Report 2004/04

SOTER-based soil parameter estimates for Southern Africa

(Version 1.0)

Niels H Batjes

(October 2004)

ISRIC World Soil Information

Disclaimer:

Correct citation:

Batjes NH 2004. SOTER-based soil parameter estimates for Southern Africa. Report 2004/04. ISRIC – World Soil Information, Wageningen.

Inquiries:

c/o Director, ISRIC – World Soil Information
PO Box 353
6700 AJ Wageningen
The Netherlands
Telefax: +31-(0)317-471700
E-mail: soil.isric@wur.nl
Web: www.isric.org

Contents

List of Tables

List of Figures

ABSTRACT

This report presents a harmonized set of soil parameter estimates for Southern Africa. The 1:2M Soil and Terrain Database for Southern Africa (SOTERSAF ver. 1.0) and ISRIC-WISE soil profile database provided the basis for the current study.

The land surface of Southern Africa has been characterized using 4022 unique SOTER units, corresponding with 6099 polygons. The major soils have been described using 941 profiles, selected by national soil experts as being representative for these units. The associated soil analytical data have been derived from soil survey reports. These sources seldom hold all the physical and chemical attributes ideally required by SOTER (Dijkshoorn 2003, p. 6). Gaps in the measured soil profile data have been filled using a step-wise procedure that uses taxotransfer rules, based on the ~ 9600 soil profiles held in the WISE database.

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, aluminium saturation, $CaCO_3$ content, gypsum content, exchangeable sodium percentage (ESP), electrical conductivity of saturated paste (ECe), bulk density, content of sand, silt and clay, content of coarse fragments (> 2 mm), and available water capacity (-33 to -1500 kPa). 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 1:2M scale SOTERSAF map in a GIS, through the unique SOTER-unit code.

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

Keywords: soil parameter estimates, Southern Africa, environmental modelling, WISE database, SOTER database, secondary data set

1. INTRODUCTION

ISRIC and FAO and UNEP, under the aegis of the International Union of Soil, Sciences (IUSS), are updating the information on world soil resources in the World Soils and Terrain Digital Databases (SOTER) project. Once global coverage has been attained, SOTER is to supersede the 1:5M Soil Map of the World (FAO 1995; FAO-Unesco 1974-1981).

The SOTER methodology has been applied at scales ranging from 1:250 000 to 1:5M. Continental scale SOTER databases are available for Latin America and the Caribbean (FAO *et al.* 1998), Central and Eastern Europe (FAO and ISRIC 2000), and Southern Africa (FAO and ISRIC 2003).

Primary SOTER databases are composed of two main elements: a geographic and an attribute data component (van Engelen and Wen 1995). The first shows the delineations of the SOTER units, while the second holds information on their composition in terms of main soil types described by a suite of representative profiles.

Representative soil profiles for SOTER are selected from existing soil survey reports. Often there are gaps in the associated soil analytical data, in particular the soil physical data. This precludes the direct use of primary SOTER data in models, so far requiring varying approaches to gap-plugging (Batjes and Dijkshoorn 1999; Mantel and van Engelen 1999; van Engelen *et al.* 2004). ISRIC has therefore developed a uniform methodology for filling gaps in primary SOTER databases, for general purpose applications. The taxotransfer rule-based procedure draws heavily on soil physical and chemical data held in the ISRIC-WISE soil profile database (Batjes 2003). This report discusses its application to SOTERSAF, the SOTER database for Southern Africa (FAO and ISRIC 2003), for possible use in the *Green Water Initiative* (GWI 2003; Ringersma *et al.* 2003).

Chapter 2 describes the materials and methods 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 data file for Southern Africa (Appendix 5).

2. MATERIALS AND METHODS

2.1 Source of data

Release 1.0 of the Soil and Terrain database for Southern Africa (FAO and ISRIC 2003) provided the basis for this study. It covers 8 countries: Angola, Botswana, Mozambique, Namibia, South Africa, Swaziland, Tanzania and Zimbabwe (~ 6.1 10^6 km^2). The soil geographical and attribute data have been harmonized into SOTER format by various national soil survey organizations and ISRIC, using disparate data sources. SOTERSAF has a generalized scale of 1:2M, but the detail and quality of primary information available within the various country varies widely (Dijkshoorn 2003).

2.2 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 environmental applications (e.g., Batjes and Dijkshoorn 1999; Falloon *et al.* 1998; Graef 1999; Mantel *et al.* 2000; Nachtergaele *et al.* 2002). 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).

