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

(Version 1.0)

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SUMMARY

This report presents a harmonized set of soil parameter estimates for Brazil. The 1:5M Soil and Terrain Database for Latin America and the Caribbean (FAO *et al.* 1998), provided the basis for the current study. The data set has been prepared for the project on "Assessment of soil organic carbon stocks and change at national scale" (GEF-SOC), which has the Brazilian Amazon as one of its four case study areas.

The land surface of Brazil has been characterized using 299 unique SOTER units, corresponding with 839 polygons. The major soils have been described using 584 profiles, selected by national soil experts as being representative for these units. 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) collating additional measured soil analytical data where available; (2) filling gaps using expert knowledge and common sense; (3) filling 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 and clay, content of 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 1:5 M scale SOTER map in a GIS, through the unique SOTER-unit code. The subset for the Amazon region, the Brazilian GEF-SOC case study area, has been clipped out of the national set using GIS. It includes 193 unique SOTER units, corresponding with 571 mapped polygons.

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

Keywords: soil parameter estimates, Amazon region, Brazil, environmental modelling, WISE database, SOTER database, secondary data set

1. INTRODUCTION

This study[1] 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 to 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 Austria, France, the Netherlands, the United Kingdom and the USA.

The main research objectives, summarized on the project website[2], 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;

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.

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[1] Having the same scope, the structure and body of the report for Brazil are similar to those prepared for Jordan (Batjes *et al.*, 2003) and Kenya (Batjes and Gicheru, 2004).

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

This report presents parameter estimates for the major soils of Brazil, at scale 1: 5 000 000; only the subset for the Amazon region will be considered during the modelling phase 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 Brazil (Appendix 5).

The secondary SOTER data set annex GIS file for Brazil can be downloaded via www.isric.org[3].

2. MATERIALS AND METHODS

2.1 Biophysical setting

The Federative Republic of Brazil lies mainly below the equator, in South America, and is broadly bounded by 5° 16' N and 33° 45' S latitude and 35° W and 74° W longitude. It covers 8 514 879 km^2 (Times Atlas 2003), or about 48% of the continent, and has over 165 million inhabitants. Average population density, in 1995, was 19 per km^2.

The Brazilian Amazon covers some 59% (5.1 million km^2) of the national territory and includes the states of the states of Acre, Amapa, Amazonas, Maranhao, Mato Grosso, Para, Rondonia, Roraima and Tocantins.

A detailed account of the geology is given in Schobbenhaus *et al.* (1984). Altitude generally does not exceed 500 m as Brazil occurs on an old geologic base without recent tectonics. The highest peak, the Pico da Neblina (3,014 m), occurs on the plateau of Guyana near the border with Venezuela.

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

Brazil can be characterized into five main landscapes: the plateau of Guyana, the Brazilian plateau, the Amazon plain and low lands, the plain of the Pantanal, and plains and coastal lowlands (Ab'Saber 1996). Knowledge on landforms, soil conditions and the biota of the Amazon region has remained sketchy until the 1960s (Ab'Saber 1967; FAO-Unesco 1971; Sombroek 1966). A wealth of new information has been gained in the context of the RADAM Project (1973-1982), which covered the entire Brazilian Amazon. It included surveys of the geology, geomorphology, vegetation, soils, and land use. The resulting reports contain results of analyses for over 2500 soil profiles (see Bernoux *et al.* 2003a). While detailed information is available about organic carbon, nitrogen and phosphorus concentration, soil texture, major cations and other chemical soil properties, there are few determinations of bulk density (Bernoux *et al.* 1998b).

RADAM and other materials were used by EMBRAPA (1981) to compile a 1:5M scale soil map of the country, showing about 2700 map units representing about 70 soil types. Subsequently, EMBRAPA compiled a 1:5M scale soil and terrain database for the country in the framework of the world-encompassing SOTER project (FAO *et al.* 1998; Peters and Van Engelen 1993).

