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Soil Fertility Survey in Western Usambara Mountains, Northern Tanzania*[1]

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ABSTRACT

Soil samples from thirty sites representing four agro-ecological zones in the Western Usambara Mountains (WUM) of the Lushoto District in northern Tanzania were collected and analyzed for different nutrients. The results suggested that the major soil fertility constraint was P deficiency. On the basis of critical levels established in other areas, 90% of the soils were ranked as P deficient. This was followed by N, which was ranked as inadequate in 73% of the sites. Magnesium, K, and Ca also appeared limiting with 67%, 53% and 50% of the soils falling below the established critical values, respectively. A few soils (10%) were also found to contain exchangeable Al. The metallic micronutrients (Cu, Fe, and Zn) were adequate in all soils. Two sites had excessive Mn that could lead to toxicity in crops, and one was Mn deficient.

Key Words: agro-ecological zone, P deficiency, soil fertility, Western Usambara Mountains

INTRODUCTION

Agriculture, with approximately 84% of the Tanzanians employed in this sector (World Bank, 1994), is the backbone of the Tanzanian national economy and provides most of the employment, food, export commodities, and foreign exchange. The Western Usambara Mountains (WUM) are amongst the potential agriculture areas in the country (Pfeiffer, 1990; Moshi, 1996) where a variety of agricultural activities are undertaken. The area is famous for supplying food and cash crops such as maize, beans, vegetables (tomatoes, cabbages, onions and others), fruits, tea, coffee, bananas and timber to some major cities in Tanzania.

The WUM are densely populated. Poor farmers, with few resources to purchase inorganic fertilizer inputs, own most of the farms. Many of the farming areas are also located on steep slopes that are intensively cultivated and highly degraded. Such degraded soils in Tanzania have a major impact on the livelihood of the people (Wiig *et al.*, 2001). Therefore, information on the soil nutrient status in the WUM is vital as it may be used to predict performance and to recommend crops that will grow in the area.

To date, soil survey work in Tanzania has been limited to only a few areas (Muchena and Kiome, 1995), leaving a lot of the nation's soils and land potentials unknown. Therefore, very little information is currently available on soil fertility status of the WUM. In the future, this information could play a key role in land use planning and soil fertility management decisions.

MATERIALS AND METHODS

The soils used in this study were collected from 30 sites representing four agro-ecological zones in the western part of the WUM in the Lushoto District of the Tanga Region, Tanzania (04° 47.976′ S,

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38° 17.623′ E) (Table I). The WUM are located at an altitude ranging from 900 up to 2 300 m, and the major soil types can be classified in descending order of importance as Humic and Chromic Acrisols, Luvisols and Lixisols (Wickama and Mowo, 2001).

TABLE I

Some chemical properties of soils collected from the Western Usambara Mountains in the Lushoto District of the Tanga Region, Tanzania

