Pedon Characteristics and Their Implications for Land Management in Two Villages of Mbinga District, Tanzania

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Abstract

A land resources study was carried out in Lupilo and Tukuzi villages in Mbinga District. Two pedons representing the villages were selected for the study to obtain data that are important for land management. Standard soil and land resources survey procedures were employed. The results show that the soils are very deep, well drained, red and dark reddish brown sandy clays to clays and classify as Haplic Acrisol (Isohyperthermic, very deep, kaolinitic, Typic Rhodustult) at Lupilo and Ferric Acrisol (Isohyperthermic, very deep, kaolinitic, Ustic Haplohumult) at Tukuzi. The structure is generally poor for the two pedons. Bulk density values are low throughout Tukuzi pedon. Both pedons have medium available water capacity and generally low soil fertility. The clay mineralogical composition is dominantly kaolinitic with accessory amounts of sesquioxides. These characteristics are associated with poor soil conditions. The study shows that the two pedons represent fragile ecosystems that require careful management. Due to poor chemical, mineralogical and physical characteristics, the study recommends areas of further research. The commonly used tie-ridge (Ngolo) cultivation system should be studied further to find out its contribution to soil fertility. The use of rock phosphate as a P-fertilizer and as a possible liming material should be further investigated.

Keywords: Pedon characteristics, *Ngoro*, Mbinga

Introduction

Proper land management is crucial in agriculture. Successful agriculture requires good knowledge of land resources. The most important factors affecting land management in Tanzania include clearing and burning of vegetation, farming practices, topography and soil characteristics. To understand these factors research and field experimentation are required to generate data needed in the development of land management technologies such as fertilizer application and erosion control measures.

Many experiments on land management in Tanzania have been carried out without proper prior site characterization. For this reason the results of such experiments cannot be extrapolated to other areas with similar agro-ecological conditions. A good data bank on soil properties and related site characteristics is inevitable for one to be able to advise both current and potential land users, on how to use the land in the best possible way (Msanya *et al.*, 1995a). Proper site selection and characterization are also basic to the success of agronomic experiments and to the effectiveness of extending research results to a large number of farmers.

Recognizing this, a project named the *Miombo* Woodland Agroecological Research Project (MWARP), was initiated and Mbinga District was chosen as an area for research aimed at various aspects of land management representing the *Miombo* woodland environment of Tanzania. Two villages i.e. Lupilo and Tukuzi were selected for this study with the broad aim of providing information on natural

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resources for technological and land management packages. The specific objectives of the study were:

1. to characterize the soils of Lupilo and Tukuzi villages in terms of their physical, chemical and mineralogical properties;
2. to classify the soils of the villages using international systems adopted in Tanzania;
3. to provide data that will be used for the development of land management technologies such as fertilizer application, soil conservation and improved tillage practices.

Materials and Methods

Physical environment of the study areas

Both study sites are underlain by similar geological formation i.e. mixed intermediate and mafic rocks (Geological Survey Department, 1956), and have similar temperature regime (Mchau, 1993). However, they represent contrasting agro-ecological conditions.

Lupilo

Lupilo village representing the *Rolling Hills* is located approximately at longitude 35°8'48.1" E and latitude 10°52'39.0" S. The area has been invaded for agriculture since the last 15 years and is typified by a secondary *Miombo Woodland*. The prevailing vegetation species include *Brachystegia spp.*, *Parinari curatelifolia*, *Uapaka kirikiana* and *Pterocarpus angolensis* (Msanya *et al.*, 1995b). The type of agriculture being practiced in Lupilo and other newly opened areas is *ridge* cultivation with maize and beans, and *slash and burn* cultivation system involving finger millet. The topography is undulating to rolling with low to medium altitude ranging between 600 and 900 m above sea level. The rainfall is about 1000 mm per annum (Mchau, 1993).

Tukuzi

Tukuzi village represents the steeply dissected *Matengo Highlands* and is located approximately at longitude 34°57'28.4" E and latitude 11°01'20.6" S. The area is intensively cultivated and the original *Miombo* vegetation has been cleared completely and replaced by agriculture. The type of agriculture being practiced is a tie-ridge (*Ngolo)* cultivation system (Kimaro *et al.*, 1995). The main crops grown include maize, beans and wheat. In some areas, coffee under *Grevillea robusta* is grown; in other parts where agriculture is not feasible *Eucalyptus* trees are planted. The topography is rolling to hilly with high altitude ranging between 1200 to 1500 m above sea level. The rainfall is about 1200 mm per annum (Mchau, 1993).

