Uganda Journal of Agricultural Sciences, 2004, 9: 215 - 221
ISSN 1026-0919

Soil resource information and linkages to agricultural production

M. Isabirye, D. Mwesige, H. Ssali, M. Magunda, J. Lwasa
Kawanda Agricultural Research Institute, P.O. Box 7065 Kampala, Uganda.

Abstract

The Plan for Modernisation of Agriculture (PMA) recognizes the high contribution of the environment and natural resources (ENR) to Uganda's gross domestic production and that sustainable use of the ENR provides the only cost effective and viable option for the rural poor. Soil productivity is a major factor in sustainable use of ENR. However, information on natural resources and soils in particular, have had limited use in agriculture and resource conservation activities. The existing soils information is not available in digital forms that can be manipulated to suit requirements of different stakeholders and this is one of the major causes of limited use of available natural resource information. The paper describes steps that have been taken to revise and update soils information; establish a soils geographic data base (SGDB) and its application in explaining the spatial distribution of coffee wilt disease in some parts of Uganda. Existing soils information has been updated and correlated to 13 World Reference Base (WRB) soil orders with 37 % classified as *Gleysols*, 25 % as *Luvisols*, 23 % as *Ferralsols*, 12 % as *Plinthosols*, among others. The information is stored in a SGDB which has been successfully tested in a case where soils were linked to the spatial distribution of the coffee wilt disease. Coffee wilt was linked mostly to *Lixic Ferralsols* (38%) and *Acric Ferralsols* (48 %). Preliminary results indicate that some boundaries on the existing soil map are not a true reflection of the ground truth.

Key words: PMA, sustainability, environment and natural resources, SGDB, GIS

Introduction

Better natural resource management and utilisation and protection of the environment are a major contributor to economic growth. Increasing the awareness of the poor towards the importance of the natural resource base in enhancing rural livelihood is a response to the third pillar of the PMA namely; the increased ability of the poor to raise their incomes. This entails provision of information on the nature, extent, accessibility, and suitability of natural resources for various activities.

Land resources and soils in particular, are basic to agricultural production and resource conservation. Soil information is relevant for the transfer of soil technologies that will allow informed management and conservation of soil resources under different uses. Most of the soil information is obtained through surveys at various scales. Reconnaissance surveys are done to locate and give initial assessments of areas suitable for more intensive studies; and to locate and investigate areas which are unlikely to justify the costs of more detailed studies such as those suitable only for non-intensive agriculture, or rough grazing. In Uganda, the surveys were initiated as a result of recommendations of the then Agricultural Productivity Committee. The main purpose of the survey was to classify and map soils of the country with an objective of assessing their productivity.

In 1959 a reconnaissance soil survey was done for Uganda wherein soils were identified using species type of legend that is named using places where representative profiles were observed (Chenery, 1960; Ollier and Harrop, 1960; Ollier, 1960, Radwanski, 1960; Wilson, 1960; Harrop, 1960). With this legend, a total of 138 mapping units were identified, very many of them, having developed under similar conditions with identical properties but were in different places. Since there was no universal classification system at the time, Chenery (1960) reviewed 12 systems of soil classification and found D' Hoore and Sys's systems to be most appropriate for Ugandan soils. Based on this criterion, the soils of Uganda where classified at a scale of 1:1,500,000. Consequently most (about 70%) of the soils were classified as *Ferralsols*. Soil information was stored in form of reports with respective maps attached to each. Such information is not easy to update or manipulate to meet client requirements and for strategic planning.

The availability of computers and software has now made it possible to store the soils information in a Geographic Information System (GIS) based SGDB. The system allows organisation, storage, retrieval, manipulation, ease of updating and analysis of soils information (Rossiter, 1999). Manipulation of data within a SGDB allows relational spatial analysis of soils with various themes of interest including analysis of the suitability of soils for various uses.