Agro-ecological zone	Site	pH[a]	Exchangeable Al	Al saturation	Exchangeable Ca	Ca saturation	Mg	K	Mg:K ratio	Na	H	CEC	Bray I P
			$cmol_c\ kg^{-1}$	%	$cmol_c\ kg^{-1}$	%	$cmol_c\ kg^{-1}$			$cmol_c\ kg^{-1}$			$mg\ kg^{-1}$
Soni	Magamba	4.9	0.35	8.4	3.19	73	0.50	0.11	4.6	0.23	0.40	4.9	4.20
	Ngulwii	5.5	–	–	5.59	76	1.43	0.08	17.9	0.24	0.20	7.5	2.80
	Irente	5.4	–	–	2.79	66	1.00	0.07	14.3	0.24	0.25	4.4	4.20
	Ubiri	5.8	–	–	3.99	76	1.20	0.07	17.1	0.20	0.20	5.7	3.16
	Mbuzii	5.9	–	–	4.79	77	1.10	0.08	13.8	0.25	0.20	6.4	2.80
	Silviculture	5.3	–	–	3.99	68	1.50	0.12	12.5	0.26	0.30	6.2	4.55
	Soni	5.9	–	–	5.59	75	1.52	0.12	12.7	0.25	0.20	7.6	1.68
Shume	Viti	5.9	–	–	5.19	77	1.07	0.36	3.0	0.16	0.25	7.0	3.16
	Maringo	5.2	1.15	19.49	3.99	64	0.67	0.09	7.4	0.30	0.30	6.5	4.55
	Lulozi	7.1	–	–	15.57	82	2.70	0.50	5.5	0.30	0.20	19.3	5.94
	Manolo	7.5	–	–	16.77	83	3.00	0.20	15.0	0.23	0.19	20.4	3.16
	Kibaoni	5.7	–	–	5.91	71	1.54	0.24	6.4	0.32	0.20	7.4	7.68
	Longoi	6.0	–	–	5.59	69	2.00	0.31	6.5	0.25	0.20	8.4	3.16
	Malindi	6.2	–	–	5.59	66	2.10	0.59	3.6	0.24	0.20	8.7	54.60
	Mnadani	6.1	–	–	5.59	70	2.00	0.15	13.3	0.28	0.20	8.2	2.80
Mlola	Mkuzi	5.2	–	–	4.79	74	1.20	0.21	5.7	0.24	0.25	6.7	4.20
	Kwai	6.1	–	–	7.98	75	2.13	0.31	6.9	0.26	0.20	10.9	4.20
	Mshangai	6.4	–	–	10.38	78	2.50	0.16	15.6	0.30	0.20	13.5	8.40
	Kwekanga	5.4	–	–	3.19	77	0.60	0.12	5.0	0.30	0.20	4.4	1.75
	Malibwi	6.1	–	–	5.59	69	2.10	0.12	17.5	0.26	0.20	8.3	5.94
	Kwekame	5.5	–	–	3.59	68	1.20	0.19	6.3	0.30	0.20	5.4	4.20
	Migambo	6.1	–	–	7.58	73	2.40	0.12	20.0	0.25	0.20	10.6	7.70
	Milungui	5.9	–	–	7.58	74	2.00	0.36	5.6	0.26	0.25	10.5	4.20
Mlalo	Mlalo	5.2	0.30	11.58	1.50	53	0.50	0.29	1.7	0.22	0.75	3.5	21.04
	Nyasa	5.7	–	–	2.79	57	1.39	0.39	3.6	0.34	0.25	5.2	2.80
	Zaizo	5.5	–	–	1.50	43	1.50	0.17	8.8	0.33	0.25	3.8	2.80
	Mhelo	5.7	–	–	5.59	72	1.50	0.35	4.3	0.30	0.25	7.9	15.40
	Ngazi	5.4	–	–	2.79	74	0.50	0.21	2.4	0.28	0.25	4.0	6.30
	Handei	5.9	–	–	4.39	70	1.50	0.10	15.0	0.26	0.20	6.5	1.75
	Bungoi	5.7	–	–	3.99	65	1.60	0.28	5.7	0.30	0.20	6.4	4.20

[a] In water.

Before collecting soil samples, a survey was conducted in the whole WUM area during the cropping season to assess crop growth in the field. After the survey 30 cultivated fields with known management history were selected. A composite sample made up of 15–20 subsamples of topsoil (to a depth of 20 cm) was collected from each selected site, and then a representative sample of about one kg of soil was taken. The soils collected were air dried and sieved through a 2 mm-sieve.

Soil pH in water was determined by a pH meter using a soil to water ratio of 1:1 as described by Peech (1965). Available P was extracted following the Bray I procedure (Bray and Kurtz, 1945), and P in the extract was determined by the ascorbic acid-molybdate blue method of Murphy and Rilley (1962). Organic carbon was determined by the Walkley and Black method (Allison, 1965), and total organic matter was calculated by multiplying the organic carbon by a factor of 1.72 as described by Walkey and Black (1934). Total N was determined by the micro-Kjeldahl method (Bremner, 1965). The cation exchange capacity (CEC) was determined by the ammonium saturation method (Chapman, 1965); and exchangeable bases (Ca, Mg, Na, and K) in ammonium acetate leachates were determined by atomic absorption spectrophotometry as described by Hesse (1971). Both exchangeable Al and acidity were extracted with KCl and determined by titration (McLean, 1965). Available metallic micronutrients, *i.e.*, Cu, Zn, Fe, and Mn, were extracted using 5 mol m^{-3} DTPA (diethylenetriamine pentaacetate) at pH 7.3 and determined by atomic absorption spectrophotometry. Finally, the particle size distribution was determined by the Bouyoucos hydrometer method (Day, 1965).

RESULTS AND DISCUSSION

Soil pH

The soil pH ranged from 4.9–7.5 with 11 out of the 30 sites (37%) having pH $\leq$ 5.5. Soils with such low pH values could be associated with deficiencies of phosphorus (Table I) and some of the important bases. The remaining 19 sites (63% of the soils) had pH values ranging from > 5.5 to 7.5 and these were within the favorable pH range for most crops (Sanchez *et al.*, 2003) that were grown in the WUM. The soil pH in this study was a direct indicator of some chemical characteristics of soils collected from different sites. For example, at low pH values $\leq$ 5.5 (Table I) the CEC of some of the soils showed a decreasing trend. Furthermore, three out of four soils with pH from 4.9 to 5.2, inclusive, had the highest levels of extractable acidity (Al^{3+} and H^+). In such pH ranges, problems of Al and/or Mn toxicities have been reported (Evans and Kamprath, 1970; Sanchez, 1976; Sanchez and Uehara, 1980). However, except at one site (Maringo), since the levels of extractable acidity were below a level recommended by Kamprath (1970), the level of soil acidity recorded did not warrant the application of lime.

