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Soil data derived from SOTER for studies of carbon stocks and change in Jordan

(Version 1.0)

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SUMMARY

This report presents a harmonized set of soil parameter estimates for Jordan, developed to permit modelling of soil carbon stocks and change at the national scale. The Soil and Terrain Database for Jordan (JORSOTER), at scale 1:500 000, compiled by the former National Soil Map and Land Use Project, formed the basis for the current work.

Twenty eight SOTER units have been mapped for Jordan, corresponding with 69 soil components. The major soils have been described using 48 soil profiles, selected by national soil experts as being representative for the country. The associated soil analytical data have been derived from soil survey reports.

Gaps in the measured soil profile data have been filled using a step-wise procedure which includes three main stages (Batjes 2003): (1) collate additional measured soil analytical data where available; (2) fill gaps using expert knowledge and common sense; (3) fill the remaining gaps using a scheme of taxotransfer rules.

Parameter estimates are presented by soil unit for fixed depth 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, aluminum saturation, $CaCO_3$ content, gypsum content, exchangeable sodium percentage (ESP), electrical conductivity of saturated paste (ECe), bulk density, content of sand, silt, clay, coarse fragments, and available water capacity. These attributes have been identified as being useful for agro-ecological zoning, land evaluation, crop growth simulation, modelling of soil carbon stocks and change, and analyses of global environmental change.

The current parameter estimates should be seen as best estimates based on the current selection of soil profiles and data clustering procedure. Taxotransfer rules have been flagged to provide an indication of the possible confidence in the derived data.

Results are presented as summary files and can be linked to the 1:500 000 scale SOTER map for Jordan in a GIS, through the unique SOTER-unit code.

The secondary data set is appropriate for studies at national scale. Correlation of soil analytical data, however, should be done more rigorously when more detailed scientific work is considered.

Keywords: soil parameter estimates, Jordan, environmental modelling, soil carbon, WISE database, SOTER database, secondary data set

1. INTRODUCTION

Three main sources of greenhouse gases generated or modified by human activities are: fossil fuel combustion, the chemical industry including cement production, and land use changes and system conversion (Watson *et al.* 2000; WBBGU 1998). On the other hand, agroecosystems can be adroitly managed to reduce carbon emissions and increase carbon sinks in vegetation and soil. It appears that this increased carbon uptake/storage can offset fossil fuel emissions temporarily (on a time scale from decades to a century) and partially, after which new steady state levels will be reached provided these systems remain undisturbed. Options for carbon sequestration must be chosen on the basis of knowledge of the nature and likely magnitude of C pools, whether organic or inorganic, in the soils of a given biome or agro-ecological region and the responses of these soils to different land use and management and anticipated changes in climate (Batjes 1999a; Lal *et al.* 1999; Sampson and Scholes 2000).

The current study has been carried out in the framework of the GEF co-funded project, *Assessment of Soil Organic Carbon Stocks and Change at National Scale* (GFL-2740-02-4381). The project will develop and demonstrate generic tools, which quantify the potential impact of land management and climate scenarios on change in soil carbon stocks at national and sub-national level. It involves participation from national scientists in Brazil, India, Jordan and Kenya working closely with data management and modeller groups in the Austria, France, the Netherlands, the United Kingdom and the USA.

The main research objectives, summarized on the project website[1], are:

1. To identify and use long-term, plot scale, experimental datasets to systematically evaluate and refine modelling techniques to quantify carbon sequestration potential in tropical soils;

2. To define, collate and format national-scale soils, climate and land-use datasets and to use them in the development of coupled modelling-GIS tools to estimate soil carbon stocks;

[1] http://www.reading.ac.uk/GEFSOC

3. To demonstrate these tools by estimating current soil organic carbon stocks at country-scale – using the Indo-Gangetic Plains (India), Jordan, Kenya and Amazon (Brazil) as case studies – and to compare these estimates with the existing techniques of combining soil mapping units and interpolating point data;

4. To quantify the impact of defined changes in land use and climate on carbon sequestration in soils with a view to assisting in the formulation of improved policies to optimise resource use in the four case-study countries.

This report presents parameter estimates for the major soils of Jordan, at scale 1:500 000, for use in the modelling component of the GEF-SOC project. The materials and methods are described in Chapter 2, with special focus on the procedure for preparing the secondary SOTER sets. Results are discussed in Chapter 3, while concluding remarks are drawn in Chapter 4. The structure of the various output tables is documented in the Appendices, which also include a brief description of the contents of the secondary SOTER file for Jordan (Appendix 6).

The secondary SOTER data set annex GIS file for Jordan can be downloaded via www.isric.org[2].

2. MATERIALS AND METHODS

2.1 Biophysical setting

The Hashemite Kingdom of Jordan covers 89 206 km^2 and has a population of 6.3 million (Times Atlas 2003). Altitude ranges from -411 m at the Dead Sea to 1754 m at the peak of Jabal Ramm in the south of the country. The geology includes basalt, sandstone, limestone, chalk, marl and chert and various Pleistocene and Holocene deposits, of alluvial and aeolian origin (Bender 1964-1974). The country may be divided into six physiographic provinces: (1) The Rift (Wadi al Araba, Dead Sea and Jordan Valley; (2)

[2] After official termination of the GEFSOC project (July 2005).

Mountain Ridge and Northern Highlands east of the Rift; (3) Southern Mountainous Desert; (4) Central Plateau; (5) Azraq – Wadi Sirhan Depression; (6) the North-eastern Desert, which includes the Basalt Plateau (Sunna 1984).

Climate varies over a distance of only 100 km from sub-humid Mediterranean (annual rainfall about 600 mm) in the northwestern part of the country to hyper-arid conditions (annual rainfall < 50 mm) to the east. The prevalent ecosystem in Jordan is desert or Badia (annual rainfall < 200 mm), covering over 80 percent of the country (Rawajfih *et al.* 2002).

Salinity is the major threat to irrigated soils outside the western highland and the Northern Jordan Valley, where winter rainfall is sufficient to leach salts that may have accumulated during the preceding spring and summer (Al-Qudah 2001) – this is the region where most human and agricultural activity is concentrated. The Badia provides Jordan with 60 per cent of its groundwater, 90 per cent of its rangelands, 70 per cent of its meat supply and about 25 per cent of national GDP.