However, before storage, it is important to design an appropriate SGDB, revise and categorize soil information using a recent international system. The international systems allow extrapolations/sharing of findings elsewhere and minimize duplication of effort. With the advancement of studies in soil genesis and mineralogy and new surveys, new knowledge has developed and consequently classification systems have been developed over time to allow correlations at international levels. The World Reference Base for Soil Resources (FAO/ISRIC/ISSS, 1998) is the latest system currently being promoted and used internationally.

This paper describes the establishment of a SGDB, with specific objectives of transforming existing soils attribute and spatial data into digital formats and to revise and correlate soils information with the WRB and; to test the effectiveness of the SGDB in an application linking soil information to coffee wilt distribution in some parts of Uganda.

Methodology

The soil geographical database (SGDB)

The SGDB entity – relation diagram after (Rossiter, 1990) was used to develop the SGDB at The National Soils Information and Reference Centre, KARI (Figure 1) as illustrated below. It consists of the following:

1. Soil Map Units [SMU-identifiers (ID), map unit, local classification, locality, dominant soil type, parent rock, remarks]
2. Polypedon names [Polypedon-ID, SMU-ID, Poly pedon names]
3. Profile [Profile-ID, SMU-ID, latitude, longitude, drainage, surface OM, soil taxonomy, phase
4. Horizons [Horizon-ID, profile-ID, diagnostic horizon, type of structure, coarse fragments, etc]
5. Analytical data [Table-ID, Horizon-ID, Depth, silt, clay, bases, cec, base saturation, organic carbon, pH, nitrogen and phosphorus]

Digital transformation of available soil reports and soil maps

Map digitization

This activity involved electronic drawing of the 16 sheets of soil maps covering Uganda at a scale of 1:250,000. ARCVIEW and ILWIS GIS software were used together with a digitising/drawing table. Standard map specifications recommended by the Department of Lands and Surveys were used. The maps a stored in a latitude-longitude coordinate system with a legend that provides information on the classifications used, the topography, soil type, parent material and drainage condition.

The Soil Geographic database

The Spatial Information that is produced per sheet, has got attribute data in the structure below;

Figure 2 shows the main tables used in storing and querying soil information in the SGDB. The tables are linked as shown by the arrows shown. These and other tables not indicated here can be exported in DBS format to a GIS where the tables can be linked to the soil maps. This then allows various manipulations and calculations to be done using spatial (maps) and attribute (tables) information as shown for a case of coffee wilt below. As need arises, more tables can be created and added to the structure.

Updating of existing soil information (maps)

Soil correlation

This activity involves the correlation of local soil classification units to the World Reference Base for Soil Resources (WRB). The correlation was based on the existing soil physical and chemical data. In addition to soil profile description, the existing data has laboratory chemical analyses on bases (Ca, Mg, K, Na, Mn), exchangeable H, cation exchange capacity, base saturation, pH, organic carbon, percent nitrogen and available P, and mechanical analysis for texture (silt and clay). Laboratory analytical methods used include: Bouyoucos hydrometer method (percent silt and clay), nitrogen; the exchangeable cations were determined by neutral normal ammonium acetate leachates; exchangeable hydrogen was determined in buffered p-nitrophenol extracts; pH was measured in pastes (1:1 soil/ water) by the glass electrode method; Walkley and Black method was used to determine percent organic carbon; Truog method was used to determine available P using a buffered N/500 sulphuric acid as extractant. Pedotransfer functions were used where a particular element data did not exist.

