NAMSOTER

A
SOTER DATABASE
FOR
NAMIBIA

2001

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TABLE OF CONTENTS **Page**

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MAWRD STAFF

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The AEZ Team is dedicated to development of our country, Namibia's, natural resources in a sustainable way and is proud of playing a small part in collecting and collating the required baseline data. Ultimately, as committed Christians, we accepted this task as part of our responsibility as stewards of earth for our Lord, Jesus Christ.

Marina Coetzee

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1. INTRODUCTION

All over the world environmental and agricultural researchers, policy-makers and decision-makers need baseline information on natural resources. There is strong and increasing pressure on the natural resources of earth. Nowadays, many tools are available to make up-to-date information easily accessible for informed decision-making. One of these is a geo-referenced natural resources information system using an internationally standardised format, called SOTER, the World Soils and Terrain Digital Database. It has many strengths, one of which is the capability of transforming soil and terrain data from individual countries, collected and stored at different scales and in different formats, into a world-wide system. It is for just this purpose that the Agro-Ecological Zoning Programme of the Namibian Ministry of Agriculture, Water and Rural Development compiled national-level data into the 1:1 million scale NAMSOTER, the Namibian version of SOTER. This will form part of the 'WORLD-SOTER' to be compiled by FAO.

The SOTER structure allows storage and retrieval of soil and terrain data collected at various scales, for use in applications at various scales. SOTER stores geographic and attribute data in two different ways:

- The location and topology of terrain-soil mapping units, known as SOTER units, are stored and handled by geographical information system (GIS) software, e.g. ArcView.
- The non-mappable SOTER unit characteristics, or attribute data, are stored in a set of attribute files handled by relational database management system (RDMS) software, e.g. MS-Access. The two sets of data are linked through a unique key for each SOTER unit.

The basic concept of this agro-ecological geo-referenced database is the delineation of areas of land with a distinctive pattern of landform, surface form, slope, parent material and soils. Differentiating criteria are applied in a stepwise manner, following a hierarchical structure. At the first level of differentiation, major landforms are identified and quantified. Each landform can be further divided according to parent material. At this stage terrain components may be too complex to allow individual mapping at the 1:1 million scale. In such cases, the percentage of occurrence of these non-mappable terrain components in the mapped SOTER unit is indicated in the terrain component table, while the attributes of these non-mappable terrain components are stored in the terrain component data table. Finally, soil components are identified within each terrain component. As with terrain components, these soil components can be mappable or non-mappable. Most likely any terrain component comprises a number of soil associations or soil complexes. The percentage of occurrence within the mapped unit is indicated in the soil component table, while the attributes are stored in the soil profile and soil horizon data tables.

The characteristics entered into the database are quantifiable visual observations made in the field or chemical/physical measurements made in a laboratory. Description and coding of these attributes are done according to the Guidelines for Soil Profile Description (FAO, 1990) and the SOTER Procedures Manual (Van Engelen & Wen, 1995).

SOTER also allows entry of 'non-core' data (in the sense of not being terrain or soils data) on climate, vegetation and land-use. When SOTER is used as the input for other applications, these non-core data become essential.

2. NAMIBIAN FRAMEWORK

The Namibian Ministry of Agriculture, Water and Rural Development (MAWRD) has been involved since 1993 in a programme to inventorise, computerise, process and analyse the agricultural resources of the country, with the aid of computer databases and geobases, in a geographical information system. This exercise is known as the 'NATIONAL AGRO-ECOLOGICAL ZONING (AEZ) PROGRAMME'. It encompasses several projects, such as a National Vegetation Survey, National Soil Survey, preliminary agro-ecological zoning (completed in 1997/8), climate analysis, erosion hazard assessment, inventory of crop/cultivar requirements, land evaluation for selected land uses, crop yield modelling and (possibly) seasonal biomass production estimation, final agro-ecological zoning. In all these cases the objective is production and distribution of databases and both digital and printed maps with accompanying documentation, to serve as planning tools for decision-makers in the agricultural industry. The databases are linked with a geographical information system, and are collectively known as the Namibian Agricultural Resources Information System, **NARIS**.

During the period September 1998 until August 2000, phase I of a **NATIONAL SOIL SURVEY** was carried out as one of the projects of the AEZ Programme (ICC/MAWRD, 2000). The Kingdom of Spain supported the AEZ Programme financially. The survey was carried out by the Cartographic Institute of Catalonia and the AEZ team of MAWRD. Some of the objectives were:

- Pedo-morphological mapping at 1:100 000 scale along the Kavango river (area with relatively high climatological potential for cropping) & north central Namibia (area with high population density and degradation)
- Pedo-morphological mapping at 1:250 000 scale in north-eastern Namibia, corresponding roughly with a growing period zone of more than 60 days and mean annual rainfall of more than 500 mm;
- Pedo-morphological mapping at 1:1 000 000 scale of the remainder of the country.
  (SEE FIGURE 1)

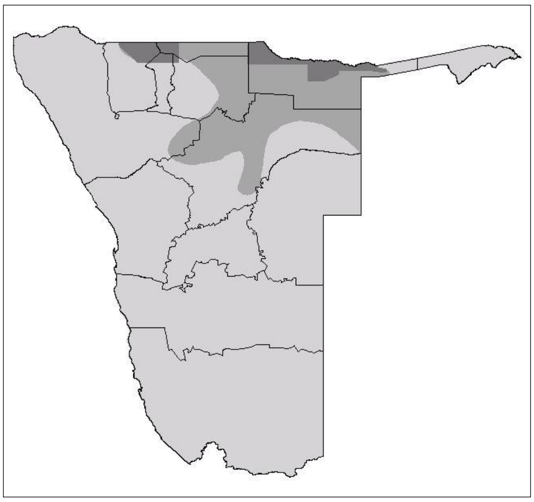

Figure 1. Mapping at 1:1 million (light gray), 1:250 000 (medium gray) and 1:100 000 (dark gray) scales

3. SOIL SURVEY METHODOLOGY (ICC/MAWRD, 2000)

In the methodology of soil surveying the soil-landscape model has been applied, according to which properties of soils vary from place to place, but this variation is not random. Natural soil bodies are the result of climate and living organisms acting on parent material, with topography or local relief exerting a modifying influence and with time required for soil-forming processes to act. For the most part, soils are the same wherever all elements of the five factors are the same. This regularity permits prediction of the location of many different kinds of soils by assuming that there is a pattern or order in the spatial distribution of soil characteristics.

Mapping at 1:1 000 000 and 1:250 000 scales made use of Landsat Thematic Mapper satellite images, taken in the dry season and processed for delineation and identification of physiographic units. The

Landsat 5 and 7 images were processed by the Cartographic Insitute of Catalonia in Barcelona. These images were plotted to serve as base-maps for fieldwork.

In the field, 1655 profile pits and 645 augerings were described according to the FAO Guidelines for Soil Description (FAO, 1990) (SEE FIGURE 2).

SURVEY	SCALE	No of PROFILES	No of AUGERINGS
Kavango river area	1:100 000	73	645
Northern Central Namibia	1:100 000	319	0
Growing period zones 2 & 3	1:250 000	435	0
Remainder of Namibia	1:1 000 000	828	0
TOTAL		1655	645

The distribution of observation points seems very lopsided, but one should keep in mind that Namibia is a very arid country and mostly used for extensive grazing.

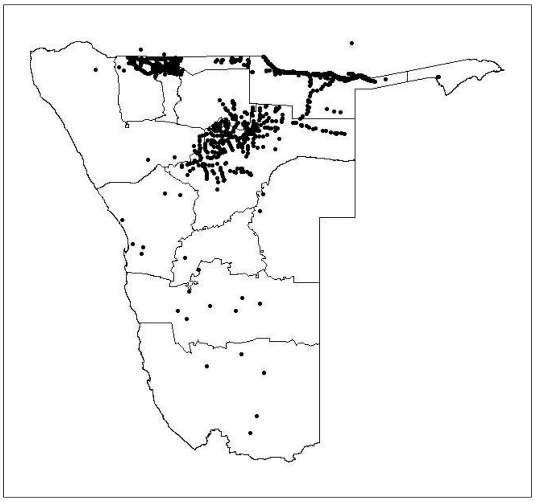

Figure 2. Soil profiles and augering sites

Figure 3. Position of three best growing period zones

Only 2 % of the country is suitable (Growing Period Zone 1), and another 6 % (Growing Period Zone 2) is considered to be moderately suitable for dryland (rainfed) cropping (SEE FIGURE 3). The Kavango river terrace is one of Namibia's few areas with enough water and reasonably good soils for irrigation, if Namibia, Angola and Botswana can agree on water extraction quotas.

Furthermore, the north-central area (former 'Owambo') houses almost two-thirds of Namibia's entire population and is intensely used for dryland farming of pearl millet ('mahangu') and grain sorghum, as well as grazing for cattle, goats and donkeys (SEE FIGURE 4). Hence the emphasis on the Kavango river terrace and north-central Namibia.

The eastern Caprivi, which is in Growing Period Zone 1, received less attention for several reasons: very poor sandy soils, frequent flooding, distance from Windhoek (as usual, the project had a strict deadline) and, mainly, an unstable political situation at the time of fieldwork. This is one area that will receive priority attention in phase II of the National Soil Survey.

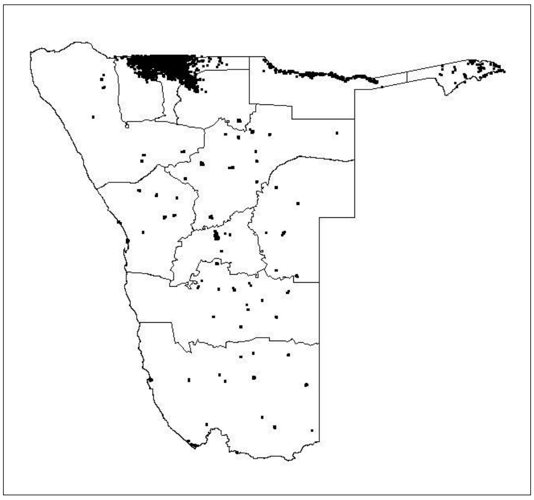

Figure 4. Population density
1 dot = 10 persons/km^2

While fieldwork was in progress, soil samples were analysed by the Agricultural Laboratory of the Namibian Ministry of Agriculture, Water and Rural Development.