2.2 Source of data

Al-Qudah (2001) reviewed the status of soil mapping and classification in Jordan, beginning with an exploratory survey of East Jordan (Moormann 1959) and culminating in a generalized soil map at scale 1:250 000 (MINAG 1993). The latter was based on analysis of LANDSAT data and aerial photography, and complemented with field observations in sample areas and traverses. More detailed surveys, at scales ranging from 1:50 000 to 1:10 000 followed in areas identified as having potential for agriculture.

The 1:250 000 inventory provided the basis for compiling a generalized 1:500 000 scale soil and terrain (SOTER) database (ACSAD 1996). The soil geographical and attribute data have been collated into the SOTER format by staff of the former National Soil Map and Land Use Project (NSMLUP 1996). ISRIC staff organised the initial SOTER training and participated in border correlation trips in Jordan and Syria and the final training workshop (Van Engelen, *personal communication*).

2.3 SOTER methodology

The SOTER methodology allows mapping and characterization of areas of land with a distinctive, often repetitive, pattern of landform, lithology, surface form, slope, parent material, and soils (Van Engelen and Wen 1995). The approach resembles physiographic or land systems mapping. The collated materials are stored in a SOTER database linked to GIS, permitting a wide range of applications (e.g., Batjes 2000; Mantel and Van Engelen 1999; Savin *et al.* 1997; Varallyay *et al.* 1994). The SOTER methodology is mainly applied at scales ranging from 1:250 000 to 1:5M.

Each SOTER database is comprised of two main elements, a geographical component and an attribute data component (Figure 1). The *geographical database* holds information on the location, extent and topology of each SOTER unit. The *attribute database* describes the characteristics of the spatial unit and includes both area data and point data. A geographical information system (GIS) is used to manage the geographic data, while the attribute data are handled in a relational database management system (RDBMS).

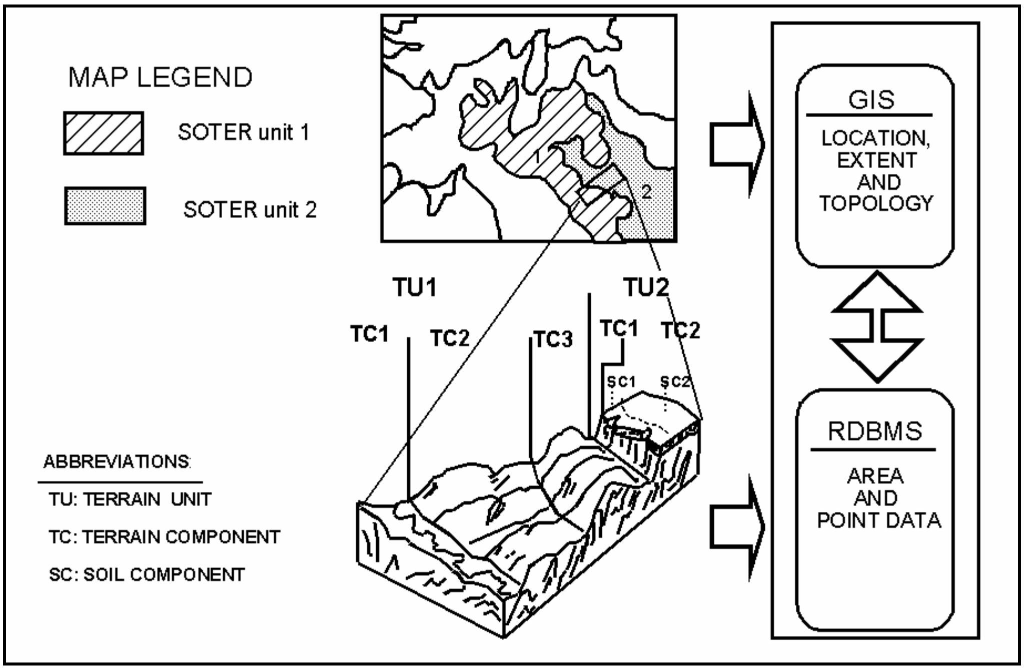

Figure 1. Schematic representation of two SOTER units and their terrain and soil components

Each SOTER unit in the geographic database has a unique identifier, called SOTER unit-ID (SUID). This primary key provides a link to the attribute data for its constituent terrain, terrain component(s) (TCID) and soil component(s) (SCID) (see Appendix 4).

Each soil component within a SOTER unit is described by a profile (PRID), identified by the national soil experts as being regionally representative. Profiles are characterised according to the Revised Legend of FAO (1988). Representative profiles are selected from available soil survey reports, as the SOTER program does not involve new ground surveys. Batjes (1999b) reviewed issues of data acquisition, quality control and sharing in the context of SOTER projects.

A comprehensive description of the methodology and coding conventions is given by Van Engelen (1995). The SOTER attribute data are managed with an automated data entry facility (Tempel 2002). In addition, SOTER uses commercially available Access® and ArcView® software.

2.4 Preparation of secondary SOTER data sets

2.4.1 List of soil parameters

Special attention has been paid to the key attributes required for the spatial runs of the two organic carbon models considered in the GEF-SOC project: RothC and Century. These are: the extent and type of soil, soil drainage status, content of clay, content of organic carbon, and bulk density per depth layer (Falloon *et al.* 1998; Paustian *et al.* 1997). This limited set has been expanded to include 18 soil parameters (Table 1) commonly required in studies of agro-ecological zoning, food productivity, soil gaseous emissions/sinks and environmental change (see Batjes 2004; Bouwman *et al.* 2002; Cramer and Fischer 1997; Fischer *et al.* 2002; Scholes *et al.* 1995).

Table 1 does not consider soil hydraulic properties. Although these are essential for many simulation studies these are seldom measured during soil surveys. As a result, the corresponding records are lacking in databases such as SOTER and WISE. Information on soil hydraulic properties and pedotransfer functions for Western Europe and the USA may be found in auxiliary databases (see Nemes *et al.* 2003; Wösten *et al.* 1998) but similar work for tropical soils has just begun (Tomasella and Hodnett 1997, 1998; Van den Berg *et al.* 1997).