Soil boundary check in the field

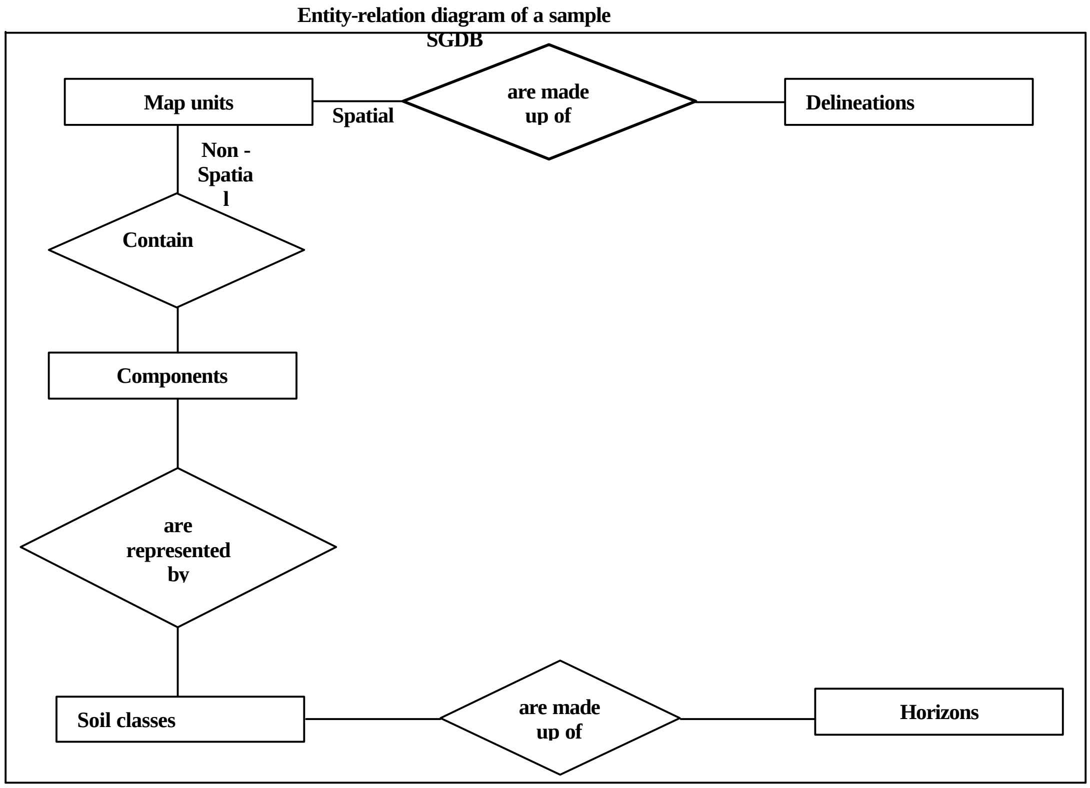
Soil boundaries were checked in the field with the help of existing soil and topographic maps (1:250,000), and a global positioning system (GPS).

Where changes to soil boundaries were found necessary, the GPS was used to obtain the coordinates that were later used to draw boundaries using GIS software. Coordinates of new soil boundaries or units were easily incorporated into the new map using the GIS software. This has enabled a quick and relatively accurate location of soil boundaries without going thru the often long analogue cartographic procedures. Updated maps presented here were produced using this method.

Normally after 30 years soil chemical and physical properties are expected to have significantly changed and this would justify the need to redo the survey for updating purposes. It was beyond the scope of this investigation to do fresh profile descriptions and chemical laboratory analyses.

Linking of the Spatial Data to the Relational database

Geographic Information Systems are capable of integrating geographical data with other data from various sources to provide the information necessary for effective decision-making in planning sustainable development. Typically a GIS serves both as a toolbox and a database. As a toolbox, a GIS allows planners to perform spatial analysis using its geo-processing or cartographic modelling functions such