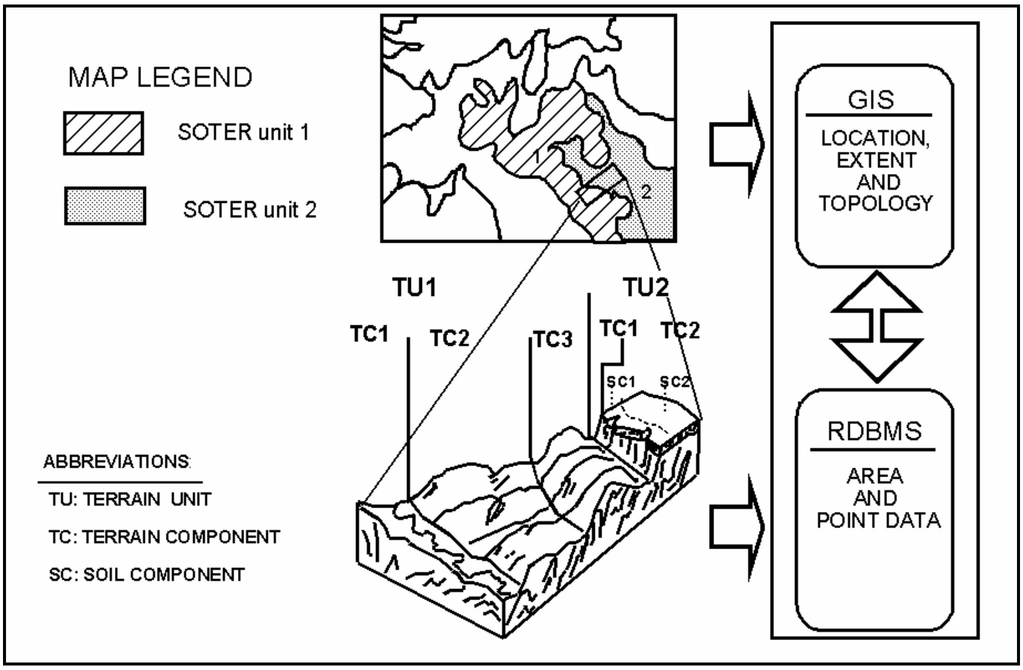

Figure 1. Schematic representation of two SOTER units and their terrain and soil components

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. This selection is based on purposive sampling (Webster and Oliver 1990). Profiles are characterised according to the Revised Legend of FAO (1988) and World Reference Base for Soil Resources (WRB 1998). Representative profiles are selected from available soil survey reports, as the SOTER program does not involve new ground surveys. Batjes (1999) reviewed issues of data acquisition, quality control and sharing in the context of SOTER projects.

2.3 Preparation of secondary SOTER data sets

2.3.1 List of soil parameters

Special attention has been paid to the key attributes (Table 1) commonly required in studies of agro-ecological zoning, food productivity, soil gaseous emissions/sinks and environmental change (see Batjes *et al.* 1997; 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 essential for many simulation studies, these properties 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) † ‡
Aluminium saturation (as % of ECEC) ‡
$CaCO_3$ content
Gypsum content
Exchangeable sodium percentage (ESP) ‡
Electrical conductivity of saturated paste (ECe)
Bulk density
Coarse fragments (> 2mm, volume %)
Sand (mass %)
Silt (mass %)
Clay (mass %)
Available water capacity (AWC; mm m^{-1}, 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 $cmol_{cmm}$ 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.

2.3.2 Procedure for filling gaps in the measured data

The standardized procedure for filling gaps in key measured data in primary SOTER data sets includes three main stages (Batjes 2003):

a) Collating additional measured soil data where these exist, in uniform SOTER format;

b) Using 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, based on the ~ 9600 profiles held in the global WISE profile database (Batjes 2002).

The desirability of the above stages decreases from highest (a) to lowest (c). Step a) has essentially been carried out during the compilation of the SOTERSAF database (FAO and ISRIC 2003), using readily accessible data (Dijkshoorn 2003). In the context of this follow-up study, the focus has been on applying steps b) and c).

The SOTERSAF set contains 941 representative soil profiles with measured data. This corresponds with an average profile observation density of 0.15 profiles per 1000 km^2.

There are also 7076 so-called virtual and synthetic profiles for which only the FAO and WRB classification have been given. About 89% (6926) of these profiles are linked to the South African part of the database (see Dijkshoorn 2003). Virtual profiles for South Africa have been characterized in terms of their classification only; all other fields being empty this lead to an unnecessary wastage of database space. Therefore, the 6926 virtual profiles for South Africa have been replaced with 57 synthetic profiles coded ZAV-XXx, where ZA is the country ISO-code, V shows the virtual nature of the profile, and XXx is the Revised Legend code. This coding convention is similar to the one adopted for other countries in SOTERSAF, for example profile ZWSYN20, where SYN stands for synthetic.

Some soil components have been coded as XX-FAO on the map only. The code AO-GLd, for example, indicates that the corresponding part (soil component) of the given SOTER unit in Angola (AO) has been mapped as dystric Gleysols on the source maps. However, so far, there are no representative profiles yet for the region under consideration. In such cases, new synthetic profiles had to be created in the attribute data base to permit application of the taxotransfer scheme.

Three polygons for Namibia, with SOTER identifier NA999, have no attribute data so that no derived data can be presented for these polygons.

Following the above ‘data condensation’, the original number of real and synthetic profiles (8017) has been reduced to 1157, greatly reducing overall needs for disk space and computing time.

Fictitious depth ranges were assigned to all synthetic profiles — with reference to their classification (FAO 1988) and auxiliary information held in SOTERSAF — so as to permit use of the taxotransfer scheme.

Soil drainage class has not been given for numerous profiles. These gaps were filled using information embedded in the Revised Legend code.