Table 1. List of soil parameters

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) † ‡
Aluminum 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; from -33 to -1500 kPa; % w/v) ‡ □

‡ Calculated from other measured soil properties.

† ECEC is defined as exchangeable (Ca^{++}+Mg^{++}+K^{+}+Na^{+}) + exchangeable (H^{+}+Al^{+++}) (Van Reeuwijk 1995).

• 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 1988).

□ The soil water potential limits for AWC conform to USDA standards (Soil Survey Staff 1983). Values shown have not been corrected for the presence of coarse fragments.

2.4.2 Consistency and integrity checks of the primary data

Data consolidation started with the conversion of the unpublished SOTER set for Jordan (ACSAD 1996; NSMLUP 1996) from dBaseIV® into Access 2000®. This exercise included an intensive, and essential, check on data consistency and integrity.

Obvious errors and gaps have been corrected using expert knowledge and common sense, complemented with reference materials available at ISRIC – World Soil Information. Subsequently, all alphanumeric and selected numeric data, such as pH, sum of (sand + silt + clay) and available water capacity, were subjected to a rigorous scheme of data checks (see p. 52 in Batjes

1995). In view of glaring inconsistencies in the original data set, all numeric data were further checked for errors in units of measurement – notably, the erroneous use of per cent (%) instead of the mandatory per thousand (‰) for organic carbon, inorganic carbon, total nitrogen and gypsum content in SOTER. Inconsistencies in flagging expert estimates in the primary database were corrected. This necessitated going back to the original profile descriptions, kindly supplied by the case study partners.

2.4.3 Soil characterization according to FAO Revised Legend

The system of soil classification adopted in Jordan is Soil Taxonomy (Soil Survey Staff 1992). FAO classifications are also provided but certain diagnostic properties (FAO) were overlooked during the initial SOTER exercise by NSMLUP (1996): in particular, the occurrence of salic properties within the top 30 cm of soil which led to an under-representation of Solonchak units. Vast areas in the Badia contain high amounts of gypsum, carbonates and soluble salts, providing limited scope for a viable agricultural production system (Rawajfih *et al.* 2002).

The new, re-classified data set is based on 48 representative soil profiles (including 9 synthetic profiles). This corresponds with an average density of 0.06 profiles per 100 km^2. All synthetic profiles were flagged to avoid confusion with real profiles, for example JOPA120syn. Synthetic profiles can be introduced in SOTER when there are no measured data for a given soil unit, provided the soil classification is known at the level of the Soil Component.

2.4.4 Procedure for filling gaps in the measured data

The SOTER work for Jordan (1994 to 1996) drew on materials resulting from an exploratory survey at scale 1:250 000. Therefore, complete soil analytical data sets are not available for all profiles. The occurrence of such gaps precludes the direct use of primary SOTER data in models. Therefore, a standardized procedure has been developed to fill gaps in key measured data in three main stages (Batjes 2003):

a) Collating additional measured soil data where these exist, in the uniform SOTER format;
b) Using national expert estimates and common sense to fill selected gaps in a secondary data set;
c) Using taxotransfer rule (TTR) derived soil parameter estimates for similar FAO soil units, as derived from the global WISE profile database.

The desirability of the above stages decreases from highest (a) to lowest (c). Step (c) is detailed by Batjes (2003). Steps (a) and (b), being specific to the Jordanian case and, thus, strongly dependent on national inputs, are discussed in detail below.

a) Collating additional measured data

This stage is self-explanatory and depends upon the availability of suitable materials and their accessibility to the national project scientists working with the relevant soil survey organisations; no new profiles were provided for this study.

b) Using expert-based estimates

The second stage depends upon the expertise of soil scientists, well versed with the national soil conditions, and pedological common sense.

Soil organic carbon (OC), for example, has seldom been measured for the soil profiles represented in the SOTER set for Jordan. When available, it has been measured only for the top horizon. In principle, taxotransfer rules could be used to plug gaps in the measured data. This was not done, however, because profiles from hyper-arid and arid regions are still under-represented in the global WISE database, which provided the analytical basis for developing taxotransfer (TTR) rules. Therefore, application of the WISE-based TTR's for organic carbon to the Jordanian SOTER set could give a misleading picture. Hence, an expert-based approach had to be developed, like for soil pH (see Appendix 5).

c) Application of taxotransfer rules

The taxotransfer (TTR) approach was developed initially for application with the Soil Map of the World (Batjes 2002; Batjes *et al.* 1997), in collaborative studies with FAO and IIASA, using soil analytical data held in ISRIC's WISE database. The methodology has been modified in the framework of the GEFSOC project for use with national scale SOTER databases. The approach is detailed by Batjes (2003).

3. RESULTS AND DISCUSSION

3.1 General

Twenty seven SOTER units have been mapped for Jordan — excluding the Dead Sea —, corresponding with 67 soil components (NSMLUP 1996). At the small scale under consideration, most SOTER units will be compound units. Some of the spatially minor soil units, however, may be of particular relevance. For example, soils of oases can be of great importance for national inventories of carbon stocks and change in arid areas. It is therefore recommended that end-users consider all component soil units of a SOTER unit in their assessments or model runs.

Ultimately, the type of research purpose will determine which parameter estimates or single value maps are of importance. Therefore, the full map unit composition can best be addressed with tailor made programs designed to meet the scope of the application.

3.2 SOTER unit composition

A table – *sensu* Access® databases – has been generated showing the full composition of each SOTER unit in terms of its dominant soils – each one characterized by a regionally representative profile – and their relative extent.

The relative extent of each soil unit has been expressed in 5 classes to arrive at a compact map unit code: 1 – from 80 to 100 per cent; 2 – from 60 to 80 per cent; 3 – from 40 to 60 percent; 4 – from 20 to 40 per cent, and 5 – less than 20 percent.