Field methods

Study sites were selected using existing soil information, aerial photo interpretation and field observations on both landforms and soils. Representative soil profile pits were excavated, described and sampled following standard procedures (FAO, 1990; Munsell Colour Company, 1975; Soil Survey Staff, 1951).

Laboratory methods

Texture was determined by pipette method (Day, 1965). Bulk density and particle density were determined using a three-phases meter model DIK-1120 (Daiki Rika Kogyo Co. Ltd. Japan). Soil moisture characteristics were determined using pressure plate and membrane apparatus (Klute, 1986).

pH was measured at the ratio 1/2.5 soil-water and soil-KCl. Organic carbon was determined by wet oxidation method (Nelson and Sommers, 1982). Kjeldahl method (Bremner and Mulvaney, 1982) was used to determine total nitrogen. Phosphorus was extracted by Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined spectrophotometrically (Murphy and Riley, 1962). Cation exchange capacity (CEC) and exchangeable bases were extracted using neutral 1M NH_4OAc (Thomas, 1982). Bases Ca^{++}, Mg^{++}, Na^{+}, and K^{+}, displaced by NH_4^+ were measured by atomic absorption spectrophotometer. Exchangeable Al was determined using unbuffered 1 M KCl (Hesse, 1971).

Subsoil samples for clay mineralogical analysis were first treated with 30% H_2O_2 to remove organic matter. Samples were then shaken overnight in an end-over-end shaker, and to allow thorough dispersion, 1 ml of 1N NaOH was added to each sample. Soil suspensions were then allowed to settle and at appropriate time interval, clay samples were taken and mounted on glass slides for x-ray diffraction analysis. X-ray diffractometer model Shimazu XD-D1 was used for analysis. X-ray diffractograms were interpreted manually using standard guidelines and books (Brindley and Brown, 1980; Dixon and Weed, 1989).

Soil classification and interpretation

Soils were classified up to level 2-soil unit names according to FAO Classification (FAO, 1988) and up to family level according to USDA Soil Taxonomy (Soil Survey Staff, 1990). Interpretation of both physical and chemical data was based on standard guidelines (EUROCONSULT, 1989; Msanya *et al.*, 1995).

relevant for land management at the two sites are presented in Tables 2, 3 and 4, and are discussed below.

Soil structure

In Lupilo pedon, soil structure of topsoil and part of subsoil is weak. Structure of Tukuzi pedon is weak throughout the profile. Weak structures are vulnerable to destruction by tillage which leads to compaction and soil erosion.

Bulk density

Bulk densities in Lupilo pedon vary from 1.11 to 1.41 g/cc. According to Taylor *et al.* (1966) such BD values can cause deleterious effects of reducing air-filled pore space. In Tukuzi pedon, BD values are generally low throughout the profile (ranging from 0.9 to 1.15 g/cc) and hence do not pose limitations to root penetration. However, low values of BD

Table 1: Salient morphological and diagnostic features of the studied soils and their classification

Pedon	Diagnostic horizons	Other diagnostic features	Depth classes	Mineralogy class	Soil names						
					FAO - Unesco		USDA Soil Taxonomy				
					Level - 1	Level - 2	Order	Suborder	Greatgroup	Subgroup	Family
Lupilo	*ochric A (ochric epipedon); *argillic horizon)	Ustic SMR, isohyperthemic STR	Very deep	Kaolinitic	Acrisol	Haplic Acrisol (ACh)	Ultisol	Ustult	Rhodultult	Typic Rhodustult	Isohyperthermic, very deep, kaolinitic, Typic Rhodustult
Tukuzi	*ochric A (ochric epipedon); argillic horizon)	Ustic SMR; isohyperthermic STR; * ferric properties; * geric properties (small textural gradient in the B horizon)	Very deep	Kaolinitic	Acrisol	Ferric Acrisol (ACf)	Ultisol	Humult	Haplohumult	Ustic Haplohumult	Isohyperthermic, very deep, kaolinitic, Ustic Haplohumult

*terminology used particularly in the FAO-Unesco classification, those without * are used in USDA System

Results and Discussion

Both pedons are very deep, well drained, red and dark reddish brown sandy clays to clays developed on colluvium derived from mixed metamorphic rocks. The pedon at Tukuzi has a very thick, dark yellowish brown, man-made topsoil. Detailed classification of the two pedons is given in Table 1.

Important characteristics identified to be

coupled with weak topsoil structures are an erosion hazard especially after cultivation which transforms the soil into dust that is difficult to protect against wind erosion (Van Wambeke, 1992).