Source: **Rossiter 1999.**

Figure 1. The Entity-relation diagram of a sample SGDB

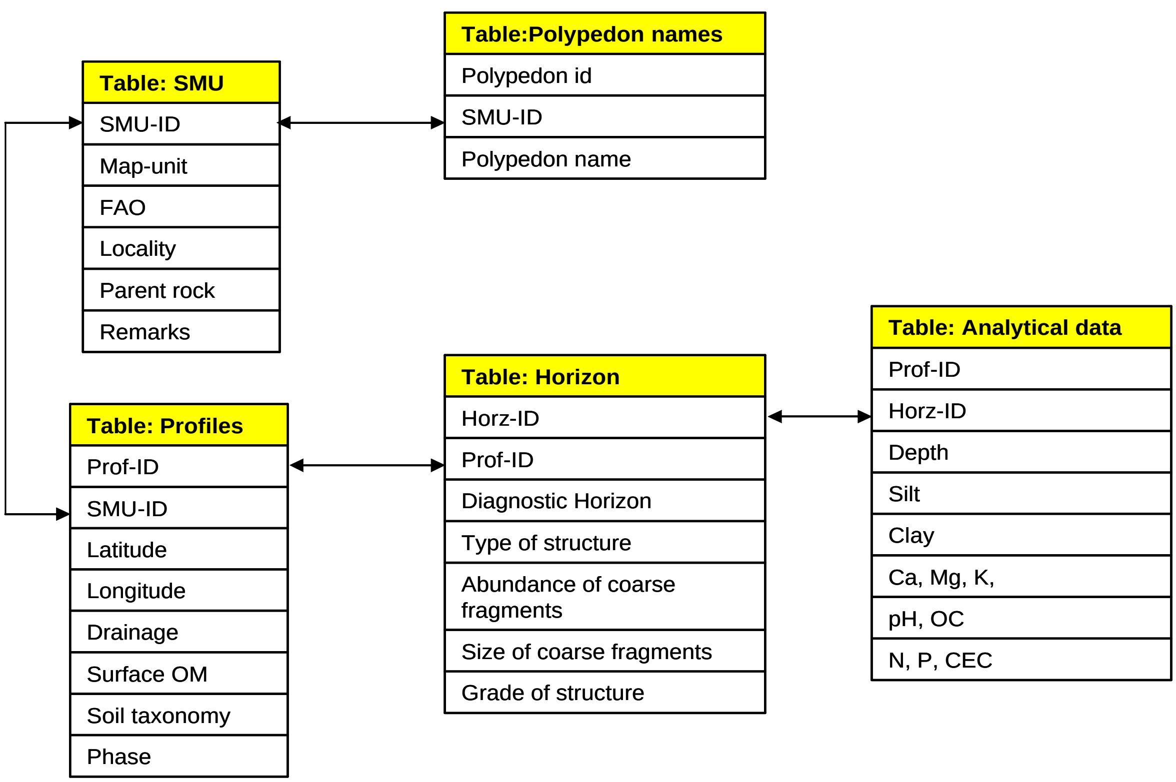


Figure 2. Structure of the SGDB at KARI

as data retrieval, topological map overlay and network analysis. A case in point is where the soils map information was overlaid with the map showing areas(points) with coffee wilt disease.

The soil map units in the spatial database are linked to attributes in the relational data base which gives the proportionate extent of the soils and their properties when queried. Using such linkages, coffee wilt disease incidences were linked to georeferenced soils data to evaluate relationships between the disease and soil properties.

Results and discussions

The SGDB. A fully functional SGDB has been established based on the structure in figure 2 at Kawanda Agricultural Research Institute. The SGDB has enabled easy and fast extraction and analysis of information for various users who include farmers, policy makers, students and researchers. It has also been easy update information based on new findings in the field

Soil map and soil correlations at national and regional scale

The 138 local soil categories correlated to 13 WRB soil categories at a higher level of classification. 37 % classified as *Gleysols*, 25 % as *Luvisols*, 23 % as *Ferralsols*, 12 % as *Plinthosols*, 9 % as *Leptosols*, 7 % as *Arenosols*, 6 % as *Regosols*, 1 % as *Planosols*, *Nitisols*, *Andosols*, *Histosols*, and < 1% as *Calcisols*, and *Vertisols*.