Figure 2 shows an excerpt of the corresponding table for Jordan, and Appendix 1 its structure. Based on current knowledge (NSMLUP 1996) the SOTER or map unit with country ISO code JO and number 16 is coded as CLh3CMc4LPe4. The 16th map unit for the country is comprised of 40 per cent haplic Calcisols (CLh), 30 per cent calcaric Cambisols (CMc) and 30 per cent eutric Leptosols (LPe).

SOTERunitComposition : Table

NEWSUID	SoilMapUnit	SOIL1	PROP1	Profile-ID1	SOIL2	PROP2	Profile-ID2	SOIL3	PROP3	Profile-ID3
JO5	RGc3LPq4CLh5 [5]	RGc	55	JOM1672sy	LPq	30	JOPH046	CLh	15	JOPM149
JO6	CMc3RGc3 [6]	CMc	51	JOPT004	RGc	49	JOPA389syn			
JO7	LPe1RGc4 [7]	LPe	80	JOPN051sy	RGc	20	JOPN038			
JO8	ARc2LPe3 [8]	ARc	60	JOPN002	LPe	40	JOPN051syn			
JO9	CLh2RGc4 [9]	CLh	75	JOPM149	RGc	25	JOM1672syn			
JO10	CMc3CLh4GYh4 [10]	CMc	50	JOPN099sy	CLh	30	JOPM149	GYh	20	JOPD056
JO11	RGc3GYh4LPe4 [11]	RGc	50	JOPN009	GYh	30	JOPD056	LPe	20	JOPN051syn
JO12	CMv4VRk4CLh4 [12]	CMv	35	JOPA070	VRk	35	JOPA078	CLh	30	JOPA082
JO13	CLh3LPe3 [13]	CLh	50	JOPA082	LPe	50	JOPA210syn			
JO14	CMc2LPe4 [14]	CMc	70	JOPS062	LPe	30	JOPB073			
JO15	CMc2LPe3 [15]	CMc	60	JOPD097	LPe	40	JOPD098			
JO16	CLh3CMc4LPe4 [16]	CLh	40	JOPG007	CMc	30	JOPT017	LPe	30	JOPW041
JO17	GYk3SCk4SCn4 [17]	GYk	40	JOPA100	SCk	30	JOPN050	SCn	30	JOPT009

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Figure 2. Characterization of SOTER units in terms of their main component soils – with their representative profile – and their relative extent

3.3 Soil Parameter estimates

The depth-weighted primary and TTR-derived data, by layer, for the 18 soil properties under consideration (Table 1) have been stored in a secondary SOTER data set (Figure 3); the cut-off point for applying any TTR is $n_{WISE} < 5$. The structure of the corresponding file is described in Appendix 2.

SOTERparameterEstimates : Table

CLAF	PRID	Drain	Layer	TopDe	BotDe	CFRAG	SDTO	STPC	CLPC	PSCL	BULK	TAWC	CECS	BSAT	CECc	PHAQ	TCEQ	GYPS	EL
CMc	JOPA130	W	D1	0	20	1	2	60	38	F	1.38	14	23	100	59	8.3	204	43	
CMc	JOPA130	W	D2	20	40	1	2	60	38	F	1.41	14	22	100	56	8.2	204	41	
CMc	JOPA130	W	D3	40	60	1	2	68	30	Z	1.47	13	23	100	49	7.8	175	46	
CMc	JOPA130	W	D4	60	80	1	2	68	30	Z	1.44	14	23	100	47	7.8	175	46	
CMc	JOPA130	W	D5	80	100	1	2	68	30	Z	1.46	13	23	100	52	7.8	175	46	
CLh	JOPA179	W	D1	0	20	4	21	53	26	M	1.30	9	21	100	70	8.3	213	36	
CLh	JOPA179	W	D2	20	40	4	12	48	40	F	1.35	10	27	100	63	8.0	213	40	
CLh	JOPA179	W	D3	40	60	20	12	48	40	F	1.39	9	22	100	51	8.0	314	40	
CLh	JOPA179	W	D4	60	80	28	12	48	40	F	1.38	9	19	100	45	8.0	369	40	
CLh	JOPA179	W	D5	80	100	28	12	48	40	F	1.40	10	19	100	56	8.1	369	47	
LPe	JOPA210syn	W	D1	0	20	52	25	65	10	M	1.35	16	14	90	41	6.5	3	1	
LPe	JOPA210syn	W	D2	20	26	60	25	65	10	M	1.26	17	10	78	40	6.6	39	1	

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Figure 3. Example of ultimate result of the application of the TTR-scheme and depth-weighing for three profiles

The type of TTR used, if any, has been flagged by profile and depth layer in a separate table (Figure 4, Appendix 3). The field TTRsub indicates that the data substitution for a given attribute, in the secondary SOTER set, is based on WISE-derived parameter estimates for similar soil units. Otherwise, should the corresponding population in WISE be too small ($n_{WISE} < 5$) for a meaningful substitution, the rules used are flagged under TTRmain (see Batjes 2003).

SOTERflagPTRrules : Table

CLAF	PRID	Layer	Newtopdep	Newbotdep	TTRsub	TTRmain
CMc	JOPA130	D1	0	7	b3c2h3j3o3r2	a2
CMc	JOPA130	D1	7	20	b3c2h3j3o3r2	a2
CMc	JOPA130	D2	20	40	b3c2h2j2o3r2	a3
CMc	JOPA130	D3	40	60	b3c3d3h3j3o3r3	A2
CMc	JOPA130	D4	60	80	B1C1d3H1j3O2R1	A2
CMc	JOPA130	D5	80	100	b3c3d3h3J1O2r3	A2
CLh	JOPA179	D1	0	7	b1c1h1j1o3	-
CLh	JOPA179	D1	7	20	b1c1h1j1o3r1	-
CLh	JOPA179	D2	20	40	b2c2h2j2O2r3	-
CLh	JOPA179	D3	40	47	b2c2h2j2O2r3	-
CLh	JOPA179	D3	47	60	b2c2h2j2O2r3	-
CLh	JOPA179	D4	60	80	b2c2h2j2O3r3	-
CLh	JOPA179	D5	80	86	b3c2h3j3O3r3	-
CLh	JOPA179	D5	86	100	b3c2d3h3j3O3r3	-
LPe	JOPA210syn	D1	0	5	b2c3d1e1h2i3j2k3l1O3p3r1	A4
LPe	JOPA210syn	D1	5	20	b2c3d1e1h2i3j2k3l1O3p3r1	A4
LPe	JOPA210syn	D2	20	26	b3c3d2e2h3i3j3l2O3p3r2	A4k3