The 1:5M scale digital soil map of EMBRAPA (1981) uses the Brazilian classification system. On the other hand, SOTER follows the Revised Legend (FAO 1988) and WRB terminology (WRB 1998), facilitating international exchange and correlation. Adoption of a uniform methodology allows using similar procedures for plugging gaps in the measured soil data (Batjes 2003) and for linking soil parameter estimates to models. Hence the adoption of the SOTER approach in the GEFSOC case study countries. The SOTER methodology, albeit with some regional modifications, has also been used to compile a 1:1M database for the state of Rondonia (Cochrane and Cochrane 1998).

Ab'Saber (1996) and Sombroek (1996) studied the diversity of Amazon landforms and their soils, in relation to biological diversity. Sombroek (2001) also discussed spatial and temporal patterns of Amazon rainfall and possible consequences for the planning of agricultural occupation and the protection of primary forests. Land use change, the main driving factors of which have been described by Lambin *et al.* (2003), in combination with climate change may have a varying impact on net primary production, and thus soil carbon stocks, in the various natural regions of Brazil (e.g., Cardille and Foley 2003; de Moraes *et al.* 1996; Fearnside 1998; Fearnside 1999; Houghton *et al.* 2000; Sisti *et al.* 2004). Many of these aspects are being studied in the context of LBA, the Large Scale Biosphere-Atmosphere Experiment in Amazonia (Kabat *et al.* 1999). The GEF-SOC project is affiliated with LBA through Project number cd208. Several authors have reviewed perspectives on sustainable development of the Brazilian Amazon (Cattaneo 2002; Clustener-Godt and Sachs 1995; Vosti *et al.* 2002). A selection of these elements will be considered during the modelling phase of the GEFSOC project.

2.2 Source of data

The Soil and Terrain database for Latin America and the Caribbean (FAO *et al.* 1998) provided the basis for preparing the present 1:5M SOTER database for the country (BRASOTER). The original soil geographical and attribute data have been collated into SOTER format by staff of the Empresa Brasileira de Pesquisa Agropecuaria – Centro Nacional de Pesquisa de Solos (EMBRAPA) and ISRIC between 1993 and 1997 (FAO *et al.* 1998; Peters and Van Engelen 1993).

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 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).

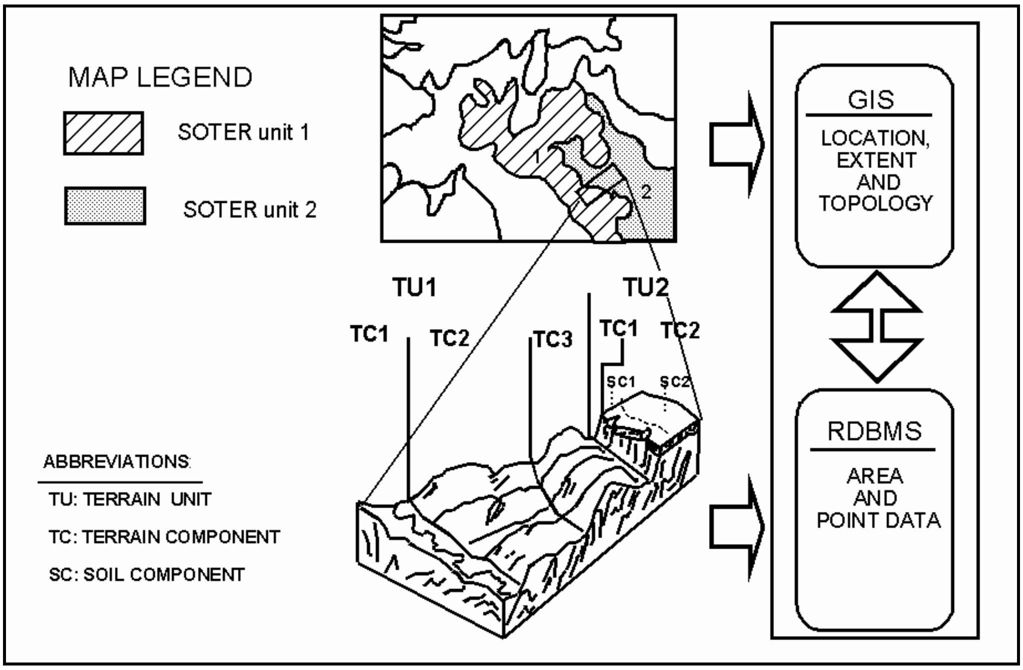

Figure 1. Schematic representation of two SOTER units and their terrain and soil components