Available water capacity

According to Landon (1984), available water capacity of both pedons can generally be rated as medium for purposes of irrigation

Table 2: Some physical characteristics of the studied soils

Sample and depth (cm)	Moist Munsell soil colour	Structure	% Texture			Textural class	Silt / Clay ratio	Bulk density g/cc	Particle density g/cc	% Porosity	% AWC (vol.)	AWC (mm/m)
			Sand	Silt	Clay							
LUPILO												
Ah 0 - 10	7.5YR3/2 (db)	weak	63	15	22	SCL	0.7	1.11	2.60	57.3	12.5	119.6
BA 10 -25	5YR3/4 (drb)	weak	57	14	29	SCL	0.5	nd	nd	nd	nd	
Bt1 25 - 60	2.5YR3/4 (drb)	moderate	51	13	36	SC	0.4	1.39	2.69	48.3	8.4	
Bt2 60 - 100	2.5YR3/4 (drb)	moderate	43	12	45	C	0.3	nd	nd	nd	nd	
Bt3 100 - 155	2.5YR4/6 (r)	moderate	42	9	49	C	0.2	1.41	2.67	47.2	14.7	
TUKUZI												
Ap 0 - 25	10YR4/4 (dyb)	weak	41	16	43	C	0.4	0.90	2.78	67.6	7.4	144.5
Bt1 25 - 70	10YR4/4 (rb)	weak	35	13	52		0.3	1.15	2.79	58.8	13.0	
Bt2 70 - 130	2.5YR4/6 (r)	weak	31	12	57	C	0.2	1.08	2.81	61.6	18.7	
Bt3 130 - 180	2.5YR4/6 (r)	weak	21	14	65	C	0.2	nd	nd	nd	nd	

*Estimated as the difference between water held at 10 kPa and that held at 1500 kPa

nd = not estimated; db = dark brown; r = red; dr = dark red; rb = reddish brown; drb = dark reddish brown; yb = yellowish brown ;

C = clay; SCL = sandy clay loam.

Table 3: Some chemical properties of the studied soils

Horizon	Sample depth (cm)	pH H₂O	pH KCl	P mg/kg	OC %	N %	Ca	Mg	K	Na	Al	CEC soil cmol(+) /kg	CEC clay cmol(+)/kg	BS %
							cmol(+) / kg soil							
LUPILO														
Ap	0 - 10	6.0	5.6	28	1.8	0.12	2.4	1.4	0.42	0.06	0.00	7.0	32	61
BA	10 - 25	5.2	4.5	20	0.9	0.07	1.3	0.7	0.33	0.04	0.04	7.0	24	34
Bt1	25 - 60	5.4	4.2	24	0.6	0.04	1.6	0.6	0.49	0.07	0.14	7.4	21	37
Bt2	60 - 100	5.3	4.5	12	0.4	0.03	1.8	1.2	0.33	0.08	0.11	8.8	20	39
Bt3	100 - 155	5.2	4.9	0.4	0.2	0.02	1.5	1.2	0.67	0.06	0.00	9.6	20	35
TUKUZI														
Ap	0 - 25	5.3	4.5	1.0	4.1	0.29	3.3	1.9	0.57	0.07	0.18	14.6	33	41
Bt1	25 - 70	4.7	4.0	0.1	1.0	0.07	0.7	0.1	0.30	0.08	0.41	10.6	20	11
Bt2	70 - 130	4.6	4.2	0.1	0.5	0.04	0.7	0.2	0.31	0.08	0.30	10.6	19	12
Bt4	130 - 180	4.7	4.2	0.1	0.2	0.02	0.7	0.4	0.36	0.09	0.38	11.6	18	14

Table 4: Clay mineralogical data of subsoil clay samples of the studied soils

Pedon	Diagnostic x-ray diffraction peaks	Mineral species and % approximate amounts
LUPILO	7.2A, 4.4A, 3.6A - the peaks disappear after heating at 550oC	kaolinite (95%)
	10A, 5A, 3.3A	illite (5%)
	4.85A	gibbsite (tr)
TUKUZI	7.2A, 4.4A. 3.6A - the peaks disappear after heating at 550oC	kaolinte (74%)
	10A, 5A, 3.37A	illite (7%)
	4.85A, 4.37A	gibbsite (15%)
	4.18A	geethite (4%)

planning.