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Figure 4. Flagging of taxotransfer rules by profile, depth zone and attribute

Each flag consists of a sequence of letters followed by a numeral (see under TTRsub and TTRmain in Figure 4). The letters indicate soil attributes for which a TTR has been applied (Figure 5). The number code reflects the size of the sample population in WISE, after outlier rejection, on which the statistical analyses was based (Table 2). This is depicted schematically for the upper 0 to 20 cm of a hypothetical profile (JOhyp04):

CLAF	PRID	LAYER	Newtopdep	Newbotdep	TTRsub	TTRmain
CMc	JOhyp04	D1	0	15	b3c2j3o3r2	a2h1
CMc	JOhyp04	D1	15	20	C3j1	A2

Soil parameter estimates based on WISE-derived data, using data for the corresponding major grouping and either the same textural class (small letter) or undifferentiated textural class (capital).

Soil parameter estimates based on WISE-derived data, using data for the corresponding soil unit and same textural class:
- b: Base saturation, 3 (n_{WISE} = 5 –14)
- c: Bulk density, 2 (n_{WISE} = 15 – 29)
- j: Exchangeable sodium percentage, 3 (n_{WISE} = 5 –14)
- o: Volumetric water content, 3 (n_{WISE} = 5 –14)
- r: Total Nitrogen, 2 (n_{WISE} = 15 – 29)

When a small letter is used, the substitution considered median data for the corresponding textural class (for example, Fine and n_{WISE} > 5). Otherwise, when a capital is used, this indicates that the substitution is based on the whole set for the corresponding soil unit and depth layer, irrespective of soil texture (i.e. undifferentiated or #). The same coding conventions apply for TTRmain.

SWcodes : Table

SOTnam	WISnam	SoilVariable	TTRflag	Comments
---	---	---	y	PSCL estimated from PTR-derived sand, silt and clay
ALSA	ALSA	ALSAT	a	exchangeable Aluminum percentage (% of ECEC)
BSAT	BSAT	BSAT	b	base saturation (% of CECs)
BULK	BULK	BULKDENS	c	bulk density
CECC	CECC	CECCLAY	d	cation exchange capacity of clay fraction (corr. for org. C)
CECS	CECS	CECSOIL	e	cation exchange capacity
CFRAG	GRAV	GRAVEL	f	coarse fragments
CLPC	CLAY	CLAY	g	clay % (see also Y for texture (g, m & n))
ECEC	ECEC	ECEC	h	effective CEC
ELCO	ECE	ECE	i	electrical conductivity
ESP	ESP	ESP	j	exchangeable Na percentage (% of CECs)
GYPS	GYPS	GYPSUM	k	gypsum content
PHAQ	PHH2	PHH2O	l	pH in water
SDTO	SAND	SAND	m	sand %
STPC	SILT	SILT	n	silt %
TAWC	TAWC	TAWC	o	volumetric water content (-33 to - 1500 kPa)
TCEQ	CACO	CACO3	p	carbonate content
TOTC	ORGC	ORGC	q	organic carbon content
TOTN	TOTN	TOTN	r	total nitogen content

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Figure 5. Conventions for coding the various attributes used in the taxotransfer scheme.

Table 2. Criteria for defining confidence in the derived data

Code	Confidence level	n_{WISE}
1	Very high	> 30
2	High	15-29
3	Moderate†	5-14
4	Low	1-4
-	No data	0

* n_{WISE} is the sample size after the screening procedure (see Figure 5)
† The cut-off point in the TTR-approach is $n_{WISE} < 5$

In the case of the synthetic profiles, such as JOPA210syn, all 18 parameter estimates have been derived via taxotransfer or using expert estimates (Appendix 5). This is already reflected by the abbreviation *syn* in the profile identifier.

The overall assumption is that the confidence in a TTR-based parameter estimate, should increase with the size of the sample populations present in WISE, after outlier rejection. In addition, the confidence in soil parameter estimates listed under TTRsub, will be higher than for those listed under TTRmain.

A high confidence rating does not necessarily imply that the soil parameter estimates shown will be representative for the soil unit under consideration. Profile selection for SOTER, as for any other database, is not probabilistic but based on available data and expert knowledge. Several of the soil attributes under consideration in Table 1 are not diagnostic in the Revised Legend (FAO, 1988). In addition, some properties are readily modified by changes in land use or management, for example the organic and inorganic carbon content upon irrigation.

Table 3 lists how often a given TTR has been applied as a percentage of the total number of horizons (up to a depth of 100 cm) in the SOTER profile data base; details may be found in table SOTERflagTTRrules (see Appendix 3). For example, bulk density (BULK) has been has been estimated using TTRs in 100 % of the cases, mainly using data for similar soil units (see under TTRsub). Similarly, there are no moisture retention (TAWC) data in the SOTER database for Jordan. In so far organic carbon and soil texture data are concerned, see the expert rules in Appendix 5.

Table 3.Type and frequency of taxotransfer rules applied

Parameter	Code	Frequency of occurrence (%)		
		TTRsub	TTRmain	Total
ALSA	A	0	47	47
BSAT	B	98	2	100
BULK	C	87	13	100
CECC	D	49	3	52
CECS	E	21	0	21
CFRAG	F	0	0	0
CLPC	G	0	0	0
ECEC	H	96	4	100
ELCO	I	18	0	18
ESP	J	100	0	100
GYPS	K	19	5	24
PHAQ	L	16	0	16
SDTO	M	0	0	0
STPC	N	0	0	0
TAWC	O	77	23	100
TCEQ	P	21	0	21
TOTC	Q	0	0	0
TOTN	R	82	10	92

3.4 Linkage to GIS

Aggregated information about the SOTER unit composition and results of the TTR-work can now be linked to the SOTER map using GIS. At the national scale, this can be done via the unique SOTER unit identifier (SUID, see Appendix 4). In transnational databases, however, linkage will be through the NEWSUID, which is a combination of the country's ISO code plus the SUID code.