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 was based on purposive sampling (Webster and Oliver 1990). 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 (1999) 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 and Wen (1995). The SOTER attribute data are managed with an automated data entry facility (Tempel 2002). In addition, SOTER uses commercially available MS 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 (Cerri *et al.* 2003; 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 *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) † ‡
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 initial SOTER database for Brazil from dBaseIV® into MS Access 2000®. This exercise included a check on data consistency and integrity. Minor errors and gaps have been corrected at this stage using expert knowledge and common sense. 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).

The geographic set for Brazil, as extracted from the 1:5M Soil and Terrain Database for Latin America and the Caribbean (FAO *et al.* 1998), has been geo-rectified to the national boundaries shown on the Digital Chart of the World using GIS.

2.4.3 Procedure for filling gaps in the measured data

The materials that underlie the SOTER work for Brazil were commissioned for an exploratory survey at scale 1:5M of the continent. Inherently, there are a number of gaps in the measured data, soil physical attributes in particular. The occurrence of such gaps limits 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).

a) Collating additional measured data

Soil characterization in Brazil is according to the national soil classification system (do Prado 1996; EMBRAPA 1999) and earlier approximations. There are over 2500 well described profiles for the country, largely originating from the RADAM Brazil surveys (see Bernoux *et al.* 2003a). About a fifth thereof have been selected to represent the main soils of Brazil in SOTER. All these profiles have been re-classified manually according to the Revised Legend of FAO (1988).

Camargo et al. (1987) discussed issues concerning the correlation between the Brazilian classification system and original FAO Legend (FAO-Unesco 1974). According to de Oliveria and van den Berg (1996), the correlations between the FAO Revised Legend (FAO 1988) and Brazilian systems are too weak for simple ''translation" from one system to the other if scientific applications and technology transfer are the objectives. In addition, they wrote that this would require additional information obtained by comparison of profile descriptions, correlation between analytical methods, and in some areas even additional fieldwork. Conversion of all remaining RADAM profiles in SOTER format — their re-classification into the FAO Revised Legend in particular — and updating of the corresponding area data in collaboration with the case study partners proved to be unrealistic within the rigid, time-limited context of the GEF-SOC project. Further, these profiles have already been linked to the 1:5M national soil map produced by EMBRAPA (1981) and used for various national and regional assessments of soil organic carbon stocks and change (Bernoux *et al.* 1998a; Bernoux *et al.* 1998b; Bernoux *et al.* 2002; Cerri *et al.* 2000; Cerri *et al.* 2003; de Moraes *et al.* 1995).

The updated BRASOTER set contains 584 representative soil profiles. Out of this total, 331 have been used to characterise the Amazon region. This corresponds with an average density of 0.07 representative profiles per 1000 km^2.

b) Using expert-based estimates

Unlike for Jordan (Batjes *et al.* 2003) and Kenya (Batjes and Gicheru 2004), it has not been necessary to introduce expert estimates or synthetic profiles in BRASOTER. Although there are several gaps in the primary data required for assessing soil carbon stocks and change, notably bulk density, these have been filled using taxotransfer.

c) Application of taxotransfer rules

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

3. RESULTS AND DISCUSSION

3.1 General

Brazil has been described using 298 unique SOTER units, corresponding with 839 mapped polygons; the subset for the Legal Amazon comprises 193 unique SOTER units and 571 polygons. 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, organic soils in the Amazon basin may be of great importance for national inventories of carbon stocks and change. 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. Therefore, 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 Brazil, and Appendix 1 its structure. Based on current knowledge, the SOTER or map unit with NEWSUID number BR136 is coded as PTd2Acf3. The 136th map unit for the country is comprised of 60 per cent of dystric Plinthosols (PTd) and 40 percent of ferric Acrisols (ACf).