The taxonomic units are the soil units of the World Reference Base. Classification has been performed to the level of soil sub-units (WRB, 1998). In order to facilitate correlation with previous work, the taxonomic units have also been classified according to the Revised Legend of FAO (FAO, 1988) and the Soil Taxonomy System (SSS, 1996). The map units consist of associations and complexes of taxonomic units. Furthermore, in the more detailed maps, phases (slope, texture of the superficial horizon, salinity and sodicity) have been used in order to give more relevant information to evaluate the agriculture potential of units.

All information has been recorded in digital format by digitizing the soil map and typing the attribute data in databases. In the case of the surveys at scale E=1:250.000 and 1:1.000.000 this basically followed the SOTER structure (Van Engelen & Wen, 1995). In the case of the 1:100 000 maps, the SOTER structure was adapted and extended to allow more detail.

Entry, storage, processing and analysis of geographical data were done with ArcView 3.2. The ICC also made use of ArcInfo. Attribute data, linked to geographical data, were stored and processed in MSAccess-2000.

The final maps were printed on mosaics of the satellite images.

Three areas of Namibia were excluded from phase I of the National Soil Survey (FIGURE 5):

- ETOSHA NATIONAL PARK was mapped previously by Dr Manfred Buch and students from the University of Regensburg, Germany. Their map and profile data must still be adapted to the SOTER format.
- The DIAMOND AREA in the south-west of Namibia is forbidden terrain for the general public. We should be able to obtain permission to survey there, but it will be at the leisure of the diamond company, Namdeb, and with their staff accompanying us. This is planned for phase II.
- The SKELETON COAST in the north-west of Namibia is a concession area. We also need special permission and must be accompanied by officials of the Ministry of Environment and Tourism to work in that area. This is another project for phase II of the NSS.

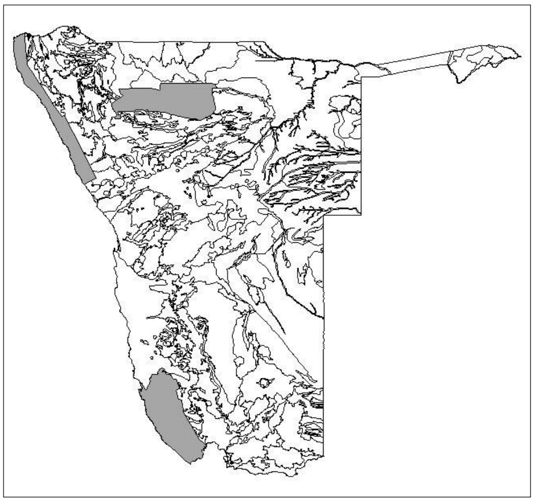

Figure 5. Grey areas excluded from NSS phase 1

No cross-border mapping was carried out with soil or SOTER maps of neighbouring countries. This is another aim of phase II.

The products of the 1:1 million and 1:250 000 scale mapping described above served as direct input for the establishment of **a NAMIBIAN SOTER DATABASE AND GIS COVERAGE**. It is envisaged that further larger scale mapping (phase II of the National Soil Survey) will improve the accuracy and completeness of NAMSOTER. We thus consider the current product as 'version 1' and intend to continually improve upon it.

4. SOTER MAPPING APPROACH

A basic principle of the SOTER methodology is the identification of areas of land with a distinctive, often repetitive, pattern of landform, lithology, surface form, slope parent material and soil. Tracts of land distinguished in this manner are named SOTER units. Each SOTER unit thus represents one unique combination of terrain and soil characteristics. It resembles physiographic soil mapping. The SOTER methodology applies certain hierarchically structured differentiating criteria step by step to reach an accurate identification. Thus, **the SOTER unit progressively obtains its definition in terms of terrain, terrain components and soil components:**

- **TERRAIN** is described in physiographic terms as **major landforms**, based on the **dominant gradient** of their slopes and their **relief intensity**. First and second level landforms are further delineated using **hypsometry** (absolute elevation above sea-level) and **degree of dissection**. These physiographic units are then subdivided according to **lithology** (parent material). In SOTER context, terrain is thus defined as a particular combination of landform and lithology that characterises an area.
- Terrain is further partitioned into **TERRAIN COMPONENTS** with a particular **surface form**, **slope**, **mesorelief** and, in areas covered by unconsolidated material, **texture** of parent material. Terrain components are often not mappable at 1:1 million scale, due to the complexity of their occurrence in a terrain and are thus entered into the attribute database, but not represented as individual units on the map. The percentage of each terrain component within the terrain is recorded.
- **SOIL COMPONENTS** are identified within each terrain component. At 1:1 million scale, the soil components within a terrain component are often not mappable and traditionally would have been described as a soil association or soil complex. The percentage of each soil component within each terrain component is recorded, as is its relative position and relationship with other soil components. Soil components are characterised by representative soil profiles and their respective horizons.
- For each soil component at least one fully described and analysed reference profile ought to be available. One of these reference profiles is selected to be the **REPRESENTATIVE PROFILE** of that soil component and typed into the relevant SOTER table. The format follows the Guidelines for Soil Profile Description (FAO, 1990) very closely.
- Individual **HORIZONS** of the representative profile are described in terms of chemical and physical properties.

5. NAMSOTER DATABASE

The database consists of a number of tables in a relational database system, in accordance with the mapping approach described above (SEE FIGURE 6). The complete SOTER table structures and codification are described in APPENDICES A and B. A summary of the most important elements is given below.

TERRAIN

The TERRAIN TABLE contains the country code, SOTER unit ID, year of data collection, map ID, elevation information, slope gradient and relief intensity, major landform, regional slope hypsometry, degree of dissection, general lithology and permanent water surface, where applicable.

NAMSOTER contains 89 terrain units and, consequently, 89 SOTER units.

TERRCOMP

The TERRAIN COMPONENT TABLE contains the SOTER unit ID (which links this table to the Terrain table), terrain component number, proportion of the SOTER unit covered by the specific terrain component, and a terrain component data ID to provide a link to the Terrain Component Data table.

NAMSOTER contains 114 terrain components.

TCDATA

The actual quantification or description of each terrain component is found in the TERRAIN COMPONENT DATA TABLE. It contains fields for characteristics of slope (angle, length and form), flooding (frequency, duration, start), local surface features (form, height, coverage), depth to bedrock and groundwater, surface drainage and texture group, if the parent material is non-consolidated.

SOILCOMP

The SOIL COMPONENT TABLE links to the Terrain Component Table through the SOTER unit ID and terrain component ID, as well as to its representative profile in the Profile table through the profile ID field. It contains the ID of each soil component and the percentage that each one covers per SOTER unit, the number of reference profiles, position in the terrain component, information on surface rockiness and stoniness, erosion (type, area, degree), sensitivity to capping, rootable depth and relation with other soil components.

NAMSOTER contains 262 soil components.

REPPROFILES

The PROFILE TABLE links to both the Soil Component table and Representative Horizon table through the representative profile ID. The table contains location data (latitude, longitude, elevation), sampling date and the ID of the laboratory that analysed the soil, information on drainage and infiltration and various fields related to classification.

NAMSOTER contains 50 representative profiles

REPHORIZONS

The Representative Horizon table links to the Profile table through the representative profile ID, and to the Minimum and Maximum Horizon tables through the horizon number. This table contains descriptors of the horizon's position within the profile, diagnostic properties, physical and chemical characteristics. It contains all the analytical data from the laboratory.

NAMSOTER contains 147 horizons of representative profiles.

ALLPROFILES

The ALLPROFILES TABLE links to the ALLHORIZONS tables through the reference profile ID's. The table contains location data (latitude, longitude, elevation), sampling date and the ID of the laboratory that analysed the soil, information on drainage and infiltration and various fields related to classification.

NAMSOTER contains 2157 reference profiles

ALLHORIZONS

The ALLHORIZONS table links to the ALLPROFILES table through the reference profile ID. This table contains descriptors of the horizon's position within the profile, diagnostic properties, physical and chemical characteristics. It contains all the analytical data from the laboratory.

NAMSOTER contains 6208 horizons of reference profiles.

LABNAME

The Laboratory Name table assigns a laboratory ID to every laboratory that carries out analyses for the survey. The laboratory ID links it to the Profile table.

NAMSOTER contains the names of three regional laboratories, although only the Agricultural Laboratory of the Namibian Ministry of Agriculture, Water & Rural Development carried out analyses for this project.

LABMETH

As different analytical methods can be followed for any given analyte, e.g. the Ohlsen and Bray-I methods for phosphorus, the LABORATORY METHOD TABLE provides the site to specify the ID of the method used. It also contains the date this type of analysis was first carried out by the particular laboratory, and the ID of the laboratory.

ANAMETH

The actual description of the method can be found in the ANALYTICAL METHOD TABLE (see also APPENDIX D of report), which is linked to the Laboratory Method table through the method ID.

These tables described above constitute the core of the SOTER Database. There are some supporting tables, but they are not mandatory for basic applications of SOTER and some are not yet completed in the current version of NAMSOTER:

CLIMSTAT

The CLIMATE STATION TABLE identifies each climate station by name, ID, latitude, longitude and altitude. Though not required by SOTER, NAMSOTER also contains fields on computer number, SA Weather Bureau number and magisterial district, for internal use.

NAMSOTER contains 1012 climate stations, although data are not included for all stations. Stations with short or inefficient record lengths were included in this table, but the data excluded from the Climdat table.

CLIMDAT

The CLIMATE DATA TABLE links to the Climate Station table through the climate station ID. This table contains monthly and annual means or medians of different climate elements, which are identified in each case. It also has some data on start, end and length of records. At present the Namibian SOTER database only contains climate data that is in the possession of the MAWRD, namely 1835 records. It will be expanded once a thorough evaluation of other data sources had been completed.

CLIMSOUR

The CLIMATE DATA SOURCE TABLE identifies the source name and ID of climate data.

VEGETAT

The VEGETATION TABLE links to the Terrain table through the SOTER unit ID and contains information on vegetation type and proportion of SOTER unit covered by it, as well as observation date.

LANDUSE

The LAND USE TABLE links to the Terrain table through the SOTER unit ID and contains information on land use type and observation date. The proportion of SOTER unit covered by it, as required by the SOTER format, had not been completed in NAMSOTER.