Local categories grouped under the same order of the WRB classification have similar genetic origins but may differ in productivity based on the available qualifier – a basis for sub division at a lower level. For example *Acric Ferralsols* are highly weathered acidic soils with very low base saturation. On the other hand *Lixic Ferralsols* are highly weathered acid soils with a base saturation greater than 50 percent. Therefore *Lixic Ferralsols* are relatively more productive compared to *Acric Ferralsols*.

Adequacy of existing soil information and soil correlation

The taxonomic units of the WRB are defined in terms of measurable and observable 'diagnostic horizons', the basic identifiers in soil classification. Diagnostic horizons are defined by (combinations of) characteristic 'soil materials' and/or 'soil materials'. (FAO/ISRIC/ISSS, 1998)

The data used for correlation purposes here is about 40 years old. There has been considerable development in soil survey methods and soil analytical techniques which have resulted in various soil classification systems with WRB as the most recent system. A few parameters that were missing could not allow correlations for *Alisols* – very acid soil material with a high level of exchangeable aluminium. Inferences on field data could not be used to for correlations to *Alisols*. On the other hand a few detailed soil profile chemical analysis indicate very low to nil Al concentrations with Al3+ saturation of less than 50 percent (MLRU, 1989; Government of Uganda, 1985). This rules out the likelihood of the existence of *Alisols* in Uganda. Hydrous aluminosilicates with Al/Si molar ratios between 1 and 2 identify *allophanes* that are used in categorising *Andosols*. Correlations to *Andosols* in this paper were based mainly on field profile description data.

Soil bulk densities are missing in all profiles yet they are relevant in assessing soil compaction and soil moisture relationships. Soil bulk densities are relevant in the estimation of total carbon stored in the soils; this information is important in determining the changes in the status of carbon sequestered in relation to changes in land use systems. The nature of soil horizon boundaries and indication of signs of clay illuviation (presence of clay skins) through the profile are not described, yet important inferences on the category of the soil can be from this information. Old highly weathered soils like *Ferralsols* are associated with diffuse boundaries that cannot easily be detected. Clay illuviation is characteristic of *Luvisols*, *Acrisols*, and *Lixisols*.

Soil boundary check

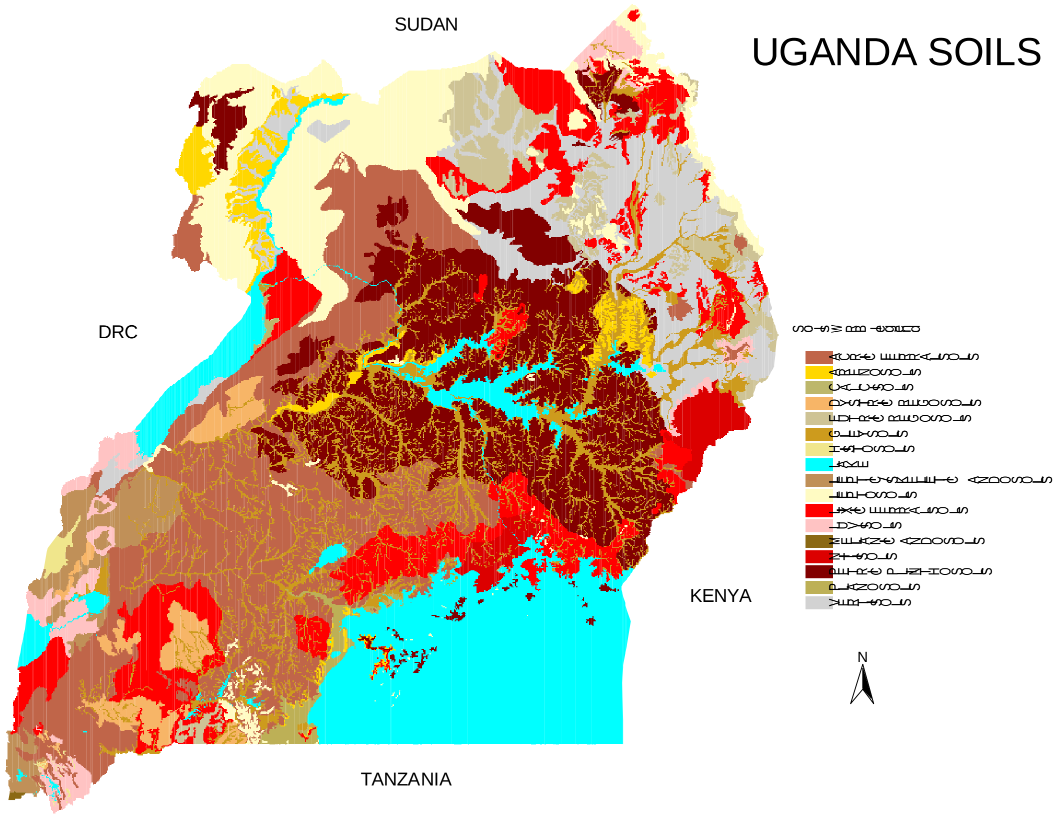
Table 1 and Figure 4 show changes that have occurred after field boundary checks for Jinja sheet that covers the districts of Jinja, Iganga, Bugiri, Tororo, Busia, and parts of Kayunga, Mukono, Kamuli, Palisa and Mbale districts. The changes are significant and may have important implications in relation to land use planning and transfer of soil technologies. The map shows that about 573 km2 of soils were categorised under Buruli catena (*Acric Ferralsols*) when on the ground the soils belong to Buyaga (*Lixic Ferralsols*). Field checks resulted in a spatial increase of soils under *Buyaga* and a decrease in soils under *Buruli* map unit.

