

SOTER summary file
To facilitate the linking between the map and the attribute file, a SOTER summary file has been created (Appendix 4). It gives for every soil component in a SOTER unit the estimated soil parameters for standard depths.

3. RASTERIZATION

The harmonized coverages for SOTERLAC, SOTERSAF, etc. were merged into a single vector file. This file was been gridded to 5 x 5 arcminutes using the convert to grid option in ArcView. This corresponds to 0.083333 decimal degrees.

Each raster cell has a code: NEWSUID, a combination of the country's ISO code plus the SOTER unit (SUID) code. This code can be used to link the aggregated information of each SOTER unit, the SOTER unit composition table and the SOTER parameter estimates for each profile, described in Appendix 1 and 2 respectively.

4. CONCLUSIONS

- The present dataset is considered appropriate for studies on agro-ecological zoning, land evaluation and modelling of global change.
- The present set of soil parameter estimates and geographic data should be seen as best estimates, based on the currently available selection of data held in the various SOTER sets and WISE.
- Adding soil horizon attributes to those parts of the SOTER databases that have no profile data (e.g. Central and Northern Eurasia, Northeast Africa) is seen as a priority provided funding is available.
- Additional attributes should be added to those SOTER databases that have still a limited number of attributes per pedon (for example parts of SOTERLAC).
- Geographic delineations should be refined using Digital Elevation Models.

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APPENDICES

Appendix 1: SOTER unit composition file

This summary table gives the full composition of each SOTER unit in terms of its main soil units, their relative extent, and the identifier for the corresponding representative profile. It contains information aggregated from a number of primary SOTER tables, *viz. SoilComponent* and *Profile*. It can be easily linked to the SOTER geographical data in a GIS through the unique SOTER unit code – NEWSUID, a combination of the fields for ISO and SUID – and linked to the table holding the soil parameter estimates through the unique profile identifier (PRID, see Appendix 2).

tructure of table SOTERunitComposition

Name	Type	Size	Description
ISOC	Text	2	ISO-3166 country code (1994)
SUID	Integer	2	The identification code of a SOTER unit on the map and in the database
NEWSUID	Text	10	Globally unique SOTER code, comprising fields ISOC plus SUID (sometimes called: ISOCSUID)
SOIL1	Text	3	Characterization of the first (main) soil component according to the Revised Legend (FAO, 1988)
PROP1	Integer	2	Proportion, as a percentage, that the main soil component occupies within the SOTER unit
PRID1	Text	15	Unique code for the corresponding representative soil profile (as selected by the national soil experts)
SOIL2	Text	3	As above but for the next soil component
PROP2	Integer	2	As above
PRID2	Text	15	As above
SOIL3	Text	3	As above but for the next soil component
PROP3	Integer	2	As above
PRID3	Text	15	As above
SOIL4	Text	3	As above but for the next soil component
PROP4	Integer	2	As above
PRID4	Text	15	As above
SOIL5	Text	3	As above but for the next soil component
PROP5	Integer	2	As above
PRID5	Text	15	As above
SOIL6	Text	3	As above but for the next soil component
PROP6	Integer	2	As above

(cont.)

PRID6	Text	15	As above
SOIL7	Text	3	As above but for the next soil component
PROP7	Integer	2	As above
PRID7	Text	15	As above
SOIL8	Text	3	As above but for the next soil component
PROP8	Integer	2	As above
PRID8	Text	15	As above
SOIL9	Text	3	As above but for the next soil component
PROP9	Integer	2	As above
PRID9	Text	15	As above
SOIL10	Text	3	As above but for the next soil component
PROP10	Integer	2	As above
PRID10	Text	15	As above

Note: Generally, not all 10 available fields for $SOIL_i$ will be filled in SOTER.

Appendix 2: Taxotransfer rule-based soil parameter estimates

This table lists soil parameters estimates for all representative profiles considered in a given SOTER database. This information can be linked to the geographical component of the SOTER database – in a GIS – through the unique profile code (PRID, see Appendix 1).

Structure of table *SOTERparameterEstimates*

Name	Type	Size	Description
CLAF	Text	3	Revised Legend FAO (1988) code
PRID	Text	15	profile ID (as documented in table *SOTERunitComposition*)
Drain	Text	2	FAO soil drainage class
Layer	Text	8	code for depth layer (from D1 to D5; e.g. D1 is from 0 to 20 cm)
TopDep	Integer	4	depth of top of layer (cm)
BotDep	Integer	4	depth of bottom of (cm)
CFRAG	Integer	2	coarse fragments (> 2mm)
SDTO	Integer	2	sand (mass %)
STPC	Integer	2	silt (mass %)
CLPC	Integer	2	clay (mass %)
PSCL	Text	1	FAO texture class (see (Batjes 2003) for codes)
BULK	Single	4	bulk density (kg dm^{-3})
TAWC	Integer	2	available water capacity (cm m^{-1}, -33 to -1500 kPa conform to USDA standards)

(cont.)