MINHORIZ & MAXHORIZ

The Horizon Minimum Value table and Horizon Maximum table give a certain degree of variability of physical and chemical horizon properties by giving the maximum and minimum values occurring within other reference profiles. These tables are empty in NAMSOTER.

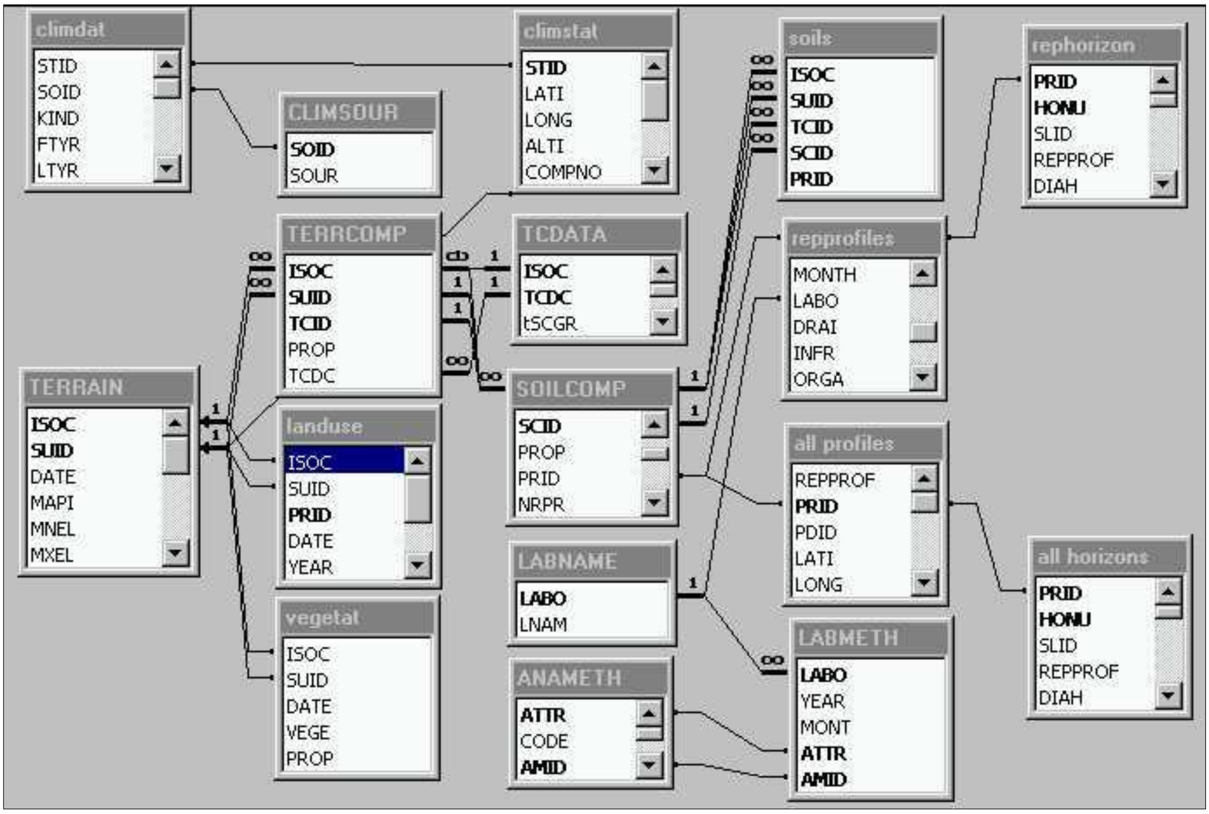

Figure 6. Relational structure of tables in NAMSOTER database

6. DATA ENTRY

Data entry was simplified by using customised data entry forms with pull-down menus to minimise typing errors. These forms are illustrated in APPENDIX C. Some data were typed in directly from field forms, some came from laboratory reports and the remainder was deduced from the soil maps.

7. NAMSOTER GEOGRAPHICAL INFORMATION SYSTEM

The SOTER mapping units can be displayed and queried by using GIS software. In the case of NAMSOTER we made use of ArcView 3.2. Once the SOTER units had been hand-drawn on plots of the rectified satellite images, digital delineation was done by on-screen digitizing. Next the individual tables in NAMSOTER were exported from the MSAccess database in dBase format. These were added to ArcView. There is no direct link between these tables in ArcView and those in MSAccess. Hence, any changes done in MSAccess will require that the relevant table is first re-exported in dBase format and that the original dBase file is overwritten. The change will then appear automatically in ArcView. Some small modifications were made to the codification of tables in ArcView, to allow easier linkage with the original soil map.

By linking all the tables in ArcView, a spatial query on the actual map can be reflected in all the tables. In the example below (FIGURE 8), SOTER unit 47 was selected from the map displayed in the View. The terrain and soil data corresponding to that unit are visible in each of the TERRAIN, TERRAIN COMPONENT, TERRAIN COMPONENT DATA, SOIL COMPONENT, PROFILE AND REPRESENTATIVE HORIZON tables. It indicates that SOTER unit 47 has two terrain components (TCID1 &TCID2), each one of those has one soil component (SCID 1 and 1). SOTER unit (SUID) 47, Terrain Component (TCID) 1, Soil Component (SCID) 1 is characterised by a representative profile with the ID (PRID) NAM-663. SOTER unit (SUID) 47, Terrain Component (TCID) 2, Soil Component (SCID) 1 is characterised by a representative profile PRID NAM-31. Lastly, one can see that NAM-663 has 2 horizons, while NAM-31 has 3 horizons. It is thus possible to view and query all the mappable and non-mappable data from NAMSOTER in the geographical information system.

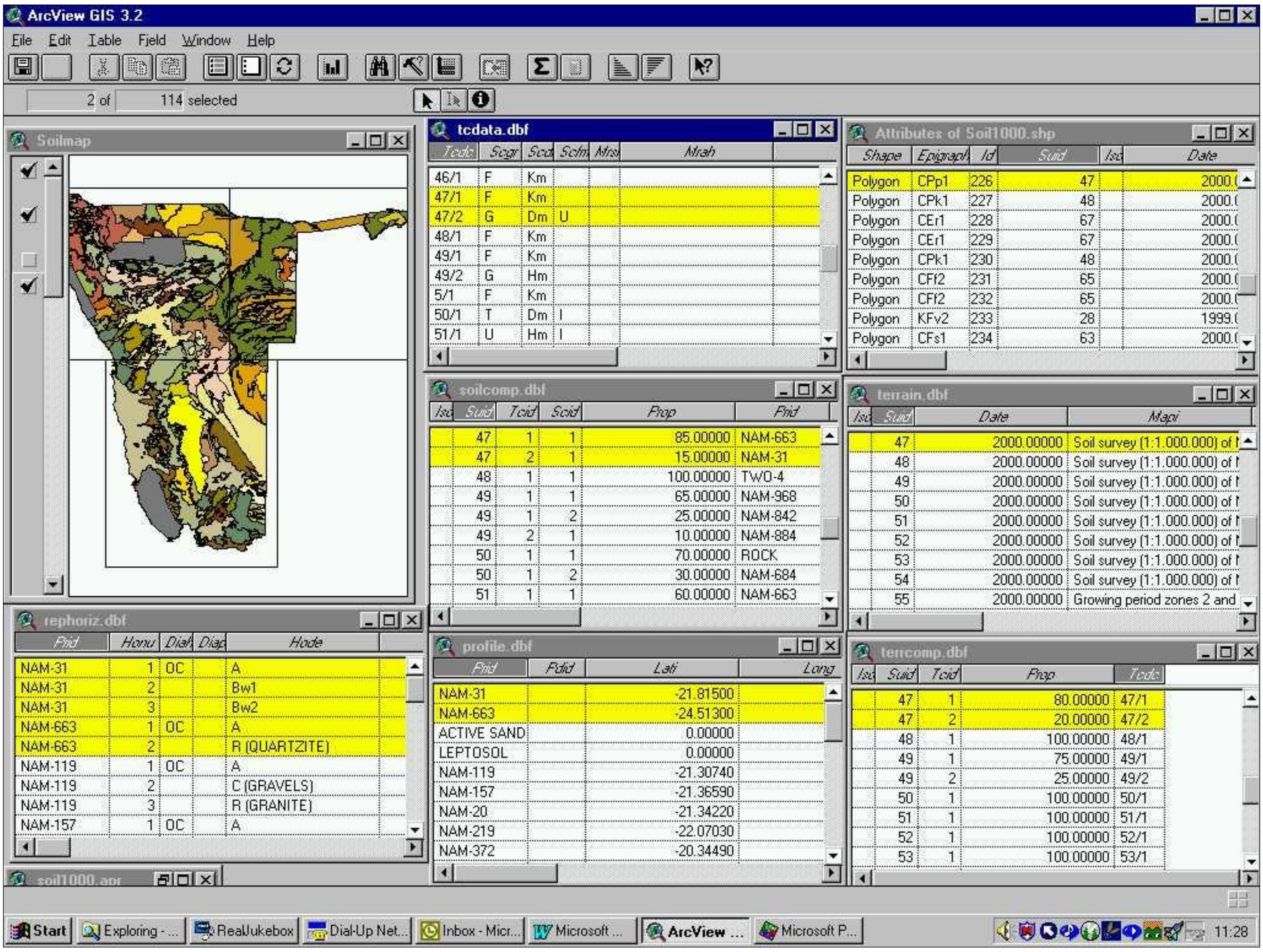

Figure 8. Snapshot of a spatial query in ArcView 3.2, illustrating how NAMSOTER tables are linked to one another, and to the map in the geographical information system.

For normal viewing and querying of the geobase, one does not need to be overly concerned with data projection. However, when overlaying satellite images, digital elevation models, grid files or other referenced image files, it becomes imperative to know in what reference system the data were captured. This is also a prerequisite for joining maps from different sources.

Projection:	**Albers Equal Area Conic**
Spheroid:	**Bessel (Schwarzeck Datum)**
Central Meridian:	**18:30 E of Greenwich**
Reference Latitude:	**22 S**
Standard Parallel 1:	**20 S**
Standard Parallel 2:	**26 S**
False Easting: 0.0	
False Northing: 0.0	

Figure 9. Reference system for 1:1 million scale mapping.