Soil reaction and exchangeable Aluminum

Soil reaction of both pedons is acid to very acid. At Lupilo, pH values are slightly higher with topsoil being moderately acid. Acid pH calls for soil management practices that will prevent further acidification of the soils. Such practices include liming and use of non-acidifying fertilizers e.g. calcium ammonium nitrate (CAN) in lieu of the commonly used sulphate of ammonia (SA). Exchangeable Al was detected in both soils, with relatively higher values in Tukuzi pedon. However, Al toxicity is currently not a problem as the exchangeable Al in both soils is less than the critical level of 2-3 cmol(+)/kg soil (Chapman, 1966) above which many crops are likely to suffer.

Available phosphorus

Available P can be rated as high and medium, respectively in the topsoils and in the subsoils of Lupilo pedon; while it is low throughout Tukuzi pedon. Phosphorus level above 7 mg/kg is considered minimum, below which P-deficiency symptoms are likely to occur in many crops. From the data it can be inferred that Tukuzi soil has a serious limitation of P.

Organic matter and nitrogen

Organic matter content is medium in topsoil of Lupilo. It decreases with depth to low and very low values in the subsoil. At Tukuzi organic matter content is very high and is concentrated in topsoil. Higher organic matter levels in topsoil is attributable to *Ngolo* management practice. This indicates that *Ngolo* system of land management is effective in improvement of organic matter. Moreover, it has been seen to be effective against soil erosion (Kimaro *et al.*, 1995). However, apart from organic matter, it does not contribute significantly to other nutrients (Table 3).

Total nitrogen content in both Lupilo and Tukuzi is low and very low except in topsoil of Tukuzi which has medium levels. C/N ratios are medium indicating only moderate quality of organic matter.

Cation exchange capacity (CEC) and exchangeable bases

Except for topsoil of Tukuzi, CEC of both pedons is low. Relatively high topsoil CEC in Tukuzi pedon is most likely due to high organic matter content of this section of pedon. Exchangeable Ca can be rated as medium in both pedons. Exchangeable Mg levels are low to medium throughout Lupilo pedon, whereas in Tukuzi they are medium in topsoil and very low to low in subsoil. At Lupilo exchangeable K is medium in topsoil and low to medium in subsoil while in Tukuzi K levels are medium in topsoil and low in subsoil.

Nutrient balance

In terms of nutrient balance, Ca/Mg ratios of 2 to 4 are considered favourable. Ca/Mg ratios of most horizons of the two pedons are outside this range, indicating that there is a nutrient imbalance in the soils. K/TEB (total exchangeable bases)ratios are above 2% which is said to be favourable for most tropical crops. Base saturation (BS) values are low (less than 50%) throughout both pedons except for topsoil of Lupilo which has a BS of 69%. BS in subsoil of Tukuzi pedon is exceedingly low reaching levels as low as 11% in some horizons.

Soil clay mineralogy

Clay mineralogical data are summarized in Table 4. Mineralogy of Lupilo pedon is predominantly kaolinitic, containing about 95% kaolinite and about 5% illite. Some traces (less than 1%) of gibbsite were also identified in this soil. Mineralogical composition of Tukuzi pedon is also predominantly kaolinitic with about 74% kaolinite and accessory amounts of gibbsite (15%), illite (7%) and goethite (4%). Dominance of kaolinite and Fe- and/or Al- oxides in both pedons clearly points to advanced stage of weathering in the soils. Content of oxides is higher in Tukuzi soil than in Lupilo soil indicating a relatively more advanced stage of weathering in Tukuzi. The mineralogical composition explains the low CEC of the soils.

Conclusions

The following concluding remarks can be made about the studied pedons:

1. the two pedons are similar in some characteristics i.e. they are both in advanced stage of weathering as indicated by dominantly kaolinitic clay mineralogy and low silt/clay ratios; and available water capacity is medium for both pedons;
2. physical characteristics of Lupilo pedon do not pose serious limitations for use and management, whereas in Tukuzi pedon, low BD values coupled with poor structure pose serious erosion hazard;
3. soil fertility of Tukuzi pedon is very low (particularly in subsoil) as indicated by very acid pH and very low levels of N and P;
4. tie-ridge *(Ngolo)* cultivation system has resulted in improvement of OM and N content in topsoil of Tukuzi pedon.

In view of the foregoing remarks on the two pedons, the following recommendations are made:

1. due to low pH values, non-acidifying inorganic fertilizers should be preferred. Use of rock phosphate in relation to its possible de-acidifying effects should be investigated;
2. further studies on *Ngolo* cultivation system should be carried out to look into ways of improving its contribution to soil fertility;
3. due to dominantly kaolinitic clay mineralogy, P-fixing capacity of the studied soils should be determined to assist in development of fertilizer-P recommendations.

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