For South Africa, it has been necessary to make broad inferences about the likely classification of major soils in soil components that have been classified as “miscellaneous units”. For example, areas mapped as “streambeds” have been assumed to consist predominantly of eutric Regosols. Similarly, areas of “marshes” have been allocated to fibric Histosols as a first approximation. Sometimes, it has been necessary to make arbitrary assumptions, for example for areas of so-called “reclaimed land (H)”. These working assumptions have only been stored in a working copy of the SOTERSAF database, for the purpose of this study.

The above type of ‘corrections’ should be done more accurately in a future update of the primary SOTER data for Southern Africa: the recommended steps, both with respect to the spatial and attribute data, have been detailed by Dijkshoorn (2003, p. 7). Additional data compilation, in terms of representative and fully analysed soil profiles, will be a critical element in any such update. This will require substantial inputs from national soil survey organizations and other custodians of national scale soil data. Subsequent to such an update, a revised set of soil parameters estimates can be generated for the region, using the approach outlined in this report.

It is likely that the SOTERSAF database includes some expert-based estimates. However, since these have not been flagged in the primary data set, except for the synthetic profiles (216), it has been assumed that all physical and chemical data were measured values.

Further, having been submitted to the routine SOTER integrity checks (Dijkshoorn 2003; Tempel 1997), all measured data have been taken at face value.

3. RESULTS AND DISCUSSION

3.1 General

Southern Africa has been described using 4022 unique SOTER units. These comprise 15703 soil components and correspond with 6099 mapped polygons. At the small scale under consideration, most SOTER units will be compound units. SOTER units in SOTERSAF are comprised of up to 7 soil components, with an average of 2. Some of the spatially minor soil units, however, may be of particular relevance for specific applications. For example, organic soils in the Okavongo delta in Botswana may be of great importance for national inventories of carbon stocks and projected changes. 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 in a special case. The full map unit composition can best be addressed with tailor made programs depending on the scope of the application.

3.2 SOTER unit composition

A table – *sensu* MS Access® databases – has been generated that shows 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 Southern Africa, and Appendix 1 its structure. Based on current knowledge, the SOTER or map unit with NEWSUID number AO190 is coded as FRx2ARo4. The 190th map unit for the Angola (AO) is comprised of 70% of xanthic Ferralsols (FRx) and 30% of orthic Arenosols (ARo).

SOTERunitComposition : Table

NEWSUII	SoilMapUnit	SOIL1	PROP1	Profile-ID1	SOIL2	PROP2	Profile-ID2	SOIL3	PROP	Profile-ID3	SOIL4	PROP	Profile-ID4
AO193	ARo3FRr3FRx5 [193]	ARo	50	AO-P.248c/63	FRr	40	AO-P.204/61	FRx	10	AO-P.61/63			
AO192	FRr2FRx5FRx5ARo5 [192]	FRr	70	AO-P.204/61	FRx	10	AO-P.77/63	FRx	10	AO-P.61/63	ARo	10	AO-P.248c/6
AO191	ARo2ARI5ARI5 [191]	ARo	75	AO-P.248c/63	ARI	15	AO-P.245c/63	ARI	10	AO-P.61/60			
AO190	FRx2ARo4 [190]	FRx	70	AO-P.61/63	ARo	30	AO-P.248c/63						
AO19	CMo3CMo4ACh4 [19]	CMo	50	AO-P.82/59	CMo	30	AO-P.80/59	ACh	20	AO-P.40/59			
AO189	ARI3ARo3PZc5 [189]	ARI	50	AO-P.245c/63	ARo	45	AO-P.248c/63	PZc	5	AO-P.32/60			

Record: 1 of 4021

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 $n_{WISE} < 5$. Appendix 2 shows the structure of the corresponding file.

SOTERparameterEstimates : Table

CLAF	PRID	Drain	Laye	TopDep	BotDep	CFRA	SDTO	STPC	CLPC	PSCL	BULI	TAWC	CECS	BSAT	CECc	PHAQ	TCEQ	GYPS	ELCO	TOTC	TOTN	ECEC	ALSA	ESP
FRx	AO-P.113c/60	W	D1	0	20	0	36	16	48	F	1.17	8	13	12	13	4.8	0	0	0	18.0	1.01	4	42	4
FRx	AO-P.113c/60	W	D2	20	40	0	33	14	53	F	1.28	7	10	9	10	4.9	0	0	0	13.8	0.79	6	42	2
FRx	AO-P.113c/60	W	D3	40	60	0	33	13	54	F	1.34	6	9	11	10	4.9	0	0	0	10.9	0.67	6	25	1
FRx	AO-P.113c/60	W	D4	60	80	0	31	11	58	F	1.45	5	7	11	7	5.0	0	0	0	8.6	0.66	6	22	2
FRx	AO-P.113c/60	W	D5	80	100	0	30	11	59	F	1.38	4	7	11	6	5.0	0	0	0	8.0	0.66	5	22	2
ARo	AO-P.120/54	P	D1	0	20	0	94	2	4	C	1.51	2	3	75	19	6.0	0	0	0	5.5	0.45	2	0	3
ARo	AO-P.120/54	P	D2	20	40	0	89	3	8	C	1.55	3	2	74	12	5.5	0	0	0	3.2	0.23	2	0	4
ARo	AO-P.120/54	P	D3	40	60	0	90	2	8	C	1.56	3	2	76	10	5.5	0	0	0	2.5	0.18	2	0	3
ARo	AO-P.120/54	P	D4	60	80	0	89	1	10	C	1.56	3	2	73	10	5.4	0	0	0	1.7	0.16	2	0	4
ARo	AO-P.120/54	P	D5	80	100	0	88	1	11	C	1.57	3	2	74	9	6.4	1	1	0	1.5	0.25	3	0	4
FRh	AO-P.120/60	I	D1	0	20	0	49	11	40	F	1.44	9	15	15	19	4.8	0	0	0	22.6	1.95	14	20	1
FRh	AO-P.120/60	I	D2	20	40	0	50	8	42	F	1.46	8	13	10	19	4.8	0	0	0	14.5	1.12	9	20	1
FRh	AO-P.120/60	I	D3	40	60	0	45	11	44	F	1.39	8	11	12	16	4.9	0	0	0	10.0	0.86	9	25	1
FRh	AO-P.120/60	I	D4	60	80	0	43	13	44	F	1.37	7	9	10	16	4.9	0	0	0	7.1	0.67	8	22	0
FRh	AO-P.120/60	I	D5	80	100	0	42	13	45	F	1.38	6	8	8	16	5.0	0	0	0	3.5	0.40	7	22	0