Another case is a situation where a soil unit completely disappears or a new one appears as a result of field checks. Figure 3 shows a soil unit in Busia district formerly categorised as Nakabango (*Nitisols*) catena when actually the soil fits well under Buyaga catena (*Lixic Ferralsols*). New mappable units at the reconnaissance scale are the shallow soils associated with hills and ridges found in Jinja district. Locally they are categorized as Metu complex and *Leptosols* according to the WRB.

Linkage of the soil information: a case for coffee wilt disease

Coffee wilt is a soil disease which enters a low surface wound or a shallow root. The disease spreads up through the stem into the vascular strands. Symptoms are yellowing and collapse of the leaf. This disease affects plants in dry warm soils of Africa's equatorial areas. It attacks robusta coffee.

The map in figure 5 shows that the coffee wilt disease is mostly associated with *Lixic Ferralsols(38%)* and *Acric Ferralsols (48 %)* . These soils are highly weathered with


UGANDA SOILS
SUDAN
DRC
KENYA
TANZANIA
N

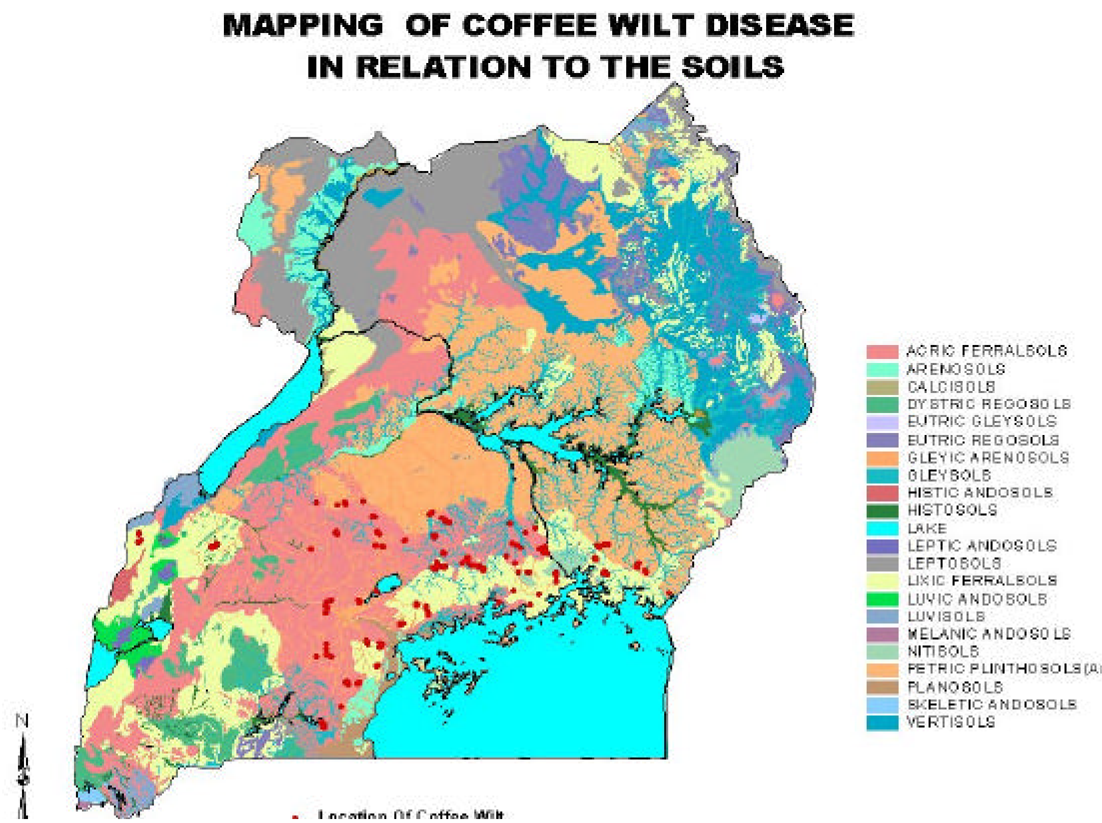

MAPPING OF COFFEE WILT DISEASE
IN RELATION TO THE SOILS
ACRIC FERRALSOLS