SOTERunitComposition : Table

NEWSUII	SoilMapUnit	SOIL1	PROP1	Profile-ID1	SOIL2	PROP2	Profile-ID2	SOIL3	PROP	
BR135	FRh2ACf4ACh5 [135]	FRh	60	BRgoRM25/P102	ACf	25	BRgoRM25/P23	ACh	15	BRgoRM22/P65
BR136	PTd2ACf3 [136]	PTd	60	BRgoRM22/P264	ACf	40	BRgoRM25/P23			
BR137	ACf2LPd3 [137]	ACf	60	BRgoRM25/P37	LPd	40	BRgoRM25/P87			
BR138	CMx3NTu4LPd4 [138]	CMx	50	BRgoRM29/P48	NTu	25	BRgoRM29/P15	LPd	25	BRgoRM25/P87
BR139	PTd3ACf4ACh5 [139]	PTd	55	BRgoRM29/P56	ACf	30	BRgoRM25/P23	ACh	15	BRgoRM22/P65

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

SOTERparameterEstimates : Table

CLAF	PRID	Drain	Layer	TopDep	BotDep	CFRAG	SDTO	STPC	CLPC	PSCL	BULK	TAWC	CECS	BSAT	CECc	PHAQ	TCEQ	TOTC	ECEC	ALSA
FRx	BRscufsm87	W	D1	0	20	0	46	17	37	F	1.26	7	10	19	18	4.6	0	10.8	5	40
FRx	BRscufsm87	W	D2	20	40	0	40	15	45	F	1.28	6	9	20	16	4.5	0	6.0	6	42
FRx	BRscufsm87	W	D3	40	60	0	40	15	45	F	1.34	5	9	22	16	4.5	0	6.0	6	25
FRx	BRscufsm87	W	D4	60	80	0	39	13	48	F	1.45	5	9	28	15	4.5	0	5.3	6	22
FRx	BRscufsm87	W	D5	80	100	0	39	12	49	F	1.38	4	9	26	15	4.5	0	5.0	5	22
GLd	BRamRM11/P26	P	D1	0	20	0	0	73	27	Z	1.25	15	7	44	16	3.9	0	7.0	13	35
GLd	BRamRM11/P26	P	D2	20	40	0	0	71	29	Z	1.30	11	6	26	16	4.3	0	5.2	13	8
GLd	BRamRM11/P26	P	D3	40	60	0	0	66	34	Z	1.13	10	7	43	17	4.3	0	3.8	12	19
GLd	BRamRM11/P26	P	D4	60	80	0	0	61	39	F	1.20	15	7	40	17	4.4	0	2.4	14	14
GLd	BRamRM11/P26	P	D5	80	100	0	0	61	39	F	1.10	18	7	41	16	4.3	0	2.9	14	9

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Figure 3. Example of ultimate result of the application of the TTR-scheme and depth weighing for two 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	
LPd	BRmtRM19/P92	D1	0	10	b3c2h3j3o3r1	A4
LPd	BRmtRM19/P92	D1	10	20	b3c2h3j3o3r1	A4
LPd	BRmtRM19/P92	D2	20	30	b3c3j3o3r2	A4h3
FRh	BRmtRM20/P05	D1	0	20	a3b2c2h2j2o3r1	-
FRh	BRmtRM20/P05	D2	20	40	A3b3c2h3j2o3r1	-
FRh	BRmtRM20/P05	D3	40	60	b3c2h3j2o3r1	a3
FRh	BRmtRM20/P05	D4	60	80	b3c2h3j2o3r1	a3
FRh	BRmtRM20/P05	D5	80	100	b3c2h3j2o3r2	A3

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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 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 (BRhyp04):

CLAF	PRID	LAYER	Newtopdep	Newbotdep	TTRsub	TTRmain
CMx	BRhyp04	D1	0	18	b3c2j3o3r2	a2h1
CMx	BRhyp04	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

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

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, several properties are readily modified by changes in land use or management, for example soil pH, aluminium saturation and organic matter content (Bernoux *et al.* 2003b; Cerri *et al.* 1985; Feigl *et al.* 1995; Freixo *et al.* 2002; Lilienfein *et al.* 1998).