8. REFERENCES

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ICC/MAWRD. 2000. **Project to Support the Agro-Ecological Zoning Programme (AEZ) in Namibia**. Cooperation Project between the Ministry of Agriculture Water and Rural Development of Namibia, the Cartographic Institute of Catalonia and the Spanish Agency for International Cooperation. Main Report, 243 pp. Annexes, 224 pp. 79 maps.

Van Engelen VWP, Wen TT (eds). 1995. **Global and National Soils and Terrain Digital Databases (SOTER) - Procedures Manual** (revised version). FAO World Soil Reference Report 74. UNEP/ISSS/ISRIC/FAO. Rome.

A. ATTRIBUTE FIELD CODES AND -DESCRIPTIONS OF NAMSOTER TABLES

Primary key fields are in **bold** and indexed fields in *italics*. In cases where a characteristic is represented by both a class (text field) and a number (number field), they are denoted by a 't' or 'n' in front of the fieldname.

TERRAIN TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
ISOC	Country code
SUID	SOTER unit ID
DATE	Year of data collection
MAPI	Map ID
MNEL	Minimum elevation
MXEL	Maximum elevation
tGSLP	Slope gradient, class/interval
nGSLP	Slope gradient, % (empty)
tRELF	Relief intensity, class
nRELf	Relief intensity, value (empty)
LNDF	Major landform
RSLO	Regional slope
HYPS	Hypsometry
DISS	Dissection
LITH	General lithology
PWAT	Permanent water surface

TERRCOMP (terrain components) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
ISOC	country code
SUID	SOTER unit ID
TCID	terrain component ID
PROP	proportion of SOTER unit
TCDC	terrain component data ID

TCDATA (terrain components data) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
ISOC	Country code
TCDC	Terrain component data code
tSCGR	Dominant slope, class
nSCGR	Dominant slope, % (empty)
tSCDL	Length of slope, class
nSCDL	Length of slope, m (empty)
SCFM	Form of slope
MRSF	Local surface form

MRAH	Average height (empty)
MRPR	Coverage (empty)
LITH	Surface lithology
TEXT	Texture of non-consolidated parent material
tBEDR	Depth to bedrock, class
nBEDR	Depth to bedrock, m (empty)
SDRA	Surface drainage
GWAT	Depth to groundwater, m (empty)
FLFR	Frequency of flooding
FLDU	Duration of flooding
FLST	Start of flooding

SOILCOMP (soil components) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
ISOC	Country code
SUID	SOTER unit ID
TCID	Terrain component ID
SCID	Soil component ID
PROP	Proportion of SOTER unit
PRID	Representative profile ID
NRPR	Number of reference profiles
POSI	Position in terrain component
RKSC	Surface rockiness
STSC	Surface stoniness
ERTY	Types of erosion/deposition
ERAA	Area affected by erosion
ERDE	Degree of erosion
SCAP	Sensitivity to capping
RDEP	Rootable depth, class
RELA	Relation with other soil components

ALL PROFILES (all reference profiles) and REP PROFILES (representative profiles only) TABLES

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
PRID	Representative profile ID
PDID	ID of profile database owner
LATI	Latitude, decimal degrees
LONG	Longitude, decimal degrees
ELEV	Elevation, m
DATE	Sampling date
YEAR	Year of sampling
MONTH	Month of sampling
LABO	ID of Laboratory
DRAI	Drainage
INFR	Infiltration rate

ORGA	Surface organic matter
CLAF	Classification
CLAV	Classification version
PHAS	Phase
CLAN	National classification
STAX	Soil taxonomy

ALL HORIZONS (from all reference profiles) and REP HORIZONS (only from representative profiles) TABLES

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
PRID	Representative profile ID
HONU	Horizon number
SLID	Sample laboratory ID (for internal use)
DIAH	Diagnostic horizon
DIAP	Diagnostic property
HODE	Horizon designation
HBDE	Lower depth of horizon
HBDI	Distinctness of transition
SCMO	Moist colour
SCDR	Dry colour (empty)
STGR	Grade of structure
STSI	Size of structure elements
STTY	Type of structure
MINA	Abundance of coarse fragments
MINS	Size of coarse fragments
SDVC	Very coarse sand (empty)
SDCO	Coarse sand (empty)
SDME	Medium sand (empty)
SDFI	Fine sand (empty)
SDVF	Very fine sand (empty)
SDTO	Total sand, %
STPC	Silt, %
CLPC	Clay, %
PSCL	Particle size class
BULK	Bulk density, kg/dm^3
MCT1	Moisture at tension 1 (empty)
TEN2	Tension 2 (empty)
MCT2	Moisture at tension 2 (empty)
TEN3	Tension 3 (empty)
MCT3	Moisture at tension 3 (empty)
TEN4	Tension 4 (empty)
MCT4	Moisture at tension 4 (empty)
MCT5	Moisture at tension 5 (empty)
HYDC	Hydraulic conductivity (empty)
INFI	Infiltration rate (empty)
PHAQ	pH H_2O, 1:2.5 soil-water mixture
PHKC	pH KCl, 1:2.5 soil-KCl mixture (empty)

EL25Us/cm	Electrical conductivity of supernatant of 1:2.5 soil-water mixture, uS/cm (for internal use)
EL25	Electrical conductivity of supernatant of 1:2.5 soil-water mixture, dS/m
ELCOuS/cm	Electrical conductivity of saturation extract, uS/cm (for internal use)
ELCO	Electrical conductivity of saturation extract, dS/m
SONA	Soluble sodium, meq/l
SOCA	Soluble calcium, meq/l
SOMG	Soluble magnesium, meq/l
SOLK	Soluble potassium, meq/l
SOCL	Soluble chloride, meq/l
SSO4	Soluble Sulphate, ppm
HCO3	Soluble carbonate, meq/l
SCO3	Soluble bicarbonate, meq/l
EXCA	Exchangeable calcium, cmol(+)/kg
EXMG	Exchangeable magnesium, cmol(+)/kg
EXNA	Exchangeable sodium, cmol(+)/kg
EXCK	Exchangeable potassium, cmol(+)/kg
EXAL	Exchangeable aluminium, cmol(+)/kg (empty)
EXAC	Exchangeable acidity, cmol(+)/kg (empty)
CECS	CEC soil, cmol(+)/kg
TCEQ	Total carbonate equivalent, g/kg
GYPS	Gypsum, g/kg
TOTC	Total carbon, g/kg
TOTNppm	Total nitrogen, mg/kg = ppm (for internal use)
TOTN	Total nitrogen, g/kg
P	Phosphorus, mg/kg = ppm (for internal use)
P2O5	Diphosphor pentoxide, mg/kg = ppm
PRET	Phosphate retention (empty)
FEDE	Fe dithionite (empty)
FEPE	Fe pyrophosphate (empty)
ALDE	Al dithionite (empty)
ALPE	Al pyrophosphate (empty)
CLAY	Clay mineralogy (empty)

CLIMSTAT (climate stations) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
STID	Climate station ID
SUID	SOTER unit ID
STNA	Climate station name
LATI	Latitude
LONG	Longitude
ALTI	Altitude
COMPNO	Computer number (for internal use)
WBNO	South African Weather Bureau number (for internal use)
DIST	Magisterial district, SA stations (for internal use)

CLIMDAT (climate data) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
STID	Climate station ID
KIND	Climate element (rainfall, maximum temperature, etc.)
SOID	Climate data source ID
FTYR	First year
LTYR	Last year
NYRS	Number of years
JANU	January
FEBR	February
MARC	March
APRI	April
MAY	May
JUNE	June
JULY	July
AUGU	August
SEPT	September
OCTO	October
NOVE	November
DECE	December
ANNU	Annual value

CLIMSOUR (climate data sources) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
SOID	Climate data source ID
SOUR	Source name

LABNAME (laboratory name) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
LABO	Laboratory ID
LNAM	Laboratory name

LABMETH (laboratory methods) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
LABO	Laboratory ID
YEAR	Year method was first introduced in laboratory
MONT	Month method was first introduced in laboratory
ATTR	Attribute (analyte ID)
AMID	Method of analysis ID

ANAMETH (analytical methods)TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
AMID	Method of analysis
ATTR	Attribute (analyte ID)
CODE	Code used in Rephorizon and Allhorizons tables for analyte
AMET	Description of method
ANA	Analyte; short neme of attribute (for internal use)
SOP	Standard operating procedure number (for internal use)

ISOCODE (country code) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
ISOC	Country code
COUNTRY	Country name

PROFILEDB (profile database identification) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
PDID	Profile database ID
DOWN	Description of database owner (Name of institute)

SOURCMAP (source of soil & terrain data) TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
MAPI	Map ID
TITL	Map title
YEAR	Year
SCAL	Scale (as decimal fraction)
MLAT	Minimum latitude
MLON	Minimum longitude
XLAT	Maximum latitude
XLON	Maximum longitude
TYPE	Type of map

SOILS (relationships) TABLE (to help with GIS linkage)

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
ISOC	Country code
SUID	SOTER unit ID
TCID	Terrain component ID
SCID	Soil component ID
PRID	Representative profile ID

LANDUSE TABLE

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
ISOC	Country code
SUID	SOTER unit ID
PRID	Profile ID
DATE	Date of observation
YEAR	Year of observation
MONTH	Month of observation
LUSE	Land use
PROP	Proportion of SOTER unit occupied by land use type (empty)

VEGETAT (vegetation) TABLE (partially filled in, using non-SOTER codes – to be revised)

ATTRIBUTE FIELD	ATTRIBUTE DESCRIPTION
ISOC	Country code
SUID	SOTER unit ID
DATE	Date of observation
VEGE	Vegetation (non-SOTER codes)
PROP	Proportion of SOTER unit (empty)

MAXHORIZON TABLE (fields similar to REPHORIZON, empty)

MINHORIZON TABLE (fields similar to REPHORIZON, empty)

B. NAMSOTER CODIFICATION

In order to construct the entry form and facilitate database implementation, dictionary tables were created with this structure:

