

SOKOINE UNIVERSITY OF AGRICULTURE

Research Achievements of SUA in Agriculture, Forestry and Animal Health

PROCEEDINGS OF THE FIRST UNIVERSITY WIDE
SCIENTIFIC CONFERENCE HELD AT INSTITUTE
OF CONTINUING EDUCATION, SUA, MOROGORO,
TANZANIA, 5TH – 7TH APRIL 2000

VOLUME 2

AGRICULTURE



Sokoine University of
Agriculture



Norwegian Agency for
Development Cooperation

Published by the Directorate of Research and Postgraduate Studies
Sokoine University of Agriculture, Morogoro, Tanzania
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FACTORS INFLUENCING SOIL DISTRIBUTION AND THEIR IMPLICATION FOR AGRICULTURAL LAND MANAGEMENT IN MOROGORO URBAN DISTRICT, TANZANIA

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ABSTRACT

A standard soil and land resources survey was conducted in Morogoro Urban District, Tanzania to investigate the factors influencing characteristics and spatial distribution of soils and their implication for land management. Landforms, parent materials, climate, soil morphological, physico-chemical and mineralogical properties were the main attributes studied. Soils were classified according to the FAO-World Reference Base for Soil Resources. Six major landforms were identified namely; strongly dissected mountain ridges, mountain foothills, hills, piedmonts, peneplains and valleys. The strongly dissected mountain ridges comprise complex soils developed on pyroxene granulites. The soils include shallow, excessively drained sandy clay loams and deep well drained sandy clays and clays. The soils were classified as Lithic-Paralithic Leptosols, Hapli-Profondic Lixisols, Orthidystri-Episkeletic Cambisols and Hypereutri-Episkeletic Cambisols (Haplic). The hills are a complex of rock outcrops and shallow soils developed on muscovite-biotite migmatites. The soils are excessively drained, extremely gravely sandy loams and sandy clay loams. The soils were classified as Lithic Leptosols. The piedmonts and peneplains comprise largely associations of deep and very deep, well drained clays and sandy clays. These soils developed on colluvium derived from granulites and migmatites were classified as Chromi-Profondic Acrisols, Chromi-Profondic Lixisols, Rhodi-Profondic Luvisols and Cutani-Profondic Luvisols (Haplic). In the valleys, the soils are developed on alluvium of diverse mineralogical composition and are a complex of Calcari- and Stagni-Mollic Fluvisols and Calcari-Salic Vertisols. All the studied soils except those of the valleys have low soil fertility as shown by low organic carbon (<1.0%), low levels of major nutrients (nitrogen <0.1%, phosphorus <5 mg/kg) and low CEC (<12.0 cmol(+)/kg soil). Although the soils of the valleys are fertile, they are characterised by one or more of the following problems: poor drainage condition, high alkalinity and salinity (ESP >5%) and difficult workability. The results of this study show a close relationship between landforms, parent materials and soil types. The paper establishes some land qualities which are important for sustainable agricultural land management in the district.

Key words: Factors, Soil distribution, Management, Morogoro Urban District

INTRODUCTION

Soil resources form an important component of natural resources. The expansion of urban Areas has placed an inevitable stress on soil resources by the need to increase production

in order to feed the growing urban population. These resources are dynamic in the sense that their properties are altered according to how they are used. Knowledge on the factors influencing soil resources development and distribution and their differing properties is of paramount importance for proper use and management and increased productivity. Factors such as climate, parent material, landform, vegetation and time are important in influencing soil distribution (Dokuchaev 1898, Jenny 1941, 1980, Buol *et al.* 1980). Studies carried out on soil associations in some parts of Morogoro, Tanzania show that a close relationship exists between soil types and soil forming factors including climate, parent material and mineralogical composition (Msanya 1980, Moberg *et al.* 1982, Msanya *et al.* 1999, Kimaro *et al.* 1999). In Morogoro Urban District information on soils and their relationship with soil forming factors is scanty (Msanya 1980, Kaaya *et al.* 1994, Kaaya 1997). There is therefore a need for more studies in this direction. The present study was aimed at providing broader understanding of the factors influencing soil distribution and their implication for agricultural land management in Morogoro Urban District. The specific objectives were (1) to establish the dominant soils occurring in the District, (2) to identify the main factors influencing soil distribution in Morogoro Urban District and (3) to establish the key limiting land qualities that are important for agricultural land management.