Most SOTER units in Jordan comprise at least two soil components. In the primary database, the associated information is stored in a range of relational databases to enhance data storage and management efficiency. To assist end-users, a new table has been created that incorporates data held in the primary SOTER database and the present information on soil parameter estimates (Figure 6, Appendix 4). Clearly, this wealth of information, although needed for the modelling work, complicates linkage to GIS.

SOTERsummaryFile : Table

NEWSUID	TCID	SCID	Propc	CLAF	PRID	Drain	Layer	TopDe	BotDe	CFRA(	SDTO	STPC	CLPC	BULK	TAWC	CECS	BSAT	CECc	PHAQ	T
JO10	1	1	50	CMc	JOPN099syn	W	D1	0	20	8	75	15	10	1.40	12	10	98	56	8.0	
JO10	1	1	50	CMc	JOPN099syn	W	D2	20	40	1	60	15	25	1.44	12	17	100	54	8.1	
JO10	1	1	50	CMc	JOPN099syn	W	D3	40	60	1	60	15	25	1.45	13	18	100	62	8.2	
JO10	1	1	50	CMc	JOPN099syn	W	D4	60	65	1	60	15	25	1.40	16	18	100	61	8.1	
JO10	1	2	30	CLh	JOPM149	M	D1	0	20	8	48	36	16	1.30	9	4	100	25	8.8	
JO10	1	2	30	CLh	JOPM149	M	D4	60	80	28	39	33	28	1.34	9	4	100	60	8.3	
JO10	1	2	30	CLh	JOPM149	M	D5	80	90	28	39	33	28	1.36	8	4	100	42	8.3	
JO10	1	2	30	CLh	JOPM149	M	D2	20	40	4	42	35	23	1.35	9	5	100	60	8.1	
JO10	1	2	30	CLh	JOPM149	M	D3	40	60	15	42	31	27	1.35	9	4	100	56	7.8	
JO10	1	3	20	GYh	JOPD056	W	D1	0	20	0	58	22	20	1.30	9	9	100	76	7.6	
JO10	1	3	20	GYh	JOPD056	W	D2	20	40	0	62	15	23	1.36	12	8	100	44	7.5	
JO10	1	3	20	GYh	JOPD056	W	D3	40	60	1	68	9	23	1.34	11	7	100	42	7.4	
JO10	1	3	20	GYh	JOPD056	W	D4	60	80	3	78	6	16	1.37	9	5	100	36	7.5	
JO10	1	3	20	GYh	JOPD056	W	D5	80	100	10	78	9	13	1.39	14	4	100	30	7.6	
JO11	1	1	50	RGc	JOPN009	S	D1	0	20	1	55	31	14	1.30	27	2	100	82	8.1	
JO11	1	1	50	RGc	JOPN009	S	D2	20	40	1	57	29	14	1.50	14	2	100	58	8.0	
JO11	1	1	50	RGc	JOPN009	S	D3	40	60	16	52	32	16	1.51	8	2	100	74	8.0	
JO11	1	1	50	RGc	JOPN009	S	D4	60	80	60	36	42	22	1.48	3	1	100	59	8.0	
JO11	1	1	50	RGc	JOPN009	S	D5	80	100	52	42	39	19	1.49	16	1	100	34	8.0	
JO11	1	2	30	GYh	JOPD056	W	D5	80	100	10	78	9	13	1.39	14	4	100	30	7.6	
JO11	1	2	30	GYh	JOPD056	W	D2	20	40	0	62	15	23	1.36	12	8	100	44	7.5	
JO11	1	2	30	GYh	JOPD056	W	D1	0	20	0	58	22	20	1.30	9	9	100	76	7.6	
JO11	1	2	30	GYh	JOPD056	W	D3	40	60	1	68	9	23	1.34	11	7	100	42	7.4	
JO11	1	2	30	GYh	JOPD056	W	D4	60	80	3	78	6	16	1.37	9	5	100	36	7.5	
JO11	1	3	20	LPe	JOPN051syn	E	D1	0	16	48	59	15	26	1.35	16	14	90	41	7.2	

Record: 1 of 273

Figure 6. Excerpt of a SOTER summary file for units JO10 and JO11

For visualization and analysis in GIS, it will often be necessary to make an extra selection. For example, in the case of the RothC and Century models, information may be required about the properties of the topsoil – that is layer D1: 0-20 cm – for the dominant soil. In this case, the necessary selection will be for the first Terrain Component (TCID=1), first Soil Component (SCID= 1) and the upper most layer (D1= 1). The corresponding selection is included as a separate table in the secondary database for Jordan. Details about the database structure are given in Appendix 4.

Figure 7 schematically shows the procedure for linking the various secondary attribute data to the geographical SOTER data held in the GIS. For ease of visualization, it considers only the upper layer (D1) of the spatially dominant (first) soil component of SOTER unit JO19.