CECS	Single	4	cation exchange capacity ($cmol_c$ kg^{-1}) for fine earth fraction
BSAT	Integer	2	base saturation as percentage of CECsoil
CECc	Single	4	CECclay, corrected for contribution of organic matter ($cmol_c$ kg^{-1})
PHAQ	Single	4	pH measured in water
TCEQ	Single	4	total carbonate equivalent (g kg^{-1})
GYPS	Single	4	gypsum content (g kg^{-1})
ELCO	Single	4	electrical conductivity (dS m^{-1})
TOTC	Single	4	organic carbon content (g kg^{-1})
TOTN	Single	4	total nitrogen (g kg^{-1})
ECEC	Single	4	effective CEC ($cmol_c$ kg^{-1})

Note: These are depth-weighted values.

The above table should be consulted in conjunction with table *SOTERflagTTRrules* which documents the taxotransfer rules that have been applied (see Appendix 3).

Appendix 3: Flagging taxotransfer rules

The type of taxotransfer that has been used when creating the table *SOTERparameterEstimates* (Appendix 2) is documented in table *SOTERflagTTRrules*. Further details on coding conventions may be found in Batjes (2003).

Structure of table *SOTERflagTTRrules*

Name	Type	Size	Description
CLAF	Text	3	Revised Legend (FAO, 1988) code
PRID	Text	15	Unique identifier for representative profile
Newtopdep	Integer	2	Depth of top of layer (cm)
Newbotdep	Integer	2	Depth of bottom of layer (cm)
TTRsub	Text	50	Codes showing the type of taxotransfer rule used (based on data for soil *units*; see text)
TTRmain	Text	50	Codes showing the type of taxotransfer rule used (based on data for *major units*; see text)
TTRfinal	Text	25	Codes showing the type of expert rules used

Note: For example, the exchangeable aluminium percentage (ALSA) has been set at zero when pH_{water} is higher than 5.5. Similarly, the electrical conductivity (ELCO), content of gypsum (GYPS) and content of carbonates (TCEQ) have been set at zero when pH_{water} is less than 6.5. Finally, the CEC of the clay fraction (CEC_{clay}) has always been re-calculated from the depth-weighted measured and TTR-derived data for CEC_{soil} and content of organic carbon, assuming a mean contribution of 350 $cmol_c$ kg^{-1} OC (Klamt and Sombroek 1988b). When applicable, this has been flagged in the field TTRfinal. Details may be found in.Batjes (2003).

Appendix 4: SOTER summary file

Interpretations of a SOTER database, in combination with the current set of soil parameter estimates requires a good knowledge of relational database handling systems and a sound understanding of the SOTER database structure. This may be an obstacle to end-users with limited programming expertise. Therefore, to facilitate access to the data and its ultimate linkage to GIS, a SOTER summary file has been created. The structure of the corresponding table is shown below.

Structure of table *SOTERsummaryFile*

Name	Type	Size	Description
ISOC	Text	2	ISO-3166 country code (1994)
SUID	Integer	2	The identification code of a SOTER unit on the map and in the database
NEWSUID	Text	10	Globally unique SOTER code, comprising fields ISOC plus SUID
TCID	Integer	1	Number of terrain component in given SOTER unit
SCID	Integer	1	Number of soil component within given terrain component and SOTER unit
PROP	Integer	3	Relative proportion of above in given SOTER unit
CLAF	Text	3	Revised Legend FAO (1988) code
PRID	Text	15	Profile ID (as documented in table SOTER-unitComposition)
Drain	Text	2	FAO soil drainage class
Layer	Text	8	Code for depth layer (from D1 to D5; e.g. D1 is from 0 to 20 cm)
TopDep	Integer	4	Upper depth of layer (cm)
BotDep	Integer	4	Lower dept of layer (cm)
CFRAG	Integer	2	Coarse fragments (> 2mm)
SDTO	Integer	2	Sand (mass %)
STPC	Integer	2	Silt (mass %)
CLPC	Integer	2	Clay (mass %)
PSCL	Text	1	FAO texture class (see Figure 8)
BULK	Single	4	Bulk density (kg dm^{-3})

(cont.)

TAWC	Integer	2	Available water capacity (cm m^{-1}, -33 to -1500 kPa, USDA standards)
CECS	Single	4	Cation exchange capacity ($cmol_c$ kg^{-1}) of fine earth fraction
BSAT	Integer	2	Base saturation as percentage of CECsoil
CECc	Single	4	CECclay, corrected for contribution of organic Matter ($cmol_c$ kg^{-1})
PHAQ	Single	4	pH measured in water
TCEQ	Single	4	Total carbonate equivalent (g kg^{-1})
GYPS	Single	4	Gypsum content (g kg^{-1})
ELCO	Single	4	Electrical conductivity (dS m^{-1})
TOTC	Single	4	Organic carbon content (g kg^{-1})
TOTN	Single	4	Total nitrogen (g kg^{-1})
ECEC	Single	4	Effective CEC ($cmol_c$ kg^{-1})

Notes:
1) These are depth-weighted values, per 20 cm layer.
2) Terrain Components, and their constituent Soil Components, within a given SOTER unit are numbered starting with the spatially dominant one. The sum of the relative proportions of all Soil Components within a SOTER unit is always 100 per cent.
3) A limited number of TTR-derived records may contain a negative value; this indicates that it has not yet been possible to plug the corresponding gaps using the current set of taxotransfer rules.