MATERIALS AND METHODS

Physical Environment of the Study Area

Morogoro Urban District is located between latitudes 6°37' and 6°55'S and longitudes 37°33' and 37°51'E. The district is bordered by Uluguru Mountains on the eastern side and Mindu-Lugala hills on the western side. The climate of the study area is tropical savannah with mean annual rainfall varying between 800 mm at the altitude of 400 m asl to 2,300 mm at the latitude of 1,500 m asl and above (Figure 1). The rainfall distribution is bimodal with a short rain season (*Vuli*) starting from October to December and a long rain season (*masika*) starting from March to May. The mean annual temperature varies from 25°C at lower elevations to 19°C at 1,500 m asl.

Field Methods

Aerial photographs of scale 1:35,000 were used for the identification of existing landforms units in the study area. A combination of both free survey (Dent and Young 1981) and transect observations were used to collect data on landforms and soil related properties.

Laboratory Methods

Both physical and chemical analyses of soil samples were done following standard procedures and guidelines as outlined in Klute (1986) and Sparks (1996) respectively. X-ray diffraction analysis was done for subsoil clay samples (Dixon and Weed 1989, Msanya *et al.* 1998).

Soil Classification

Soils were classified up to level three of the FAO-World Reference Base (FAO-WRB) System of soil classification (FAO-WRB 1998).

RESULTS AND DISCUSSION

Climate

Relief and slope aspect have a great influence on the climate of the District. Areas higher in the landscape such as the Morningside are cooler than those lower in the landscape such as Tungi. The trend of precipitation reveals a similar influence of altitude on precipitation (Figure 1). Precipitation is high at high altitudes and tends to be low at low altitudes. Areas on the leeward side of the Uluguru Mountains receive relatively lower precipitation than those on the windward side. Onset dates for precipitation are unreliable, although the rain season continues for 4 to 5 months. During the growing period, precipitation is lowest in the month of May whereas peak precipitation is normally received in April. Climatic data of the District reveal a gradual decrease in precipitation from the east towards the west and northwest (Figure 1). In the Tungi-Mkonowamara areas a rather dry condition prevails. The SUA-Kingolwira areas receive relatively more precipitation than Tungi-Mkonowamara area. This trend can be attributed to the rainshadow effect of the Uluguru Mountains.

Landforms

Climate and its effects on geological processes influence evolution of landforms in the study area. Marked influence on landforms by water erosion as well as colluvio-alluvial processes were observed in the field and through soil profile development (Msanya *et al.* 1999, Kimaro *et al.* 1999). Similar observations were reported by Moberg *et al.* (1982). In the current study, six major landform types were identified in the District (Table 1). The landforms of the Uluguru Mountains display a marked variation in altitude, relief and intensity of dissection. The strongly dissected ridges (1500-2000 m asl) are a manifestation of intense erosion in form of mass movements (Kimaro *et al.* 1999). The Uluguru mountain foothills (600-900 m asl) are predominantly steep convex slopes. The Mindu-Lugala hills situated at an altitude range of 700-1100 m asl are strongly dissected with hilly topography. The Mzinga-Bigwa piedmonts consist of glacia and alluvial fans. They are gently sloping and are characterised by moderate to severe erosion. Extensive areas of alluvial fans and hill wash sands are found around the strongly dissected Mindu-Lugalla hills. Whereas the piedmont slopes associated with the Uluguru Mountains are gently undulating, those of the Mindu-Lugalla hills have an undulating topography. Another major important landform in the District is the peneplain which is situated at an altitude of 300-600 m asl. The peneplains consist of ridge summits and slopes alternating with narrow valley bottoms. The valleys, being flat to almost flat with river terraces and flood plains occur at an altitudes lower than 400 m asl.