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 secondary SOTER database; details may be found in table SOTERflagTTRrules (see Appendix 3). For example, the aluminum saturation percentage (ALSA) has been estimated using TTRs in 89 % 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 aluminum were not required as input in the original data compilation work (FAO *et al.* 1998; Peters and Van Engelen 1993). For bulk density (BULK) this is 92 %, which indicates that measured bulk density are available for 8 % of the horizons under consideration. Alternatively, TTRs have been used in only 4 per cent of the cases for CEC_{soil}, organic carbon content, and soil textural data (PSCL, SDTO, STPC).

Table 3. Type and frequency of taxotransfer rules applied

Parameter	Code	Frequency of occurrence (%)		
		TTRsub	TTRmain	Total
ALSA	A	32	57	89
BSAT	B	95	5	100
BULK	C	90	2	92
CECC	D	12	0	12
CECS	E	4	0	4
CFRAG	F	1	0	1
CLPC	G	4	0	4
ECEC	H	79	21	100
ELCO	I	9	3	12
ESP	J	96	4	100
GYPS	K	7	4	11
PHAQ	L	4	0	4
SDTO	M	4	0	4
STPC	N	4	0	4
TAWC	O	89	11	100
TCEQ	P	9	3	12
TOTC	Q	4	0	4
TOTN	R	24	1	25

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 Brazil 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	Propo	CLAF	PRID	Drain	Layer	TopDep	BotDep	CFRAG	SDTO	STPC	CLPC	PSCL	BULK	TAWC	CECS	BSAT
BR140	1	1	60	ACf	BRgoRM25/P37	M	D1	0	20	60	60	19	21	M	1.40	10	5	54
BR140	1	1	60	ACf	BRgoRM25/P37	M	D2	20	40	60	52	21	27	M	1.39	12	4	54
BR140	1	1	60	ACf	BRgoRM25/P37	M	D3	40	60	41	43	22	35	F	1.47	13	4	31
BR140	1	1	60	ACf	BRgoRM25/P37	M	D4	60	70	28	40	23	37	F	1.50	14	5	29
BR140	2	1	40	CMd	BRgoRM25/P118	W	D1	0	20	6	64	22	14	M	1.35	15	5	28
BR140	2	1	40	CMd	BRgoRM25/P118	W	D2	20	40	10	57	25	18	M	1.37	13	4	28
BR140	2	1	40	CMd	BRgoRM25/P118	W	D3	40	60	2	54	34	12	M	1.40	13	3	29
BR140	2	1	40	CMd	BRgoRM25/P118	W	D4	60	80	0	53	37	10	M	1.43	12	3	36
BR140	2	1	40	CMd	BRgoRM25/P118	W	D5	80	100	0	50	34	16	M	1.44	12	6	38
BR141	1	1	60	CMd	BRgoRM29/P39	W	D1	0	20	1	4	62	34	Z	1.30	14	6	32
BR141	1	1	60	CMd	BRgoRM29/P39	W	D2	20	40	1	3	59	38	F	1.25	13	5	30
BR141	1	1	60	CMd	BRgoRM29/P39	W	D3	40	60	0	3	58	39	F	1.25	15	5	40
BR141	1	1	60	CMd	BRgoRM29/P39	W	D4	60	80	0	3	61	36	F	1.30	15	5	46
BR141	1	1	60	CMd	BRgoRM29/P39	W	D5	80	90	0	3	61	36	F	1.30	12	5	38
BR141	1	2	20	ACf	BRgoRM25/P23	W	D1	0	20	60	77	12	11	C	1.46	10	3	81
BR141	1	2	20	ACf	BRgoRM25/P23	W	D2	20	40	60	74	10	16	M	1.48	12	2	63
BR141	1	2	20	ACf	BRgoRM25/P23	W	D3	40	60	60	57	15	28	M	1.49	12	2	42
BR141	1	2	20	ACf	BRgoRM25/P23	W	D4	60	80	60	54	16	30	M	1.48	11	2	42
BR141	1	2	20	ACf	BRgoRM25/P23	W	D5	80	100	60	53	18	29	M	1.49	3	2	37
BR141	2	1	20	FRr	BRgoRM29/P01	W	D1	0	20	1	34	20	46	F	1.14	8	9	55
BR141	2	1	20	FRr	BRgoRM29/P01	W	D2	20	40	1	34	18	48	F	1.33	7	8	56
BR141	2	1	20	FRr	BRgoRM29/P01	W	D3	40	60	1	35	18	47	F	1.37	7	7	48
BR141	2	1	20	FRr	BRgoRM29/P01	W	D4	60	80	1	35	18	47	F	1.34	7	7	42
BR141	2	1	20	FRr	BRgoRM29/P01	W	D5	80	100	1	35	18	47	F	1.30	6	6	55