Record: 108 of 5201

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 are flagged under TTRmain (see Batjes 2003).

SOTERflagTTRrules : Table

CLAF	PRID	Layer	Newtopdep	Newbotdep	TTRsub	TTRmain	TTRfinal
FRh	AO-P.101c/63	D1	0	8	A3B1c3H2J2	I3K3P3	A D
FRh	AO-P.101c/63	D1	8	20	A3c3H2	-	A D I K P
FRh	AO-P.101c/63	D2	20	25	A3c3H2	-	A D I K P
FRh	AO-P.101c/63	D2	25	40	A3c3H2	-	A D I K P
FRh	AO-P.101c/63	D3	40	50	C1H3	A3	A D I K P
FRh	AO-P.101c/63	D3	50	60	c3H3	A3	D I K P
FRh	AO-P.101c/63	D4	60	80	c3H3	A3	D I K P
FRh	AO-P.101c/63	D5	80	81	c3H3	A3	D I K P
FRh	AO-P.101c/63	D5	81	100	c2d1H3o3q1r1	a3	D I K P

Record: 1 of 7187

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 were based (Table 2).

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

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. This is depicted schematically for the upper 0 to 20 cm of a hypothetical profile from country XX (XXhyp04):

CLAF	PRID	LAYER	Newtopdep	Newbotdep	TTRsub	TTRmain
CMx	XXhyp04	D1	0	18	b3c2j3o3r2	a2h1
CMx	XXhyp04	D1	18	20	C3j1	A3h2

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)

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.

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

Record: 9 of 20

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

A high confidence rating, however, 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 soil 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, several properties are readily modified by changes in land use or management, for example soil pH, aluminium saturation and organic matter content, while information on land use/management history is seldom available.

Table 3 lists how often each TTR has been applied as a percentage of the total number of horizons (up to a depth of 100 cm) in the secondary SOTER database; details may be found in table SOTERflagTTRrules (see Appendix 3). For example, the aluminium saturation percentage (ALSA) has been estimated using TTRs in 75% of the cases, mainly using data for similar major soil groupings (see under TTRmain). For base saturation (BSAT), TTR-derived values are mainly derived from soil parameter estimates for similar soil units (see TTRsub); this is a reflection of the fact that primary data for exchangeable bases and exchangeable aluminium were often lacking in the source materials. For bulk density (BULK) this is 95%, which indicates that measured bulk density are seldom available for the region. Alternatively, TTRs have been used in only

18% of the cases for sand, silt and clay content (PSCL, SDTO, STPC). The later substitutions were mainly for the synthetic profiles.

Table 3. Type and frequency of taxotransfer rules applied

Parameter	Code	Frequency of occurrence (%)		
		TTRsub	TTRmain	Total
ALSA	A	11	64	75
BSAT	B	38	1	39
BULK	C	92	3	95
CECC	D	44	1	45
CECS	E	20	0	21
CFRAG	F	24	0	24
CLPC	G	18	1	19
ECEC	H	84	8	92
ELCO	I	42	9	51
ESP	J	37	1	38
GYPS	K	38	24	62
PHAQ	L	32	0	32
SDTO	M	18	1	18
STPC	N	18	1	18
TAWC	O	55	11	66
TCEQ	P	44	11	55
TOTC	Q	34	1	35
TOTN	R	34	1	35

Note: For definitions of abbreviations see text and Figure 5; also see the footnote in Appendix 3.