Parent materials (lithology)

Lithology of the Morogoro Urban District comprises of four major types. These include hornblende-pyroxene granulites, muscovite-biotite gneiss and migmatite, colluvium and alluvium (Table 1). The hornblende-pyroxene granulites are the dominant rock types and occupy the major part of the Uluguru Mountains and foothills. The dominant minerals in these rocks are calcium-rich plagioclase, hypersthene ($(\text{Mg,Fe})\text{SiO}_3$) and diopside ($\text{Ca,MgSi}_2\text{O}_6$) (Sampson and Wright 1964). The Muscovite-biotite gneisses and migmatites are dominant in the Mindu-Lugalla hills and a bigger part of the Tungi-Mkonowamara peneplains. They are of a high metamorphic grade containing equal amounts of potassium-feldspars (microcline) and sodium-rich plagioclase (oligoclase). Quartz is present in fairly high amounts. Colluvial materials of diverse mineralogical composition dominate most of the piedmont slopes and peneplains. Alluvial materials are dominant in the river terraces and flood plains. Msanya and Msaky (1983) reported presence of high amounts of easily weatherable minerals such as biotite, chlorite and epidote in these alluvial materials.

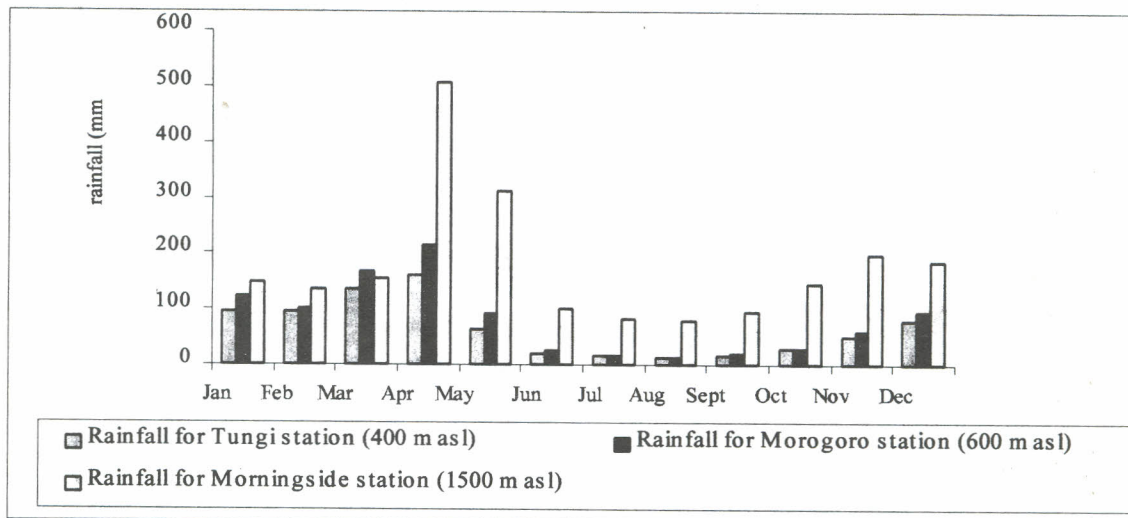


Figure 1. Mean monthly rainfall data for Morogoro Urban District

Table 1: Landform characteristics, lithology, and associated soil types in the Morogoro Urban District