- FIELDNAME
- CODE
- DESCRIPTION

TERRAIN TABLE

FIELDNAME	CODE	DESCRIPTION
LNDF	LP	Plain
LNDF	LL	Plateau
LNDF	LD	Depression
LNDF	LF	Low-gradient footslope
LNDF	LV	Valley floor
LNDF	SM	Medium-gradient mountain
LNDF	SH	Medium-gradient hill
LNDF	SP	Dissected plain
LNDF	TM	High-gradient mountain
LNDF	CV	Valley
RSLO		Not described
RSLO	W	0-2% flat, wet
RSLO	F	0-2% flat
RSLO	G	2-5% gently undulating
RSLO	U	5-8% undulating
RSLO	R	8-15% rolling
RSLO	S	15-30% moderately steep
RSLO	T	30-60% steep
RSLO	TE	Terraced
RSLO	IN	Inselberg covered (at least 1% of level land)
RSLO	DU	Dune-shaped
RSLO		Not described
HYPS	1	< 300 m (level & sloping lands, relief intensity < 50m/slope unit)
HYPS	2	300-600 m (level & sloping lands, relief intensity < 50m/slope unit)
HYPS	3	600-1500 m (level & sloping lands, relief intensity < 50m/slope unit)
HYPS	4	1500-300 m (level & sloping lands, relief intensity < 50m/slope unit)
HYPS	6	< 200 m (sloping lands, relief intensity > 50m/slope unit)
HYPS	8	> 400 m (sloping lands, relief intensity > 50m/slope unit)
HYPS	9	600-1500 m (steep & sloping lands, relief intensity > 600 m/2 km)
HYPS	10	1500-3000 m (steep & sloping lands, relief intensity > 600 m/2 km)
HYPS		Not described
DISS	1	Slightly dissected < 10 km/km^2

DISS	2	Dissected 10-25 km/km^2
DISS	3	Strongly dissected < 10 km/km^2
DISS		Not described
LITH	IA	Acid igneous rock
LITH	IB	Basic igneous rock
LITH	M	Metamorphic rock
LITH	MA	Acid metamorphic rock
LITH	MB	Basic metamorphic rock
LITH	SC	Clastic sediments
LITH	SO	Organic (sedimentary rock)
LITH	UF	Fluvial
LITH	UL	Unconsolidated lacustrine material
LITH	UC	Unconsolidated colluvial material
LITH	UE	Unconsolidated eolian material
LITH		Not described

TERRAIN COMPONENT DATA TABLE

FIELDNAME	CODE	DESCRIPTION
tSCGR	F	Flat, 0-0.5%
tSCGR	A	Almost flat, 0.5-2 % (no records)
tSCGR	G	Gently undulating, 2-5 %
tSCGR	U	Undulating, 5-10 %
tSCGR	R	Rolling, 10-15 %
tSCGR	H	Hilly, 15-30 % (no records)
tSCGR	S	Steep,>30 %, moderate elevation
tSCDL	Km	Slope length in the order of kilometers
tSCDL	Hm	Slope length in the order of hundreds of meters
tSCDL	Dm	Slope length in the order of tens of meters
SCFM	U	Uniform / straight slope
SCFM	C	Concave
SCFM	V	Convex
SCFM	I	Irregular slope
SCFM		Not described
MRSF	H	Hummocky
MRSF	S	Strongly dissected (drainage density > 25 km/km^2)
MRSF	D	Dissected areas with drainage density > 10 km/km^2)
MRSF	L	Slightly dissected (drainage density < 10 km/km^2)
MRSF		Not described
LITH	IA	Acid igneous rock
LITH	IB	Basic igneous rock
LITH	IB2	Basalt
LITH	M	Metamorphic rock
LITH	MA	Acid metamorphic rock
LITH	MA1	Quartzite
LITH	MB	Basic metamorphic rock
LITH	SC	Clastic sediments
LITH	SO	Organic (sedimentary rock)

LITH	SO1	Limestone, other carbonate rocks
LITH	UF	Fluvial
LITH	UL	Unconsolidated lacustrine material
LITH	UC	Unconsolidated colluvial material
LITH	UE	Unconsolidated eolian material
LITH		Not described
TEXT	L	Loamy
TEXT	S	Sandy
TEXT	X	Extremely sandy
TEXT		Not described
tBEDR	D	Deep, > 100 cm
tBEDR	M	Moderately deep, 50-100 cm
tBEDR	S	Shallow, 30-50 cm
TBEDR	V	Very shallow, 15-30 cm
TBEDR	X	Extremely shallow, < 15 cm
SDRA	E	Extremely slow
SDRA	S	Slow
SDRA	W	Well
SDRA	R	Rapid
SDRA	V	Very rapid
SDRA		Not described
FLFR	N	None
FLFR	A	Annually
FLFR	F	Once every 2-5 years
FLFR	R	Rare (less than once in every 10 years)
FLFR		Not described
FLDU	2	1-15 days
FLDU	3	15-30 days
FLDU	4	30-90 days
FLDU		Not described
FLST	1	Flooding starts in January
FLST	12	Flooding starts in December

SOIL COMPONENT TABLE

FIELDNAME	CODE	DESCRIPTION
POSI	H	High
POSI	M	Middle
POSI	L	Low
POSI	D	Lowest
POSI	A	All
POSI		Not described
RKSC	N	None (0%)
RKSC	V	Very few (0-2%)
RKSC	F	Few (2-5%)
RKSC	C	Common (5-15%)
RKSC	M	Many (15-40%)
RKSC	A	Abundant (40-80%)
RKSC	D	Dominant (> 80%)

RKSC		Not described
STSC	N	None (0%)
STSC	V	Very few (0-2%)
STSC	F	Few (2-5%)
STSC	C	Common (5-15%)
STSC	M	Many (15-40%)
STSC	A	Abundant (40-80%)
STSC	D	Dominant (> 80%)
STSC		Not described
ERTY	N	No visible evidence of erosion
ERTY	S	Sheet erosion
ERTY	R	Rill erosion
ERTY	G	Gully erosion
ERTY	P	Deposition by water
ERTY	W	Water and wind erosion
ERTY	L	Wind deposition
ERTY	A	Wind erosion and deposition
ERTY	D	Shifting sand
ERTY		Not described
ERAA	1	0-5%
ERAA	2	5-10%
ERAA	3	10-25%
ERAA	4	25-50%
ERAA	5	> 50%
ERAA	0	Not described
ERDE	S	Slight
ERDE	M	Moderate
ERDE	V	Severe
ERDE		Not described
SCAP	N	None
SCAP	W	Weak
SCAP	S	Strong
SCAP		Not described
RDEP	V	Very shallow (< 30 cm)
RDEP	S	Shallow (30-50 cm)
RDEP	M	Moderately deep (50-100 cm)
RDEP	D	Deep (100-150 cm)
RDEP	X	Very deep (> 150 cm)
RDEP		Not described

ALL PROFILES TABLE AND REPPROFILES TABLE

FIELDNAME	CODE	DESCRIPTION
REPPROF	Y	Is a representative profile
REPPROF	N	Is not a representative profile
DRAI	E	Excessively well drained
DRAI	S	Somewhat excessively well drained
DRAI	W	Well drained
DRAI	M	Moderately well drained

DRAI	I	Imperfectly drained
DRAI	P	Poorly drained
DRAI	V	Very poorly drained
DRAI		Not described

REPHORIZ TABLE

FIELDNAME	CODE	DESCRIPTION
DIAH	AL	Albic
DIAH	AR	Argic
DIAH	CA	Calcic
DIAH	CB	Cambic
DIAH	GY	Gypsic
DIAH	HC	Hypercalcaric
DIAH	HI	Histic
DIAH	LE	Leptic
DIAH	MO	Mollic
DIAH	OC	Ochric
DIAH	PC	Petrocalcic
DIAH	PG	Petrogypsic
DIAH	VE	Vertic
DIAP	CO	Calcareous
DIAP	CA	Calcaric
DIAP	RO	Continuous hard rock
DIAP	FA	Ferralic properties
DIAP	FI	Ferric properties
DIAP	FL	Fluvic properties
DIAP	GY	Gypsiferous
DIAP	NI	Nitic properties
DIAP	SA	Salic properties
DIAP	SO	Sodic properties
DIAP	VE	Vertic properties
DIAP		Not described
HBDI	A	Abrupt: 0-2 cm
HBDI	C	Clear: 2-5 cm
HBDI	G	Gradual: 5-15 cm
HBDI	D	Diffuse: ≥15 cm
HBDI		Not described
STGR	N	Structureless
STGR	W	Weak
STGR	M	Moderate
STGR	S	Strong
STGR		Not described
STSI	V	Very fine
STSI	F	Fine
STSI	M	Medium
STSI	C	Coarse
STSI	X	Very coarse
STSI		Not described

STTY	P	Platy
STTY	R	Prismatic
STTY	C	Columnar
STTY	A	Angular blocky
STTY	S	Subangular blocky
STTY	G	Granular
STTY	M	Massive
STTY	N	Single grain
STTY		Not described
MINA	N	None: 0%
MINA	V	Very few: 0-2%
MINA	F	Few: 2-5%
MINA	C	Common: 5-15%
MINA	M	Many: 15-40%
MINA	A	Abundant: 40-80%
MINA	D	Dominant:> 80%
MINA		Not described
MINS	V	Very fine: <2 mm
MINS	F	Fine: 2-6 mm
MINS	M	Medium: 6-20 mm
MINS	C	Coarse: > 20 mm
MINS		Not described
PSCL	C	Clay
PSCL	CL	Clay loam
PSCL	L	Loam
PSCL	LS	Loamy sand
PSCL	S	Sand
PSCL	SC	Sandy clay
PSCL	SCL	Sandy clay loam
PSCL	SL	Sandy loam
PSCL	SiC	Silty clay
PSCL	SiL	Silty loam
PSCL		Not described

LANDUSE TABLE

FIELDNAME	CODE	DESCRIPTION
LNDU	SR	Residential use, cities
LNDU	SC	Recreation
LNDU	A	Land used for cultivation of crops
LNDU	AA	Annual field cropping
LNDU	AA1	Shifting cultivation
LNDU	AA2	Fallow system cultivation
LNDU	AA3	Ley system cultivation
LNDU	AA4	Rainfed arable cultivation
LNDU	AA5	Wet rice cultivation
LNDU	AA6	Irrigated cultivation
LNDU	AP1	Non-irrigated perennial field cropping
LNDU	HE	Extensive grazing

LNDU	HE1	Nomadism
LNDU	HE3	Ranching
LNDU	HI	Intensive grazing
LNDU	HI1	Animal production
LNDU	FN	Exploitation of natural forest and woodland
LNDU	M	Mixed farming
LNDU	MF	Agro-forestry
LNDU	MP	Agro-pastoralism
LNDU	PD1	Degradation control - non-interference
LNDU	U	Not used and not managed
LNDU		Not described