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 Southern Africa comprise at least two soil components, up to a maximum of 7. 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

NEWSUII	TCID	SCID	Propor	PRID	CLAF	Drain	Layer	TopDep	BotDep	CFRAG	SDTO	STPC	CLPC	PSCL	BULK	TAWC	CECS	BSAT	PHAQ	TCEQ	TOTC
BW22	1	1	35	BW-RM0901	LVh	M	D1	0	20	1	59	11	30	M	1.55	9	11	100	7.2	2	7.7
BW22	1	1	35	BW-RM0901	LVh	M	D2	20	40	1	57	10	33	M	1.50	11	12	100	6.9	6	5.6
BW22	1	1	35	BW-RM0901	LVh	M	D3	40	60	1	53	7	40	F	1.50	8	14	100	6.7	3	4.7
BW22	1	1	35	BW-RM0901	LVh	M	D4	60	80	1	50	6	44	F	1.52	7	15	100	6.8	76	3.8
BW22	1	1	35	BW-RM0901	LVh	M	D5	80	100	1	46	7	47	F	1.49	7	17	100	6.9	101	3.0
BW22	1	2	15	BW-G 0901	LXh	W	D1	0	20	1	80	4	16	M	1.66	3	4	97	5.9	0	2.0
BW22	1	2	15	BW-G 0901	LXh	W	D2	20	40	1	79	4	17	M	1.62	3	5	78	5.9	0	2.0
BW22	1	2	15	BW-G 0901	LXh	W	D3	40	60	1	76	4	20	M	1.53	3	5	78	5.8	0	2.0
BW22	1	2	15	BW-G 0901	LXh	W	D4	60	80	1	75	3	22	M	1.46	5	5	75	5.6	0	2.0
BW22	1	2	15	BW-G 0901	LXh	W	D5	80	100	1	75	3	22	M	1.46	5	5	74	5.6	0	2.0
BW22	1	3	10	BW-BE0903	LVx	I	D1	0	20	4	38	13	49	F	1.40	5	31	100	7.7	10	3.6
BW22	1	3	10	BW-BE0903	LVx	I	D2	20	40	4	20	21	59	F	1.45	11	31	100	7.9	9	5.0
BW22	1	3	10	BW-BE0903	LVx	I	D3	40	60	4	20	21	59	F	1.47	11	31	100	7.9	8	4.8
BW22	1	3	10	BW-BE0903	LVx	I	D4	60	80	4	15	23	62	V	1.50	11	32	100	8.2	2	3.0
BW22	1	3	10	BW-BE0903	LVx	I	D5	80	100	68	38	21	41	F	1.51	12	17	90	7.0	1	2.8
BW22	1	4	10	BW-G 0509	LXf	W	D1	0	20	1	80	8	12	C	1.47	7	5	70	6.5	1	2.0
BW22	1	4	10	BW-G 0509	LXf	W	D2	20	40	1	77	7	16	M	1.46	6	5	62	6.4	0	1.4
BW22	1	4	10	BW-G 0509	LXf	W	D3	40	60	1	71	8	21	M	1.42	6	5	60	6.2	0	1.5
BW22	1	4	10	BW-G 0509	LXf	W	D4	60	80	1	54	14	32	M	1.42	7	6	74	5.8	0	3.0
BW22	2	1	20	BW-PA0080	LPe	S	D1	0	20	20	58	26	16	M	1.36	16	20	90	6.9	6	7.6
BW22	2	1	20	BW-PA0080	LPe	S	D2	20	40	20	46	31	23	M	1.30	17	10	79	6.4	0	5.1
BW22	2	1	20	BW-PA0080	LPe	S	D3	40	50	20	45	34	21	M	1.40	15	8	66	6.5	100	4.9
BW22	2	2	10	BW-TA0009	RGe	W	D1	0	20	1	78	12	10	C	1.23	6	5	98	6.2	0	2.0
BW22	2	2	10	BW-TA0009	RGe	W	D2	20	40	46	73	15	12	C	1.18	8	5	82	6.4	1	2.5

Record: 1 of 24 (Filtered)

Figure 6. Excerpt of a SOTER summary file for unit BW22

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 carbon models (Falloon *et al.* 2002; Paustian *et al.* 1997), 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). The corresponding selection is included as a separate table in the secondary database for Southern Africa, as an example. The database structure is detailed 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 NA19 from Namibia.