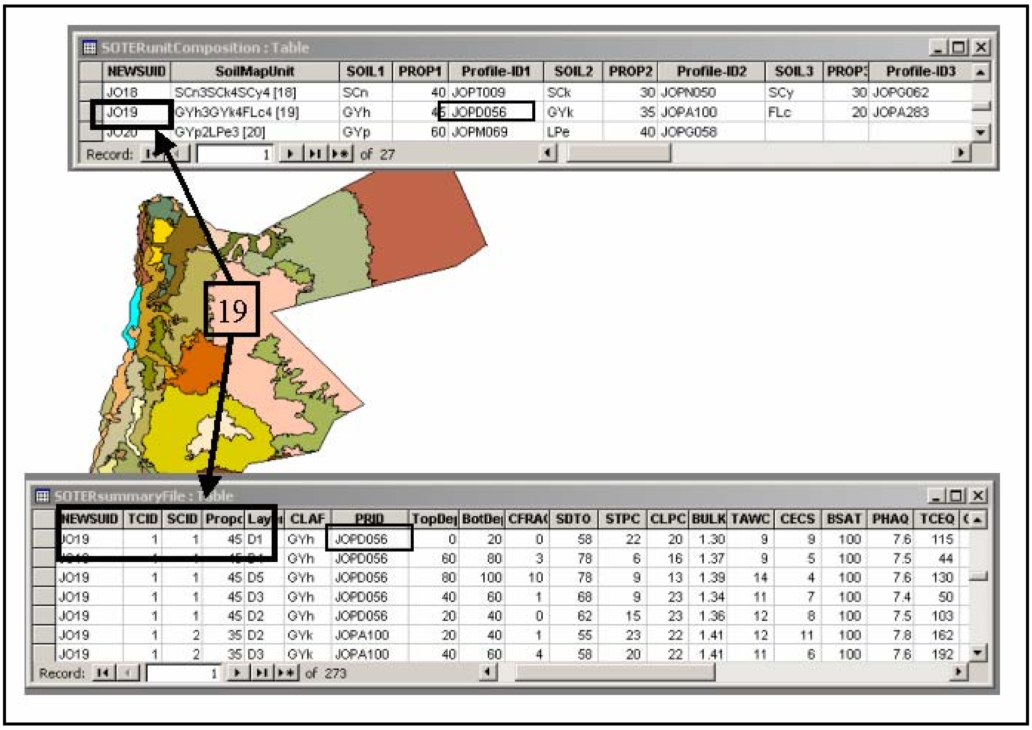

Figure 7. Linking soil parameter estimates for the top 20 cm of the dominant soil (JOPD056) of SOTER unit JO19 with the geographical component of SOTER

All geographic data in SOTER are presented in vector format. However, should grid-based soil layers be required, these can be generated using the convert-to-grid module of the spatial analyst extension to ArcView (ESRI 1996). The minimum legible delineation implied by the mapping scale of 1:500 000 is about 6.3 km^2. Gridding should be based on the SUID field to permit subsequent linkage with the various attribute tables discussed in this report. The procedure will be same as described earlier in Figure 7.

4. CONCLUSIONS

- Linkage between soil profile data and the spatial component of a SOTER map, for environmental applications, requires generalisation of measured soil (profile) data by soil unit and depth zone. This involves the transformation of variables that show a marked spatial and temporal variation and that may have been determined in a range of laboratories according to various analytical methods.

- A pragmatic approach to the comparability of soil analytical data has been adopted. This is considered appropriate at the present scale of 1:500 000 but must be done more rigorously when more detailed scientific work is considered.
- The present set of soil parameter estimates for Jordan should be seen as best estimates, based on the currently available selection of profile data held in JORSOTER and WISE.
- Modellers should familiarize themselves with the assumptions and taxotransfer rules used to develop the set of soil parameter estimates, before using these in their models.
- Assessments and model simulation of soil organic carbon stocks and change – like any other environmental study – should consider the full SOTER unit composition, not only the dominant soil component.
- The detail and quality of primary information available within the country results in a variable resolution of the products presented.
- The data set is appropriate for studies at national scale, including agro-ecological zoning, land evaluation, and modelling of carbon stocks and changes.

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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 (FAO, 1988), 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 and Figure 7).

Structure 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
SOIL1	Text	3	Characterization of the first (main) according to the Revised Legend (FAO, 1988)
PROP1	Integer	2	Proportion, as a percentage, that the main soil 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
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

(cont.)

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	SOTER texture class (see Figure 8)
BULK	Single	4	bulk density (kg dm^{-3})
TAWC	Integer	2	available water capacity (mm m^{-1}, -33 to -1500 kPa conform to USDA standards; not yet corrected for coarse fragments)
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})

(cont.)

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. In view of the TTR-rules applied and depth weighting, the parameters listed for TOTC and TOTN may not be used to compute C/N ratios!

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 the text.

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	Additional flags

Note: The exchangeable aluminum 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 lower 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, 1988 #1567]. When applicable, this has been flagged in the field TTRfinal; the coding conventions are given in Figure 5.

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.

Information on landform, lithology and slope has been be derived from the primary database (NSMLUP 1996).

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 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	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	SOTER texture class (see Figure 8)
BULK	Single	4	Bulk density (kg dm^{-3})
TAWC	Integer	2	Available water capacity (mm 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

(cont.)

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 (see Figure 6). The sum of the relative proportions of all Soil Components within a SOTER unit is always 100 per cent.
3) A condensed file showing only soil parameter estimates for the main Terrain Component (TCID= 1) and Soil Component (SCID =1) for the upper layer (D1) is attached as table SoterSummaryFile_T1S1D1 (see Figure7). This type of tables can be created directly in the GIS, in the table mode, using the SQL-connect option.

Appendix 5: Expert-rules

Soil organic carbon

The available profile descriptions (MINAG 1993) seldom contain data on soil organic carbon. Hence, a simple expert-based approach to fill data gaps has been developed in consultation with the Jordanian case study partners during the Third GEF-SOC Project Workshop (October 2003, Nairobi).

Data on organic content in the topsoil of the representative profiles, considered in SOTER, was correlated with the mean annual rainfall at the site. The latter was taken as the mid point of the ranges shown on the printed profile descriptions; e.g. 25 mm yr^{-1} for the range 0 to 50 mm yr^{-1}. The range of precipitation considered is from less than 50 mm yr^{-1} to 550-600 mm yr^{-1}.

The regression was fitted through the origin, assuming that the content of organic carbon would become nil were annual precipitation is nil:

$$OC = 0.000284 * R \qquad (n = 23; r^2 = 0.63; P < 0.001)$$

where:

OC, is the organic carbon content of the topsoil (g kg^{-1})

R, is the mean annual rainfall (mm yr^{-1})

The likely decrease in OC content with depth was inferred from the printed profile descriptions. The expert-based approach considered the root distribution, horizon by horizon, and information about strongly limiting soil constraints, such as a high salinity or the occurrence of a petrocalcic horizon.