Record: 548 of 3857

Figure 6. Excerpt of a SOTER summary file for units BR140 and BR141

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). The corresponding selection is included as a separate table in the secondary database for Brazil. 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 BR19.

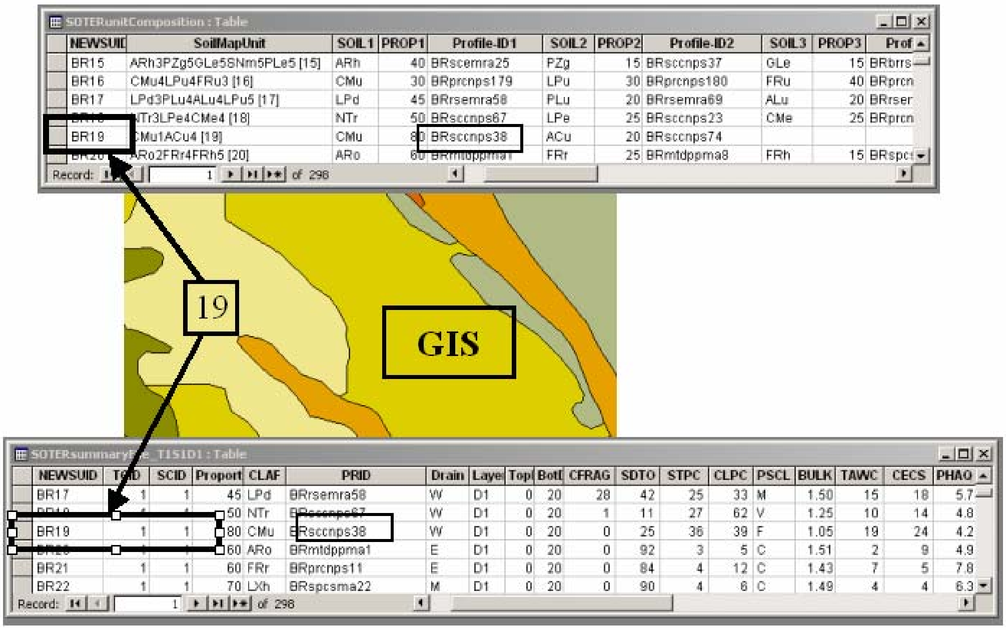

Figure 7. Linking soil parameter estimates for the top 20 cm of the dominant soil (Brsscnps38) of SOTER unit BR19 with the geographical component of SOTER

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 1:5M is about 625 km^2. 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.

The 1:5M subset for the Amazon region, the GEF-SOC case study area, has been “clipped” from the national data set using GIS.

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 1:5M but must be done more rigorously when more detailed scientific work is considered.
- The present set of soil parameter estimates for Brazil should be seen as best estimates, based on the currently available selection of profile data held in BRASOTER 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 secondary 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

(cont.)

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 (cm m^{-1}, -33 to -1500 kPa conform to USDA standards)
CECS	Single	4	cation exchange capacity ($cmol_c$ kg^{-1}) for 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})

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

Notes:
1) These are depth-weighted values, per 20 cm layer.
2) Terrain Components, and their constituent Soil Components, within a given SOTER unit are numbered starting with the spatially dominant one (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: Contents of GIS-folder

The SOTER-GIS coverage for Brazil and soil parameter estimates are provided in one single zip file called: SOTWIS_Brazil_ver1.zip.