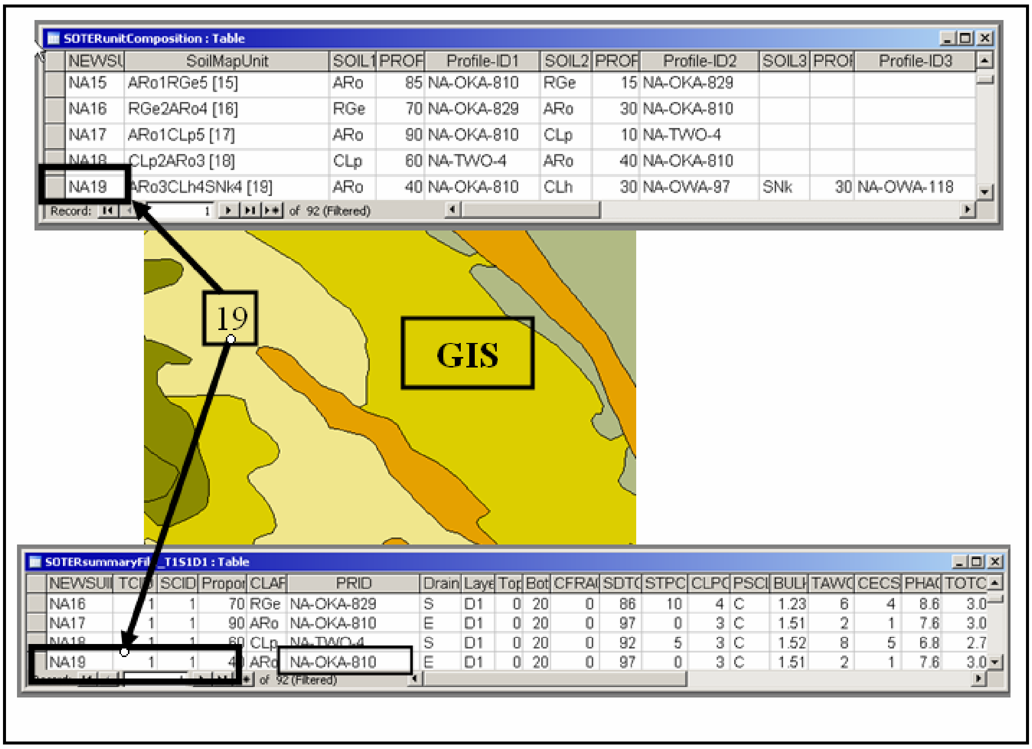

Figure 7. Linking soil parameter estimates for the top 20 cm of the dominant soil (NA-OKA-810) of SOTER unit NA19 with the geographical component of SOTER

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). Gridding should be based on the NEWSUID field to permit subsequent linkage with the various attribute tables discussed in this report. The procedure will be same as depicted earlier in Figure 7.

4. CONCLUSIONS

- Linkage between soil profile data and the spatial component of a SOTERSAF map, for environmental applications, required generalisation of measured soil (profile) data by soil unit and depth zone. This involved the transformation of variables that show a marked spatial and temporal variation and that 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 was considered appropriate at the present scale of 1:2M, but must be done more rigorously when more detailed scientific work is considered.
- The present set of soil parameter estimates for Southern Africa should be seen as best estimates, based on the currently available selection of profile data held in SOTERSAF 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.
- The detail and quality of primary information available within the various countries of Southern Africa resulted in a variable resolution of the products presented.

ACKNOWLEDGEMENTS

This study has been carried out in the framework of *ISRIC Project 3.12 — Derived soil parameter estimates for SOTER-based applications*. I thank Koos Dijkshoorn, coordinator of the SOTERSAF project at ISRIC, for his constructive comments concerning the primary database.

REFERENCES

Batjes NH 1999. Soil vulnerability mapping in Central and Eastern Europe: Issues of data acquisition, quality control and sharing. In: Naff T (editor), *Data Sharing for International Water Resource Management: Eastern Europe, Russia and the CIS*. NATO Science Series 2: Environmental Security (Vol. 61). Kluwer Academic Publishers, Dordrecht, pp 187-206

Batjes NH 2002. Revised soil parameter estimates for the soil types of the world. *Soil Use and Management* 18, 232-235

Batjes NH 2003. *A taxotransfer rule based approach for filling gaps in measured soil data in primary SOTER databases*. Report 2003/03, ISRIC - World Soil Information, Wageningen

Batjes NH and Dijkshoorn JA 1999. Carbon and nitrogen stocks in the soils of the Amazon Region. *Geoderma* 89, 273-286

Batjes NH, Fischer G, Nachtergaele FO, Stolbovoy VS and van Velthuizen HT 1997. *Soil data derived from WISE for use in global and regional AEZ studies (ver. 1.0)*. Interim Report IR-97-025, FAO/ IIASA/ ISRIC, Laxenburg

Bouwman AF, Boumans LJM and Batjes NH 2002. Modeling global annual N_2O and NO emissions from fertilized fields. *Global Biogeochemical Cycles* 16, 1080, doi:10.1029/2001GB001812

CEC 1985. *Soil Map of the European Communities (1:1,000,000)*. Report EUR 8982, Office for Official Publications of the European Communities, Luxembourg

Cramer W and Fischer A 1997. Data requirements for global terrestrial ecosystem modelling. In: Walker B and W Steffen (editors), *Global Change and Terrestrial Ecosystems*. Cambridge University Press, Cambridge, pp 529-565

Dijkshoorn JA 2003. *SOTER database for southern Africa (SOTERSAF; ver. 1.0)*, ISRIC - World Soil Information, Wageningen

ESRI 1996. *ArcView GIS*. Environmental Systems Research Institute, Redlands CA, 350 p

Falloon P, Smith P and Szabo JP, L. 2002. Comparison of approaches for estimating carbon sequestration at the regional scale. *Soil Use and Management* 18, 164-174

Falloon PD, Smith P, Smith JU, Szabó J, Coleman K and Marshall S 1998. Regional estimates of carbon sequestration potential: linking the Rothamsted carbon model to GIS databases. *Biology and Fertility of Soils* 27, 236-241

FAO 1988. *FAO/Unesco Soil Map of the World, Revised Legend (with corrections and updates)*. FAO World Soil Resources Report 60 (reprinted with updates as ISRIC Technical Paper 20 in 1997), ISRIC, Wageningen

FAO 1995. *Digital Soil Map of the World and Derived Soil Properties*, Food and Agriculture Organization of the United Nations, Rome

FAO and ISRIC 2000. *Soil and terrain database, soil degradation status, and soil vulnerability assessments for Central and Eastern Europe (scale 1:2.5 million; ver. 1.0)*. Land and Water Digital Media Series 10, FAO, Rome