VEGETAT TABLE

FIELDNAME	CODE	DESCRIPTION
VEGE	N	No vegetation
VEGE	G	Grassland: Grasses, subordinate forbs, no woody species
VEGE	W	Woodland: Continuous tree layer, crowns usually not touching
VEGE	S	Shrubland: Continuous layer of shrub, crowns touching
VEGE	SA	Savanna: Grasses with discontinuous layer of trees or shrubs
VEGE		Not described

C. DATA ENTRY FORMS

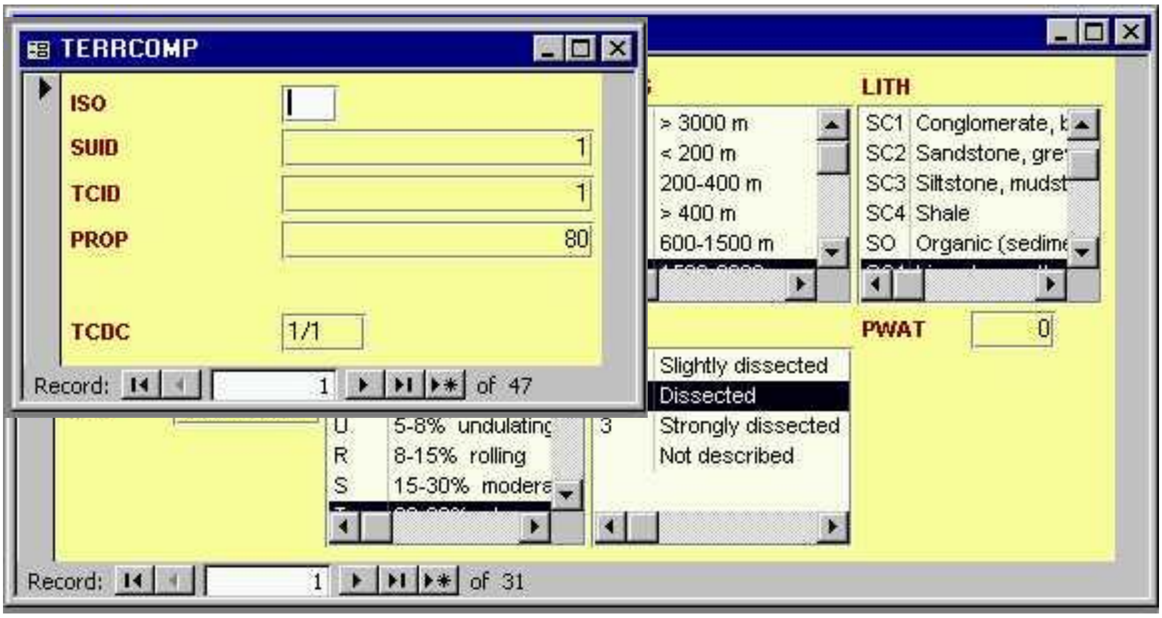
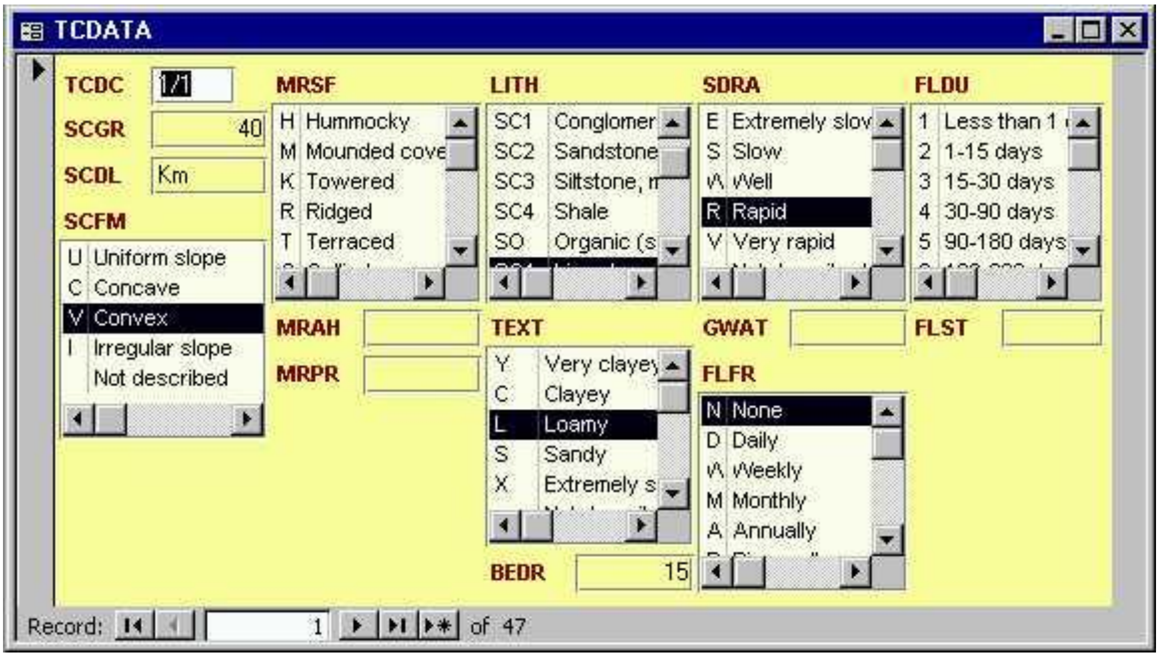


Figure 10. TERRAIN data entry form

Figure 11. TERRAIN COMPONENT entry form

Figure 12. TERRAIN COMPONENT DATA entry form



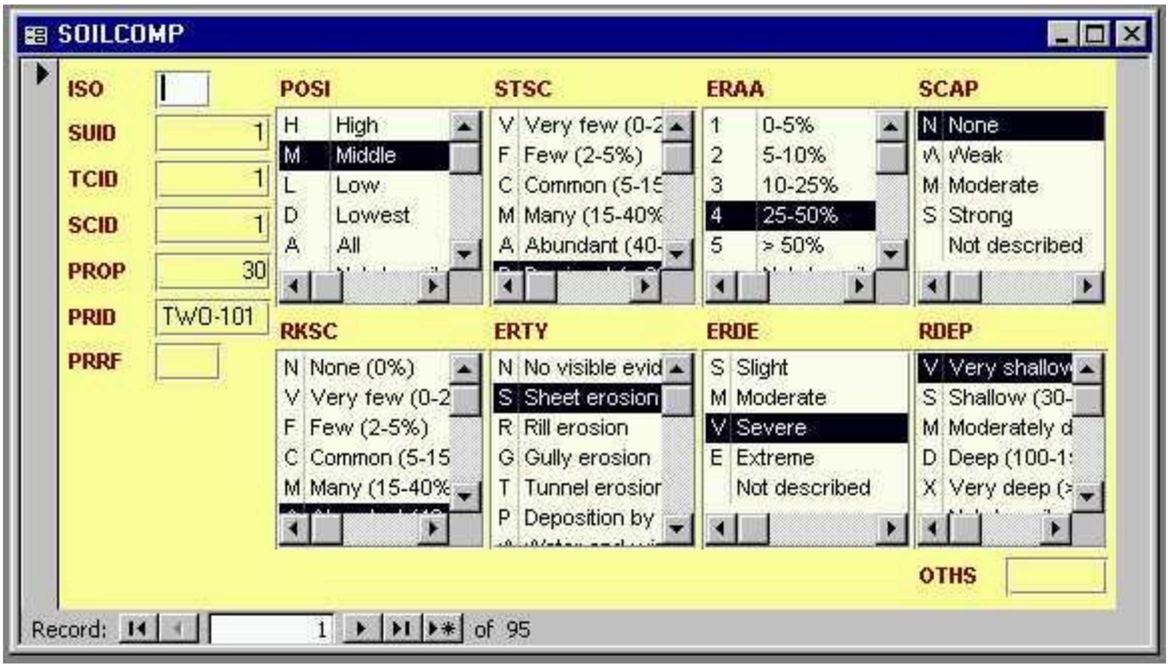


Figure 13. SOIL COMPONENT entry form

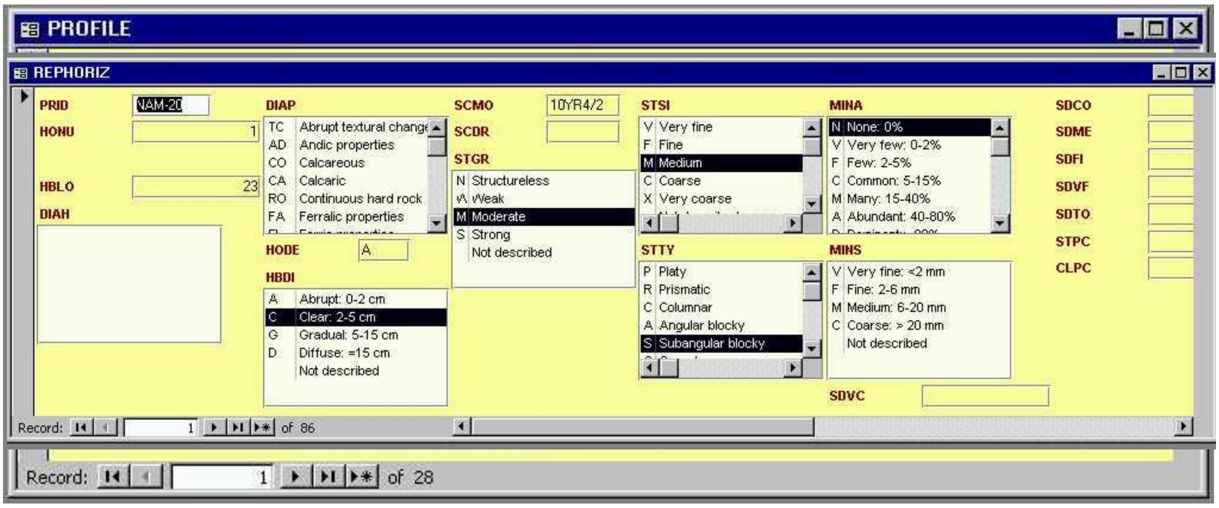


Figure 14. PROFILE entry form
Figure 15. REPHORIZON entry form

D. ANALYTICAL METHODS

D-1 Sample Reception and Documentation (SOP Soil-100)

A series of forms are available to cover the whole sequence of events from a client bringing a sample into the laboratory to the allocation of the designated sample number onto laboratory work sheets. The original forms can be accessed via the computer network.