Available P

The available P (Bray I P) in the soils ranged from 1.68 to 54.60 mg kg^{-1} (Table I). In accordance with levels given by FMANR (1990) for upland soils of P (> 15.0 mg kg^{-1}), most of these soils (90%) contained low P. Such high deficiency levels in most soils justified supplying P for sustainable crop production. Research by Wickama and Mowo (2001) in the WUM has provided evidence that field application of some locally available organic and inorganic P sources like Tughutu (*Vernonia subuligera* O. Hoffn.), Mhasha (*Vernonia amyridiantha* (Hook, J.), Alizeti Mwitu (*Tithonia diversifolia* (Hemsl.) A. Gray) and Minjingu phosphate rock improved crop yields. Thus, prospects for using cheap, locally available P sources and commercial P fertilizers in the WUM were promising.

Exchangeable Al and Ca

Exchangeable Al was observed in 3 out of the 30 sites (10%). The values ranged from 0.30 to 1.15 $cmol_c$ kg^{-1}, while the Al saturation ranged from 8.4% to 19.5% (Table I). It was at one site (Maringo) that the exchangeable Al and Al saturation were both above the critical levels for toxicity of 1.0 $cmol_c$ kg^{-1} and 10%, respectively, suggested by Schwartz and Coralles (1989). At Mlalo, the Al saturation value was above 10%. The soil acidity values recorded were generally low but did not pose a serious threat to crop production (Kamprath, 1970).

Exchangeable Ca ranged from 1.50 to 16.77 $cmol_c$ kg^{-1} (Table I). The proposed critical level of Ca for a majority of crops was 5.0 $cmol_c$ kg^{-1} (Marx *et al.*, 1996). Fifteen sites (50%) contained calcium levels lower than the suggested critical level, leaving half of the sites safe from Ca deficiency. The percentage Ca saturation ranged from 43% to 83% with 29 (97%) of the sites having above 50% saturation. This showed that Ca was the most dominant cation on the soil colloids (Table I). Other forms like foliar formulations could be used to correct Ca nutrition problems in areas where it was a serious problem.

Exchangeable Mg and K

Exchangeable Mg ranged from 0.5 to 3.0 $cmol_c$ kg^{-1} (Table I). The proposed critical value in most crops was 2 $cmol_c$ kg^{-1} (Schwartz and Coralles, 1989). In 20 out of the 30 sites (about 67%) Mg was less than this critical level, suggesting that Mg supply in many soils was low and could limit the growth of crops grown in the WUM. Therefore, to attain maximum crop yields supplemental Mg may be needed in the deficient areas.

Calculations of the Mg:K ratio revealed that except at one site, all had values above 2 (Table I). It was generally recommended to keep the ratio above 2 (Lombin and Fayemi, 1976) to maintain an adequate balance of these nutrients for optimum plant growth (Manson, 1995; Farina *et al.*, 1992).

Exchangeable K in the soil ranged from 0.07 to 0.59 $cmol_c\ kg^{-1}$ (Table I). For most crops grown in East Africa, Anderson (1973) recommended 0.20 $cmol_c\ kg^{-1}$ as a critical level of K in soils. Sixteen out of the 30 sites (53%) had K levels lower than this recommended value, and hence these soils were rated as deficient in K. Smithson *et al.* (1993) also identified K as one of the major limiting factors to bean production in the WUM. Therefore, in the WUM K application as inorganic fertilizer in crop production was recommended.

Cation exchange capacity

CEC ranged from 3.5 to 20.4 $cmol_c\ kg^{-1}$. NSS (1990) categorized soils having 6.0–12.0 $cmol_c\ kg^{-1}$ as poor in exchangeable bases. Twenty-seven out of the 30 sites (80%) had CEC < 12.0 $cmol_c\ kg^{-1}$ (Table I). Soils with such low CEC values were typical of weathered soils and had limited capacity to supply plants with nutrients such as Ca^{2+}, K^+, and Mg^{2+} (Sanchez and Logan, 1992). Due to excessive rainfall that prevailed in the WUM, such soils with low CEC were prone to leaching of nutrients like N, K^+, and Mg^{2+} (Ludwig *et al.*, 2001). The CEC in this study was also a good indicator of how the soils should be managed for better crop production. In this study most soils with very low CEC (< 6 $cmol_c\ kg^{-1}$) had low clay and OM contents. However, of the 9 sites with CEC below 6, one site had the highest OM and lowest clay content, one site had the highest clay content, and 2 out of 3 of the highest clay sites were in this group (Table II). Thus, there were implications on the ability of the soils to hold water and nutrients such as NO_3^-, NH_4^+, K^+ and Mg^{2+}. It was generally accepted that such soils had lower yield potential (Asadu *et al.*, 1997) than soils with higher CEC.