FAO and ISRIC 2003. *Soil and Terrain database for Southern Africa (1:2 million scale)*. FAO Land and Water Digital Media Series 25, ISRIC and FAO, Rome

FAO, ISRIC, UNEP and CIP 1998. *Soil and terrain digital database for Latin America and the Caribbean at 1:5 million scale*. Land and Water Digital Media Series No. 5, Food and Agriculture Organization of the United Nations, Rome

FAO-Unesco 1974-1981. *Soil Map of the World, 1:5,000,000. Vol. 1 to 10*. United Nations Educational, Scientific, and Cultural Organization, Paris

Fischer G, van Velthuizen HT, Shah M and Nachtergaele FO 2002. *Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results*. RR-02-02, International Institute for Applied Systems Analysis (IIASA) and Food and Agriculture Organization of the United Nations (FAO), Laxenburg

Graef F 1999. Evaluation of agricultural potentials in semi-arid SW-Niger: a soil and terrain (NiSOTER) study. Heft 54 Thesis, Universitat Hohenheim, Hohenheim, 217 pp

GWI 2003. Greenwater: An initiative for improving green water use for rainfed agriculture in Sub-Sahara Africa, ISRIC and FAO (http://lime.isric.nl/index.cfm?fuseaction=dsp_menu&mode=&contentid=414 ; accessed 16 June 2004)

Klamt E and Sombroek WG 1988. Contribution of organic matter to exchange properties of Oxisols. In: Beinroth FH, MN Camargo and H Eswaran (editors), *Classification, characterization and utilization of Oxisols. Proc. of the 8th International Soil Classification Workshop (Brazil, 12 to 23 May 1986)*. Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Soil Management Support Services (SMSS) and University of Puerto Rico (UPR), Rio de Janeiro, pp 64-70

Mantel S and van Engelen VWP 1999. Assessment of the impact of water erosion on productivity of maize in Kenya: an integrated modelling approach. *Land Degradation and Development* 10, 577-592

Mantel S, van Engelen VWP, Molfino JH and Resink JW 2000. Exploring biophysical potential and suitability of wheat cultivation in Uruguay at the national level. *Soil Use and Management* 16, 270-278

Nachtergaele FO, van Lynden GWJ and Batjes NH 2002. Soil and terrain databases and their applications with special reference to physical soil degradation and soil vulnerability to pollution in central and eastern Europe. In: Pagliaia M and R Jones (editors), *Advances in GeoEcology 35*. CATENA Verlag GMBH, Reiskrirchen

Nemes A, Schaap MG and Wosten JHM 2003. Functional Evaluation of Pedotransfer Functions Derived from Different Scales of Data Collection. *Soil Science Society of America Journal* 67, 1093-1102

Paustian K, Levine E, Post WM and Ryzhova IM 1997. The use of models to integrate information and understanding of soil C at the regional scale. *Geoderma* 79, 227-260

Ringersma J, Batjes NH and Dent D 2003. *Green Water: Definitions and data for assessment*. Report 2003/02, ISRIC - World Soil Information, Wageningen

Scholes RJ, Skole D and Ingram JS 1995. *A global database of soil properties: proposal for implementation*. IGBP-DIS Working Paper 10, International Geosphere Biosphere Program, Data & Information System, Paris

Soil Survey Staff 1983. *Soil Survey Manual (rev. ed.)*. United States Agriculture Handbook 18, USDA, Washington

Tempel P 1997. *Global and national Soil and Terrain Digital Databases (SOTER) - Scale 1:2,500,000 (Attribute database use manual adapted for SOVEUR Project)*. Report 97/09, ISRIC, Wageningen

Tomasella J and Hodnett MG 1997. Estimating unsaturated hydraulic conductivity of Brazilian soils using soil-water retention data. *Soil Science* 162, 703-712

Tomasella J and Hodnett MG 1998. Estimating soil water retention characteristics from limited data in Brazilian Amazonia. *Soil Science* 163, 190-202

van den Berg M, Klamt E, van Reeuwijk LP and Sombroek WG 1997. Pedotransfer functions for the estimation of moisture retention of Ferralsols and related soils. *Geoderma* 78, 161-180

van Engelen VWP and Wen TT 1995. *Global and National Soils and Terrain Digital Databases (SOTER): Procedures Manual (rev. ed.)*. (Published also as FAO World Soil Resources Report No. 74), UNEP, IUSS, ISRIC and FAO, Wageningen

van Engelen VWP, Mantel S, Dijkshoorn JA and Huting J 2004. *The impact of desertification on food security in Southern Africa: a case study in Zimbabwe*. Report 2004/02, ISRIC - World Soil Information, Wageningen

van Reeuwijk LP 1995. *Procedures for soil analysis (5th ed.)*. Technical Paper 9, ISRIC, Wageningen

Webster R and Oliver MA 1990. *Statistical methods in soil and land resource survey*. Spatial Information Systems. Oxford University press, Oxford, 316 p

Wösten JHM, Lilly A, Nemes A and Le Bas C 1998. *Using existing soil data to derive hydraulic parameters for simulation models in* *environmental studies and in land use planning*. Report 156, DLO-Staring Centre, Wageningen

WRB 1998. *World Reference Base for Soil Resources*. World Soil Resources Report 84, ISSS, ISRIC, and FAO, Rome

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 and ISRIC, 2003), 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 (sometimes called: ISOCSUID)
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

(cont.)