D-2 Sample Preparation (SOP Soil-101)

Soils received in the laboratory are registered and then mixed and placed into pans to dry at room temperature or using mild heat. Dry samples are ground with a pestle in a mortar by hand or using a machine to break up the larger clods, sieved to a uniform size (2 mm) and stored in a plastic container. Stones and gravel are removed by sieving and weighed separately where they constitute a significant proportion of the sample.

D-3 SDTO, STPC, CLPC, PSCL: Particle Size Analysis by the Rowell Autopipette Method (SOP Soil-120)

The sample is dispersed by shaking with a sodium carbonate/sodium hexametaphosphate solution. Silt and clay sized particles are separated by sampling with an autopipette at a depth of 6 cm after time intervals (related to ambient temperature) determined using Stoke's Law of Sedimentation. These are dried and weighed. Sand is separated by wet sieving through a 53 micron sieve. The sand can be further separated into fine, medium and coarse fractions by dry sieving. The amount of very fine sand may be important since it has very high moisture holding and release properties. Unit: % sand, % silt, % clay.

The USDA Texture Triangle is used to determine the texture class (PSCL).

The method is suitable to determine the proportion of sand, silt and clay in most mineral soils but treatments may be needed for soils with organic carbon contents >2% and soils containing high concentrations of soluble salts and cementing agents such as calcium carbonate and gypsum. The method is not suitable for volcanic ash soils.

REFERENCE METHOD

Rowell, M.J. 2000. Changing A Laboratory Method: An Example Concerning Particle Size Analysis. Agricola 11: 61-65. Ministry of Agriculture, Water & Rural Development, Windhoek, Namibia.

Adapted from Miller, W. P. and Miller, D. M. 1987. A micro-pipette method for soil mechanical analysis. Commun. Soil Sci. Plant Anal. 18: 1-15.

OTHER REFERENCES

Day, P.R. 1965. Particle fractionation and particle-size analysis. Pages 545-567 in Methods of Soil Analysis, C.A. Black, Ed. Agronomy No. 9, Part I, American Society of Agronomy, Madison, WI.

D-4 BULK: Bulk Density (no SOP)

The sample is collected with an Eijkelkamp Undisturbed Core Sampler in a cylinder of known volume and sealed. The sample is dried at 105°C to a constant mass, cooled in a desiccator and weighed to 0.001 g precision. The bulk density is calculated as volume per mass. Unit: $g/cm^3 = kg/dm^3$.

REFERENCE METHOD

Yerima, B.P.K. 1997. Bulk Density Determination. Pages 92-94, in Procedures for Soil Analysis, MAWRD/FAO, Windhoek.

D-5 PHAQ & PHKC: pH of Soil in Water (pHw) & 1 M Potassium Chloride (pKC) & pH of the Saturation Extract (SOP Soil-109)

The pH of the soil is potentiometrically measured in the supernatant suspension of a 1:2.5 soil: liquid suspension on a mass to volume basis. The liquid is either water (pHw) or 1 M KCl solution (pHk). It van also be measured in the saturated paste extract.

REFERENCE METHOD

Adapted from: Hendershot, W.H., Lalande, H. and Duquette, M. (1993). Soil reaction and exchangeable acidity. Pages 141-145 in Soil Sampling and Methods of Analysis, M.R. Carter (editor). Canadian Society of Soil Science and Lewis Publishers.

OTHER REFERENCES

Peech, M. 1965. Hydrogen-Ion Activity, pages 914-926 in C.A. Black (ed.) Methods of Soil Analysis, Agronomy No. 9, American Society of Agronomy, Madison, WI.

D-6 ELCO & EL25: Electrical Conductivity in a Saturated Paste or 2 : 5 Water : Soil Extract (SOP Soil-112)

EC is measured with a conductivity meter with two electrodes placed in the supernatant of a soil : water suspension at a set distance from each other. The EC of an aqueous salt solution increases with increase in temperature (about 2 % per degree °C) hence EC is referenced to a standard temperature (e.g. 20 or 25°C). Unit: dS/m.

The content of soluble salts in a soil can be estimated by measuring the EC in a saturated paste, or an extract from a saturated paste or in extracts prepared at varying ratios of soil to water. To prepare a saturated paste extract, water is added to a soil sample until a given mechanical property of the soil is attained equivalent to the liquid limit. The amount of water held at saturation is called the saturation percentage.

The 2:5 method was used generally on all samples, while the saturated extract method was used for saline and/or sodic soils.

REFERENCE METHOD

Adapted from: Bower, C.A. and Wilcox, L.V. 1965. Soluble Salts, pages 933 to 951 in Methods of Soil Analysis, C.A. Black (ed.), Agronomy No. 9, American Society of Agronomy, Madison, WI.

OTHER REFERENCES

Van Reeuwijk, L.P. 1992. Procedures for Soil Analysis. 3rd Edition, pages 3-1 and 13-1. International Soil Reference and Information Centre, Wageningen, The Netherlands.

Richards, L.A. (Editor). (1954). Diagnosis and Improvement of Saline and Alkaline Soils. U.S. Dep. Agric. Handbook. No. 60.

D-7 SOCA, SOMG, SOLK, SONA, SOCL, SHCO3, SCO3: Salinity Analysis (SOP Soil-110) and Cation (Soluble Ca^+, Mg^+, K^+, Na^+, Cl^-, HCO_3^-, CO_3^2) Calculations from Analysis of Salinity Extracts (SOP Soil-121)

An extract of a water saturated soil paste is prepared. The salinity of the soil is assessed by the electrical conductivity of the extract (SOP Soil-112). The recovered extract is analysed for the dominant cations and anions (SOP Soil-123 and SOP Soil-124). Unit: meq/l.

REFERENCE METHOD

Van Reeuwijk, L.P. 1992. Soluble Salts, pages 13-1 to 13-12 in: Procedures for Soil Analysis, International Soils Reference Centre, Wageningen, The Netherlands.

OTHER REFERENCES

Landon, J.R. (ed). 1984. Booker Tropical Soil Manual. Booker Tate Ltd., Thames, U.K (in USA Longman Inc., New York)

Richards, L.A. 1954. Saline and Sodic Soils. Handbook No. 60. USDA. Gov't. Printing Office Washington DC.

USDA Soil Conservation Service. 1984. Soil Survey Investigations. Report No. 1.

Van Reeuwijk, L.P. 1992. Procedures for Soil Analysis. 3rd Edition. International Soil Reference and Information Centre Wageningen (ISRIC). The Netherlands. P.O.Box 353. 6700 AJ Wageningen.

D-8 SOCL, SHCO3, SCO3: Anion Analysis in Water and Soil-Water Extracts (SOP Soil-123)

CARBONATE and **BICARBONATE** are determined by potentiometric titration of the extract or water sample with HCl or H_2SO_4 to pH 8.4 and 4.4 respectively. Unit: meq/l. A pH meter can also be used to read above indicated end-points when the titrations are performed manually, alternately, phenolphtalein and methyl-orange respectively can be used as indicators. When phenolphthalein is used the disappearance of its pink colour indicates half the neutralisation of carbonate or the conversion of $(CO3)^{2-}$ into $(HCO_3)^-$ At this stage methyl-orange is added and the titration continued. When the colour changes from yellow to rose red, it is an indication of the end point for the complete neutralisation of bicarbonate. The following equations illustrate these changes:

$2Na_2CO_3 + H_2SO_4$	=	$2NaHCO_3 + Na_2SO_4$
(phenolphthalein is pink)		(phenolphthalein is colourless)
$2NaHCO_3 + H_2SO_4$	=	$Na_2SO_4 + 2H_2O + 2CO_2$
(methyl orange is yellow)		(methyl orange is red)

CHLORIDE: The chloride ion in an acid medium combines with the mercuric ion, to form mercuric chloride which is almost completely unionised. Hence, in titrating a solution containing chloride with a solution of mercuric nitrate in the presence of a little nitric acid (the nitric acid neutralises the carbonates and bicarbonate) the mercuric ion reacts with the chloride ion until the chloride ion disappears from the solution. The end of the titration is marked by the presence of free mercuric ions which is detected by its sensitive reaction with diphenyl-carbazone to form a violet coloured complex. Acidity is maintained at the optimum of pH 3 using a pH meter. Unit: meq/l.

REFERENCE METHOD

Van Reeuwijk, L.P. 1992. Soluble Salts, pages 13-1 to 13-12 in Procedures for Soil Analysis, International Soils Reference Centre, Wageningen, The Netherlands.

D-9 EXCA, EXMG, EXNA, EXCK, CECS: Cation Exchange Capacity and Exchangeable Bases (SOP Soil-116)

A soil sample is pre-washed with deionised water to remove soluble salts. Thereafter it is leached with ammonium acetate to replace exchangeable bases with ammonium ions. Exchangeable calcium, magnesium, sodium and potassium are measured in this effluent (SOP Soil-124). The sample is then leached with sodium acetate to saturate the cation exchange complex with sodium ions. The excess sodium is removed by leaching with ethanol and the cation exchange capacity determined by measuring the sodium subsequently de-sorbed by a further leaching with ammonium acetate. The method uses an automatic extractor where the soils are mounted in plastic syringes for the leaching operations. Unit: cmol(+)/kg

The method may be used to estimate the CEC of most soils. The choice of saturating cation or pH of the equilibrating solution may be varied for soils containing certain clays or minerals. It may be difficult to differentiate between exchangeable and soluble cations in soils containing carbonates, gypsum or soluble salts.

MODIFICATION FOR CARBONATE/NON-SALINE SOILS

If the pH of the 2:5 H_2O water extract is > 7 with carbonates present but EC 2.5 < 0.4 mS/cm then no pre-washing is needed, but use a 50:50 mixture of NH_4OAc pH 7 and ethanol to displace the bases instead of using NH_4OAc pH 7 alone, to obviate carbonate dissolution.

MODIFICATION FOR CARBONATE/SALINE SOILS

If the pH of the 2:5 H_2O water extract is > 7 with carbonates present but EC 2.5 > 0.4 mS/cm then do a pre-washing as above followed by a 50:50 mixture of NH_4OAc pH 7 and ethanol to displace the bases instead of using NH_4OAc pH 7 alone, to obviate carbonate dissolution.