ARENOSOLS
CALCISOLS
DYSTRIC REGOSOLS
EUTRIC GLEYSOLS
EUTRIC REGOSOLS
GLEYIC ARENOSOLS
GLEYSOLS
HISTIC ANDOSOLS
HISTOSOLS
LAKE
LEPTIC ANDOSOLS
LEPTOSOLS
LIXIC FERRALSOLS
LUVIC ANDOSOLS
LUVISOLS
MELANIC ANDOSOLS
NITISOLS
PETRIC PLINTHOSOLS(A
PLANOSOLS
SKELETIC ANDOSOLS
VERTISOLS
N
Location Of Coffee Wilt

Table2. Changes in soil unit size as a result of field boundary checks for Jinja Sheet

TRADITIONAL MAPPING UNIT	Sum Area (New) KM²	Sum Area (Old) KM²	Area difference KM²	
BURILI CATENA	1816	2389	-573	REDUCED
KABIRA CATENA	1165	1323	-158	
NAKABANGO CATENA	558	684	-126	
LWAMPANGA SERIES	491	609	-118	
MWIRI CATENA	13	72	-59	
KYEBE CATENA	259	275	-16	
BUGANDA CATENA	51	35	16	INCREASED
UNDIFFERENTIATED ALLUVIUM	1754	1702	51	
MABIRA/NAKABANGO CATENA	126		126	
MAZIMASA COMPLEX CATEN	1728	1493	234	
BUYAGA CATENA	1879	1097	782	
KAMUSENE SERIES	113			NEW UNITS
METU COMPLEX	80			
BOWA CATENA		13		REMOVED UN
FORT PORTAL SERIES		126		
AMURIA CATEN		41		
USUKU SERIES		7		
MULEMBO SERIES		51		
BUYAGA CATENA,KAMUSENE SERIES		113		

:age of soils information to various research and

tion themes is demonstrated through the case where

Africa Proceedings of the 18th Conference

December, 2000: Mombasa, Kenya