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
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 note at end of this report for codes)
BULK	Single	4	bulk density (kg dm^{-3})
TAWC	Integer	2	available water capacity (mm, -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. In view of the TTR-rules applied and depth weighting, the parameters listed for TOTC and TOTN should 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 (Section 3.3).

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 (based on expert knowledge)

Note: 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 1988). 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 derived from the primary SOTERSAF database (FAO *et al.* 1998).

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 %)

(cont.)

PSCL	Text	1	FAO texture class (see Figure 8)
BULK	Single	4	Bulk density (kg dm^{-3})
TAWC	Integer	2	Available water capacity (mm, -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 (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.
4) A limited number of TTR-derived records may contain a -1 value; this indicates that it has not yet been possible to plug the corresponding gaps using the taxotransfer scheme.

Appendix 5: Contents of GIS-folder

The SOTER-GIS coverage for Southern Africa and soil parameter estimates are provided in one single zip file called: SOTWIS_SAF_ver1.zip (unzipped about 250 Mb).

By default, this compressed file should be unzipped to folder "C:\". All files will then be installed to folder C:\DATA\SOTWIS_Southern Africa_ver1.0 which contains:

1) The project's apr-file, called SOTWIS_SAF_01.apr. This file can best be accessed from within ArcView, otherwise a 'segmentation violation' may occur.

2) The SOTER shape, legend and documentation files for Southern Africa, in three separate subfolders.
3) The access database containing the soil parameter estimates (SOTWIS_SAF_1.mdb; see Appendices 1 to 4).

If the project is to be executed from another folder, for example D:\ or N:\, then the path statements in the corresponding project-file must be updated accordingly using a text editor.

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. Should other selections be needed, the underlying MS Access database (SOTWIS_SAF_1.mdb) can be 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.

Appendix 6: Limits for soil textural classes

The textural classes (PSCL, see Appendix 2 and 4) 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 shown in Appendix 6.

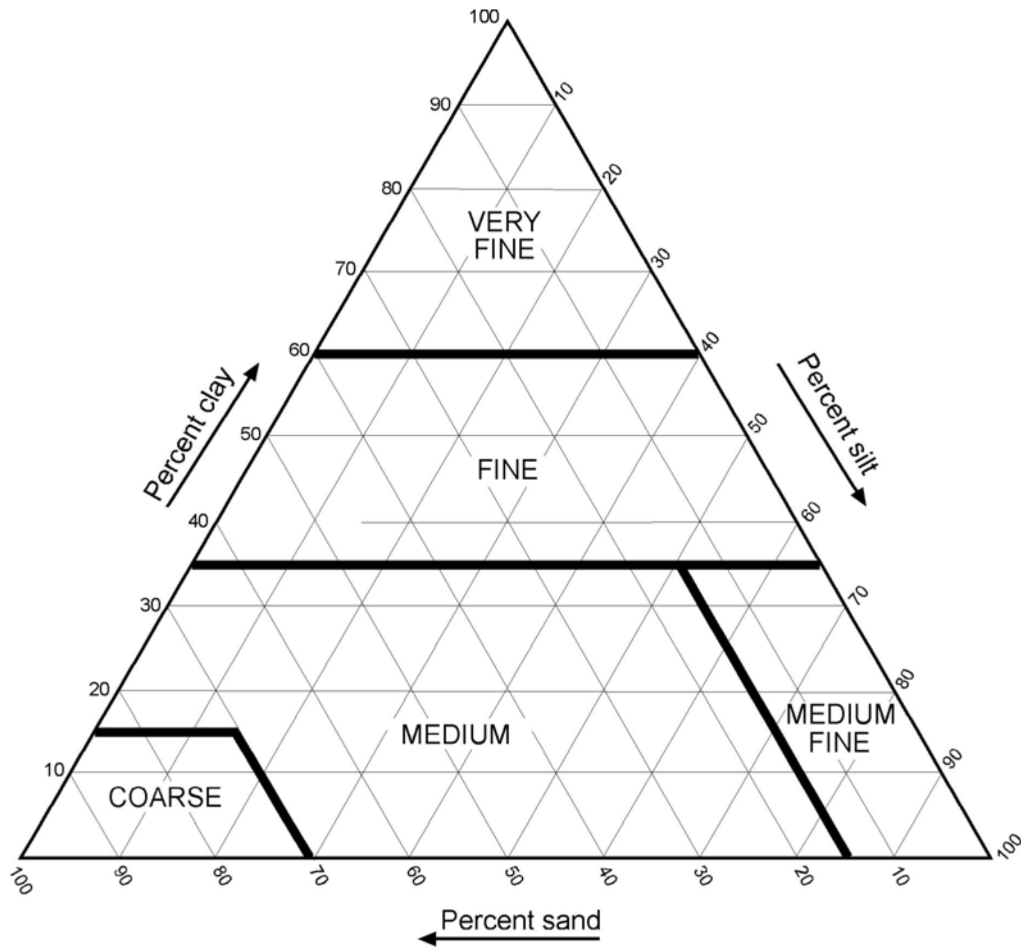

Figure 8. Soil texture classes