REFERENCE METHOD

Van Reeuwijk, L.P. (edit.) 1992. Procedures for Soil Analysis pages 9-1 to 9-11, International Soil Reference and Information Centre, Wageningen, The Netherlands.

OTHER REFERENCES

Rhoades, J.D. 1982. Cation exchange capacity. Pages 149-157 in A.L. Page et al., Eds. Methods of soil analysis, Agronomy No. 9. 2nd ed. American Society of Agronomy, Madison, WI.

Thomas, G.W. 1982. Exchangeable cations. Pages 159-165 in A.L. Page et al., Eds. Methods of soil analysis, Agronomy No. 9. 2nd ed. American Society of Agronomy, Madison, WI.

D-10 SOCA, SOMG, SOLK, SONA, EXCA, EXMG, EXNA, EXCK, CECS: Analysis using Atomic Absorption (SOP Soil-124)

Solutions are aspirated as a fine mist into an air-acetylene flame, and nitrous oxide-acetylene in the case of calcium measurement. The atoms of different elements produce absorb light at different wavelengths characteristics of their type. The extent of absorption can be amplified and measured using hollow cathode lamps emitting light at these characteristics wavelengths. Unit: meq/l.

The method described here may be used to measure soluble bases and metals in water samples or extracts and digests of plant leaf tissue and soil. This SOP concentrates on such elements in plant and soil. The standard calibrating solutions should contain the same background matrix as the samples. Lanthanum chloride is added as a suppressant in the measurement of calcium, magnesium, sodium and potassium.

ELEMENT	WAVELENGTH (nm)
Calcium	422.7
Magnesium	285.2
Sodium	589.0
Potassium	766.5

REFERENCE METHOD

Van Reeuwijk, L.P. (edit.) 1992. Procedures for Soil Analysis pages 9-1 to 9-11, International Soil Reference and Information Centre, Wageningen, The Netherlands.

D-11 SSO4: Sulphate-S by Turbidometry (SOP Soil-117)

Soil is shaken with 0.01M calcium chloride at a 1:2 extraction ratio for 30 minutes and the sulphate-S content in the filtered extract determined by estimating the turbidity produced by the precipitation of barium sulphate under acidic conditions. The absorbance is read at 620 nm within 10 minutes. Unit: meq/l.

REFERENCE METHOD

Adapted from: Bardsley, C.E. and Lancaster, J.D. 1960. Determination of reserve sulfur and soluble sulfates in soils. Soil Sci. Soc. Am. Proc., 24: 265-268.

D-12 TCEQ: Calcium Carbonate Equivalent (SOP Soil-102)

The sample is treated with an excess standard hydrochloric acid to decompose carbonates. The excess acid is back titrated with standard sodium hydroxide after clarification of the solution by filtration. Unit: g/kg.

The results are referred to as *calcium carbonate equivalent* since the dissolution is not only selective for calcite, but also other carbonates such as dolomite and sodium carbonate that also react with acid. The method may overestimate the calcium carbonate content since acid may also react with other primary minerals, organic matter or clays that are involved in buffering the soil against acidity.

The analysis is carried out on soils with a pH-H_2O < 6.7 as carbonate is assumed to be absent below this pH reading.

REFERENCE METHOD

International Soil Reference and Information Centre. 1992. Pages 7-1 and 7-2 in Procedures for Soil Analysis, Van Reeuwijk, L.P. Ed., ISRIC, Wageningen, The Netherlands.

OTHER REFERENCES

Allison, L.E. and Moodie, C.D. 1965. Carbonate, pages 1379-1396 in C.A. Black Ed., Methods of Soil Analysis, Agronomy No. 9, American Society of Agronomy, Madison, WI.

D-13 TOTC: Organic Carbon (Colourimetric Walkey-Black Method) (SOP Soil-125)

Measurement of organic carbon content gives a way of estimating the organic matter content of the soil. The amount and type of organic matter can be directly related to moisture holding capacity, the reserves of exchangeable cations, storage and supply of plant nutrients such as nitrogen and phosphorus, and the maintenance of stable soil structure and aeration.

Organic matter is oxidised with an excess of a concentrated oxidising mixture containing sulphuric acid and potassium dichromate. The amount of unused $K_2Cr_2O_7$ is determined colourimetrically at 600 nm. Results are calibrated against glucose. Unit: g/kg C.

A factor is included in calculations to take account of incomplete oxidation. Organic matter content is calculated as organic-C x 1.74.

The method is suited to the measurement of the organic carbon content of soils low in organic matter content. The method can also be used to measure the organic carbon content of humus extracts, soil water or polluted waters.

REFERENCE METHOD

Rowell, M.J. 2000. Measurement of Soil Organic Matter: A Compromise Between Efficacy and Environmental Friendliness. Agricola 11:66-69, Ministry of Agriculture, Water & Rural Development, Windhoek, Namibia.

Adapted from: Sims, J.R. and Haby, V.A. 1971. Colourimetric determination of soil organic matter. Soil Science 112: 137-141.

OTHER REFERENCES

Nelson, D.W and Sommers, L.E. 1982. Total Carbon. Organic Carbon and Organic Matter, pages 539-579 in A.L. Page et. al. Methods of Soil Analysis Part 2, 2nd ed., Agronomy No. 9, American Society of Agronomy, Madison, WI.

Soil Science Society of South Africa. 1990. Handbook of Standard Soil Testing Methods for Advisory Purposes, pages 34-1 to 34-2.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37:29-38.

DeBolt, D.C. 1974. A high sample volume procedure for the colorimetric determination of soil organic matter. Commun. Soil Sci. Plant Anal. 5:131-137.

D-14 GYPS: Gypsum in Soil (SOP Soil-118)

Gypsum is dissolved by shaking the sample with water. It is selectively precipitated from the extract by adding acetone. This precipitate is redissolved in water and the gypsum is determined by measuring the electrical conductivity and relating that to standard solutions of gypsum in water, and by measuring the calcium content by atomic absorption spectroscopy. Unit: g/kg

REFERENCE METHOD

Yerima, B.P.K. 1997. Gypsum Determination. Pages 38-40, in Procedures for Soil Analysis, MAWRD/FAO, Windhoek.

OTHER REFERENCES

Richards, L.A. (Ed.) 1954. Diagnosis and improvement of saline and alkali soils. US Salinity Lab., US Department of Agriculture Handbook 60.

Sayegh, A.H., Khan, N.A., Khan, P. and Ryan, J. 1978. Factors affecting gypsum and cation exchange capacity determinations in gysiferous soils. Soil Sci., 125: 294-300.

FAO 1990. Management of gypsiferous soils. FAO Soil Bulletin No. 62, Food and Agriculture Organisation of the United Nations, Rome.

D-15 P2O5: Available Phosphorus in Soil (Olsen Method) (SOP Soil-104)

The sample is extracted with a 0.5 M sodium bicarbonate solution at pH 8.5. Phosphate in the extract is determined colorimetrically at 882 nm, by the blue ammonium molybdate method of Murphy and Riley, using ascorbic acid as reducing agent. Unit: mg/kg P_2O_5 (where P_2O_5 = 2.291 x P).

The Olsen Method is recommended for alkaline to neutral soils.

REFERENCE METHODS

Shoenau, J.J. and Karamanos, R.E. 1993. Sodium Bicarbonate-Extractable P, K and N, pages 51-58 in Soil Sampling and Methods of Analysis, M.E. Carter Ed., Canadian Society of Soil Science, Lewis Publishers.

Soil Science Society of South Africa. 1990. Pages 24-1 to 24-3 in Handbook of Standard Soil Testing Methods for Advisory Purposes, SSSSA, Pretoria, RSA.

OTHER REFERENCES

Murphy, J. and Riley, J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta, 27: 31-36.

Olsen, S. R., and L. A. Dean. 1965. Phosphorus pages 1044 - 1046, in C. A. Black (ed.). Methods of Soil Analysis, Agronomy No. 9. American Society of Agronomy, Madison, WI.

D-16 TOTN: Total Nitrogen by Kjeldahl Oxidation (SOP Soil-111)

In the Kjeldahl procedure organic matter is oxidised by treating soil with concentrated sulphuric acid. Potassium or sodium sulphate is added to raise the temperature and selenium powder and copper sulphate are added as catalysts. The procedure determines total soil nitrogen (including adsorbed NH_4^+) except nitrates. The organic nitrogenous compounds are converted into ammonium sulphate during oxidation. Ammonia is liberated from the digest by steam distillation at high pH following the addition of excess sodium hydroxide. The distilled ammonia is absorbed in a boric acid solution, thereby increasing its pH. The amount of ammonia trapped is measured by back titration with standard sulphuric acid to the original pH of the boric acid. Unit: g/kg N.

The method described here is for use with a Büchi commercial digestion and distillation system. The particular oxidants and catalysts used here are specifically designed for the oxidation of all forms of nitrogen found in soil humus.

REFERENCE METHOD

Adapted from: McGill, W.B. and Figueirdo, C.T. (1993). Total NItrogen. Pages 201-211 in Soil Sampling and Methods of Analysis, M.R. Carter (editor). Canadian Society of Soil Science and Lewis Publishers.

OTHER REFERENCES

Yerima, B.P.K. 1997. Determination of Nitrogen – Total Nitrogen (Kjeldahl Method). Pages 32-35, in Procedures for Soil Analysis, MAWRD/FAO, Windhoek.

E. ACRONYMS

AEZ	Agro-ecological Zoning
FAO	Food and Agriculture Organisation of the United Nations
ISRIC	International Soil Reference and Information Centre
SOTER	World Soils and Terrain Digital Database
NAMSOTER	Namibian SOTER Database and GIS
GIS	Geographical Information System
ICC	Institut Cartogràfic de Catalunya (Cartographic Institute of Catalonia)
MAWRD	Namibian Ministry of Agriculture, Water and Rural Development
NARIS	Namibian Agricultural Resources Information System
NSS	National Soil Survey (of Namibia)
TM	Thematic Mapper, a specific type of radiometric sensor on Landsat satellites
SARDEP	Sustainable Animal and Range Development Programme
AECI	Cooperacion Española (Spanish Cooperation Office)
RDMS	Relational database management system
SOP	Standard Operating Procedure from the MAWRD Agricultural Laboratory's Quality Manual
WRB	World Reference Base