Landform	Lithology	Altitude m asl	Dominant slope (%)	Soil type (FAO-WRB)
Uluguru mountain strongly dissected ridge slopes	Hornblende-pyroxene granulites	800-2000	60-80	Lithic, Paralithic Leptosols, Hapli-Profondic Lixisols, Orthidystri and Hypereutri-Episkeletic Cambisols, Episkeletic and Endoskeletal Phaeozems
Uluguru mountain foothills	Colluvium, mudclays derived from granulites	600-900	35-45	Chromi-Profondic Acrisols, Chromic Lixisols
Mindu-Lugala hills	Muscovite-biotite gneiss and migmatites	700-1100	35-50	Paralithic Leptosols
Mzinga-Bigwa piedmont slopes with glacis and alluvial fans	Colluvium, clays derived from granulites	500-600	2-15	Rhodi and Chromi-Profondic Luvisols, Chromi-Profondic Lixisols
Mindu-Lugala piedmont slopes with alluvial fans and hill wash sands	Colluvium, sands and loams from biotite gneisses and migmatites	500-700	2-10	Orthieutri-Chromic Cambisols, Orthidystri Arenosols
SUA-Kingolwira peneplains with undulating slopes	Colluvium, clays and loams derived from mixed gneisses and granulites	300-550	2-8	Rhodi-Acric Ferralsols, Cutani-Profondic Luvisols
Tungi-Mkonowamara peneplains with undulating to rolling slopes	Colluvium, sands, loams and clays derived from mixed gneisses and migmatites	300-600	5-15	Hyperdystric Cambisols, Cutani-Orthidystri Luvisols
Valleys with river terraces and floodplains	Alluvium, clays and loams	200-350	0-1	Stagni-Mollic Fluvisols, Calcari-Salic Vertisols

Soils

Climate, landform patterns and parent materials have had profound influence on types and distribution of soils in the District. Soil profile development reveals marked influence of mass removal of soils by water erosion particularly mass movements in the mountains and colluvio-alluvial processes in the piedmont slopes and peneplains. Climate, parent materials and relief appear to have a close relationship with the mineralogical composition and edaphological properties of the soils in the District (Table 1 and 2). There is considerable variation in soil depth, texture, drainage condition and soil chemical properties among the landform units. The mountain ridge slopes have relatively shallow soils and gravelly soil textures. This can be attributed to severe erosion caused by mass removal of soil materials mainly by high precipitation. The piedmont slopes and peneplains with colluvial material derived from granulites and mixed gneisses have very deep soils with high amounts of clay content. This is due to constant addition of new soil materials and *in situ* weathering coupled with low rate of erosion. Landforms associated with migmatites like Mindu-Lugala piedmont slopes and Tungi Mkonowamara peneplains have the highest amount of sand content. This can be explained by the nature of the parent materials which are richer in felsic minerals. Valley soils have medium textures and are stratified as a result of cyclic deposition of materials of diverse origin.

Clay Mineralogy

Soils of the Uluguru Mountains, the piedmont slopes and the peneplains associated with mafic rock types are mainly kaolinitic (Table 2). The soils of the mountain ridges have high content of gibbsite in the clay fraction, which can be attributed to rapid weathering and strong leaching caused by high rainfall and excessive drainage (Moberg *et al.* 1982). Soils of the river terraces and flood plains have relatively high contents of smectite and illite in the clay fraction, revealing the relative young age of the soils.

Chemical Properties

Soils of the mountains are slightly acidic to acidic ($\text{pH} < 5.5$). Piedmonts have nearly neutral reaction ($\text{pH} 6.0\text{--}7.5$) except for the glacis which are strongly acidic ($\text{pH} < 5.5$). Most soils of the peneplains are moderately acid except for those associated with migmatites which are strongly acid ($\text{pH} < 5.5$). Valleys have nearly neutral to alkaline soils with ESP ranging between 5 and 37%. Organic carbon and nitrogen levels for all soils are very low with values less than 1.0% and 0.1% respectively. Available P is also low ($< 5 \text{ mg/kg}$). Nutrient retention capacity of soils is low ($\text{CEC} < 12 \text{ cmol(+) / kg}$) except in the valleys where nutrient retention is high ($\text{CEC} 20\text{--}30 \text{ cmol(+) / kg}$).