By default, this compressed file will be unzipped to folder X:\SOTWIS_Brazil_ver1.0. This folder contains:

1) The project's apr-file, called sotwis_Brazil_01.apr.
2) The SOTER shape, legend and documentation files for Brazil, in three separate subfolders.
3) The access database containing the soil parameter estimates (SOTWIS_Brazil_1.mdb; see Appendices 1 to 4).
4) A shape file for the Brazilian Legal Amazon (file: SOTER_BR_LegalAmazon.shp).

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 include: 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 MS Access database can be easily queried via the SQL-connect option of ArcView.

Regional subsets at scale 1:5M, for example the Amazon region, can be "clipped" from the national data set using GIS a template (file: br_legalamazon.shp).

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.

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.

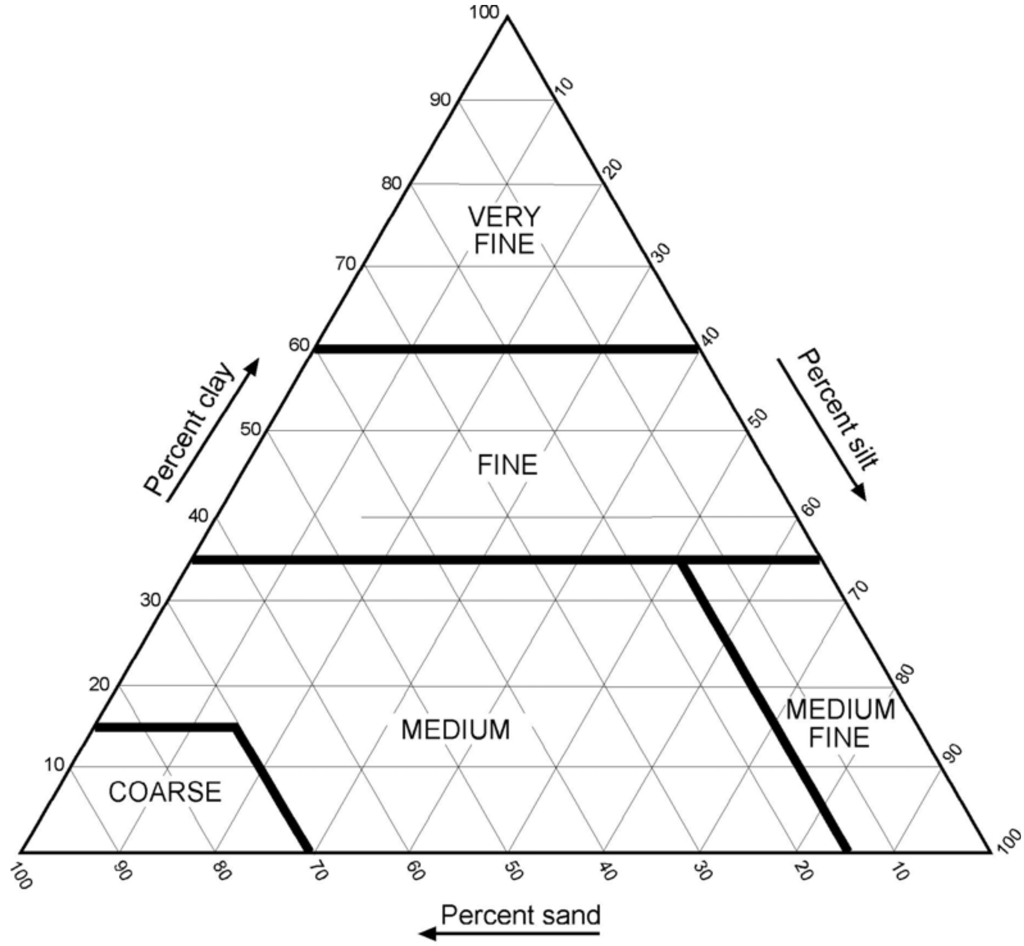

Figure 8. Soil texture classes