Soil reaction (pH)

The SOTER procedures manual requires pH values to be measured in a 1:2.5 solution. Soil pH in Jordan, however, has been in the saturated paste (see MINAG 1993). These values are always lower than the pH measured in a 1:2.5 soil/water solution, because of less dilution and higher H^+ concentrations. Using analytical data for a limited number of soil profiles available in Soil Survey Staff (1975), a regression between pH_{paste} and pH_{1tox} was calculated:

$pH_{1\ to\ 1}$ = $0.19 + 1.015 * pH_{paste}$ ($n=15$; $r^2=0.91$)

$pH_{1\ to\ 5}$ = $0.34 + 1.014 * pH_{paste}$ ($n=15$; $r^2= 0.91$)

As a coarse rule of thumb, it has been assumed that $pH_{1\ to\ 2.5}$ is 0.4 units higher than $pH_{paste.}$ The original pH values have been adapted accordingly in the secondary data set.

Soil texture

For the synthetic profiles, coded as JOxxxsyn, the content of sand, silt and clay has been derived from the profile description. The percentages have been set as the mid-point of the field-recorded soil textural class (USDA) specified for each horizon.

Note: The textural classes used in this study follow the criteria of FAO (1988) and CEC (1985). The following abbreviations are used: C–coarse, M–medium, Z–medium fine, F–fine and V–very fine. The symbol # is used for undifferentiated (i.e. C + M + F + Z + V). The class limits are given in Figure 8.

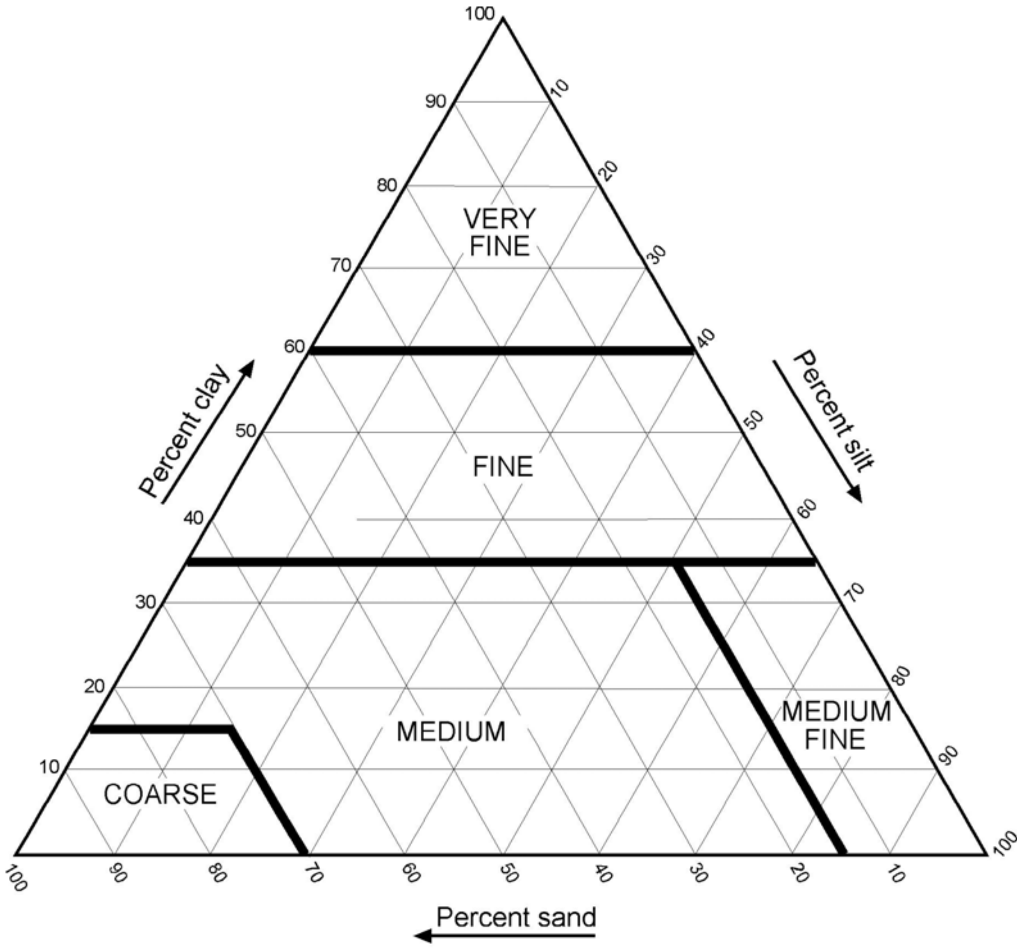

Figure 8. Soil texture classes

Appendix 6: Contents of GIS-folder

The primary SOTER-GIS coverage for Jordan, as taken from NSMLUP (1996), and the soil parameter estimates are provided in one single zip file called: SOTWIS_Jordan_ver1.zip.

By default, the compressed file will be unzipped to folder X:\SOTWIS_Jordan_ver1.0. This folder contains:

1) The project's apr-file, called sotwis_jordan_01.apr. This file can best be accessed from within ArcView.
2) The SOTER shape, legend and documentation files for Jordan, in three separate subfolders.
3) The access database containing the soil parameter estimates (SOTWIS_Jordanl_1.mdb; see Appendices 1 to 4 in ISRIC Report 2004/03).

The first time the project is loaded on a new system, the new folder settings will be automatically updated in the apr-file.

Different SQL queries will be needed depending on the applications or models. The current project file only shows a limited number of selections for the upper soil layer (D1= 0 to 20 cm, or less for shallow soils) of the dominant soil of a SOTER unit, as required by the RothC and Century models. These are: content of organic carbon; content of inorganic carbon; bulk density; content of clay; content of coarse fragments, and soil drainage class.

Should other selections be needed, the underlying Access database can be easily queried via the SQL-connect option of ArcView.

If grid-based soil layers are required, these can be generated using the convert-to-grid module of the spatial analyst extension to ArcView (ESRI 1996). Gridding should be based on the NEWSUID field to permit subsequent linkage with the various attribute tables discussed in this report.

The project file was developed for a 17 inch screen.

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