Key limiting land qualities and their implication to land management

Soil characteristics and their distribution in the district have been influenced by landforms, parent materials and climate. Human activities particularly deforestation, cultivation (without proper conservation measures) and annual bush and forest fires have also influenced the soils. A summary of some limiting land qualities for agricultural land management in the District is presented in Table 3. In the Uluguru Mountains and Mindu-Lugala hills, shallow soil depth,

excessive soil drainage and steep slopes are the key limiting land qualities. Severe soil erosion and low soil fertility pose serious constraints to agricultural production in these areas. Deliberate efforts should be taken to establish critical zones for afforestation, reduce burning through introduction of by-laws and appropriate training programmes, use of grass barriers and cultivation of perennial crops. Further research on soil erosion particularly mass movements is necessary to be able to come up with acceptable soil conservation packages for these units.

Soil fertility is a major limiting land quality that poses limitations to agricultural productivity in the Uluguru foothills, Mzingu-Bigwa piedmonts and SUA-Kingolwira peneplains. It is strongly suggested that emphasis should be put on the use of organic and non acidifying fertilisers and afforestation of hilltops. Use of indigenous fertilisers such as rock phosphate could immensely contribute to the improvement of soil fertility in these units.

Excessive soil drainage, low soil moisture due to inadequate rainfall and low water holding capacity of the soil due to low organic matter and poor supply of major nutrients form the biggest limitation to agricultural production in the Mindu-Lugala piedmonts and Tungi-Mkonowamara peneplains. Water harvesting techniques, growing of drought tolerant crops and use of organic fertilisers will improve the sustainability of agricultural production in these units.

Table 2. Landforms, physico-chemical properties and clay mineralogy of the soils of Morogoro Urban District

Landform	Soil depth	Soil drainage	Soil texture	pH	OC %	N %	P mg/kg	ESP	CEC cmol(+)/kg	BS %	Clay mineralogy
Uluguru mountain strongly dissected ridge slopes	S-MD	E-W	grSCL, SC-C	5.5-6.0	0.1-1.2	0.01-0.05	1.0-5.0	tr	4.0-12.0	20-85	kaolinite (84%), gibbsite (7%), illite (5%), mica-vermiculite (4%)
Uluguru mountain foothills	D-VD	W	SC-C	5.0-6.5	0.5-1.0	0.01-0.10	1.0-2.0	tr	10.0-13.0	30-65	kaolinite (80%), mica-vermiculite (8%), illite (6%), gibbsite (6%)
Mindu-Lugala hills	S	E	grSL-SCL	5.5-6.5	0.3-0.8	0.03-0.06	2.0-3.0	tr	7.0-10.0	70-95	kaolinite (55%), illite (35%), smectite (10%),
Mzinga-Bigwa piedmont slopes with glacia and alluvial fans	VD	W	C	6.0-7.5	0.2-0.60	0.03-0.05	0.4-1.0	tr	6.0-10.0	80-100	kaolinite (85%), illite (8%), gibbsite (6%), smectite (1%)
Mindu-Lugala piedmont slopes with alluvial fans and hill wash sands	VD	E-W	LS-SL	6.0-7.0	0.3-0.4	0.04-0.08	0.7-1.4	tr	8.0-14.0	80-100	kaolinite (50%), smectite (16%), illite (34%)
SUA-Kingolwira peneplains with undulating slopes	D-VD	W	SC-C	4.5-6.5	0.3-0.7	0.04-0.05	1.2-1.8	tr	10.0-12.0	25-45	kaolinite (78%), illite (10%), smectite (7%), mica-vermiculite (5%),
Tungi-Mkonowamara peneplains with undulating to rolling slopes	MD-D	E-W	LS, SL-SCL	4.5-5.5	0.3-0.5	0.04-0.08	1.0-1.5	tr	9.0-11.0	30-40	kaolinite (48%), smectite (20%), illite (32%)
Valleys with river terraces and floodplains	VD	MW-P	L, CL-C	6.5-8.0	0.6-1.6	0.06-0.10	8.0-9.0	5-37	20.0-30.0	75-80	kaolinite (40%), smectite (26%), illite (30%), gibbsite (4%)

S=Shallow, MD=Moderately deep, D=Deep, VD=Very deep.

E=Excessively drained, W=Well drained, MW=Moderately well drained, P=Poorly drained

tr=trace, P mg/kg = Bray I P (mg P/kg)

Table 3. Landforms, soil types, derived limitations and proposed land management

Landform	Soil type (FAO-WRB)	Key limiting land qualities	Proposed land management strategies
Uluguru mountain strongly dissected ridge slopes	Lithic and Paralithic Leptosols, Hapli-Profondic Lixisols, Orthidystri and Hypereutri-Episkeletic Cambisols, Episkeletic and Endoskeletal Phaeozems	Soil depth, soil drainage, slope, soil erosion, soil fertility	Establishment of critical zones for afforestation Reduce burning Introduction of zero grazing Use of grass barriers Cultivation of perennial crops Research on soil erosion particularly mass movements
Uluguru mountain foothills	Chromi-Profondic Acrisols, Chromic Lixisols	Soil fertility, soil erosion	Use of organic and non acidifying inorganic fertilisers Use of other indigenous fertiliser materials Introduction of contouring and grass strips Afforestation of hill tops
Mindu-Lugala hills	Paralithic Leptosols	Soil depth, soil drainage, soil erosion	Afforestation Control of bush fires
Mzinga-Bigwa piedmont slopes with glaci and alluvial fans	Rhodi and Chromi-Profondic Luvisols, Chromi-Profondic Lixisols	Soil fertility	Use of organic and non acidifying inorganic fertilisers Introduction of zero grazing
Mindu-Lugala piedmont slopes with alluvial fans and hill wash sands	Orthieutri-Chromic Cambisols, Orthidystic Arenosols	Soil drainage, soil moisture, soil fertility,	Introduction of water harvesting techniques Grow drought tolerant crops Use of organic fertilisers
SUA-Kingolwira peneplains with undulating slopes	Rhodi-Acric Ferralsols, Cutani-Profondic Luvisols	Soil fertility	Use of organic and non acidifying inorganic fertilisers
Tungi-Mkonowamara peneplains with undulating to rolling slopes	Hyperdystric Cambisols, Cutani-Orthidystic Luvisols	Soil drainage, soil moisture, soil fertility	Introduction of water harvesting techniques Grow drought tolerant crops Use of organic fertilisers
Valleys with river terraces and floodplains	Stagni-Mollic Fluvisols, Calcari-Salic Vertisols	Soil drainage, salinity/sodicity soil workability	Crop selection Provision of drainage systems Introduction of mechanisation and use of organic fertilisers

Valleys have poor soil drainage, unfavourable levels of salinity and poor workability of the soils.

Provision of drainage systems in these areas will control and keep the ground water levels low. This will also enhance regular flushing of the soils thus avoiding the building up of harmful levels of salts. Saline soils could also be managed through proper crop selection and planting of saline tolerant crops. Sorghum withstands poor drainage condition and can cope very well with drought and saline conditions. Frequent floods especially by the Ngerengere River could be reduced by flood protection works like construction of ditches and dikes with outlets to the present natural drainage system. Agricultural mechanisation and use of organic fertilisers will in the long run improve soil structure of these units and ultimately enhance soil workability.

ACKNOWLEDGEMENTS

The authors wish to express their sincere appreciation to the Norwegian Agency for Development Cooperation (NORAD) for the financial assistance to carry out this research.

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