Total soil organic matter and organic carbon

The total soil OM ranged from 21.7 to 91.0 $g\ kg^{-1}$ (Table II). Soil OM in ecosystems was regarded as an important source of soil nutrients and a determining factor in the availability of the majority of nutrients to plants (Agboola and Corey, 1973). OM was found to contain all the nitrogen and much of the phosphorus and sulfur capital of tropical soils (Sanchez *et al.*, 2003). Soil OM was also known to increase CEC (Asadu *et al.*, 1997), to improve soil aggregate stability (Boyle *et al.*, 1989), to sustain microbial populations in the soil (Facelli and Pickett, 1991), and to improve water-holding capacity of the soil (Bauer and Black, 1992). Also soil OM played a key role in the micronutrient status of the soil. For example, Baruti (1997) found that soil OM was very relevant in influencing the concentrations of heavy metals, such as Zn, Cu and Mn, in some selected soils of the WUM. OM was also positively correlated with Zn, Cu, and Mn (Baruti, 1997). Promotion of activities that enhanced OM return to the soil in the WUM was therefore highly recommended, as this would improve the soil's capacity to recycle nutrients. This could include practices such as incorporation of straw and/or crop residue in the soil, green and compost manuring, and the use of farmyard manure (FYM).

Soil organic carbon ranged from 12.6 to 52.9 $g\ kg^{-1}$ (Table II). The critical threshold of soil organic carbon is 20.0 $g\ kg^{-1}$ and below this, serious decline in soil quality has been reported (Kemper and Koch, 1966; Greenland *et al.*, 1975). The reasonably higher levels of OC in most soils were attributed to supply from the decomposing plant materials that were abundant in the sampling period. If soil samples had been collected during the non-cropping, dry season, the results could have been different.

Soils with a high C:N ratio were always N limited. Soil microbes exposed to an N-deprived environment were subjected to limited growth and their mineralization capability was greatly lowered. In this study the C:N ratios of all soils were less than 30. Uriyo *et al.* (1979) suggested that soils with a C:N

TABLE II

Some chemical and physical properties of soils collected from the Western Usambara Mountains in the Lushoto District of the Tanga Region, Tanzania

Agro-ecological zone	Site	Organic matter	Organic C	N	C:N ratio	Fe	Mn	Cu	Zn	Sand	Silt	Clay	Texture[a)]
		g kg^{-1}				mg kg^{-1}				%			
Soni	Magamba	91.0	52.9	2.4	22	59.6	10.0	1.2	2.5	77.2	9.2	13.6	SL
	Ngulwii	51.0	34.8	1.8	19	40.0	126.0	2.4	1.5	38.0	27.6	34.4	CL
	Irente	37.8	22.0	1.3	17	70.0	35.0	3.6	3.1	55.2	15.2	29.6	SCL
	Ubiri	45.6	26.5	1.3	20	24.0	86.0	6.8	2.3	37.2	19.2	43.6	Clay
	Mbuzii	36.6	21.3	1.3	16	24.0	384.0	2.8	3.4	39.2	8.4	52.4	Clay
	Silviculture	63.5	36.9	1.7	22	50.0	66.0	0.6	2.0	48.0	15.6	36.4	SC
	Soni	31.3	18.2	1.1	17	32.0	140.0	4.8	2.4	38.0	16.6	48.8	Clay
Shume	Viti	53.3	31.0	1.8	17	32.0	73.0	3.6	1.8	52.0	9.2	38.8	SC
	Maringo	67.9	39.5	2.0	20	50.0	70.0	2.4	2.6	56.0	5.6	38.4	SC
	Lulozi	90.3	52.5	2.7	19	24.0	33.0	1.2	5.8	65.2	13.2	21.6	SCL
	Manolo	88.6	51.8	2.0	26	16.0	20.0	2.0	3.6	51.2	17.2	31.6	SCL
	Kibaoni	72.1	41.9	2.0	21	48.0	26.0	0.8	2.6	55.2	11.2	33.6	SCL
	Longoi	39.7	23.1	1.0	23	48.0	106.0	4.8	4.6	62.8	11.2	26.0	SCL
	Malindi	42.8	24.9	1.2	21	32.0	53.0	2.4	4.2	47.2	19.2	33.6	SCL
	Mnadani	68.6	39.9	1.4	29	36.0	110.0	4.4	2.6	44.0	19.6	36.4	SC
Mlola	Mkuzi	81.5	47.4	2.2	22	86.0	26.0	8.8	5.8	57.2	9.2	33.6	SCL
	Kwai	63.6	37.7	4.0	9	28.0	100.0	4.8	6.2	39.2	19.2	41.6	Clay
	Mshangai	87.0	50.6	2.1	24	24.0	90.0	2.6	6.8	55.0	21.6	26.4	SCL
	Kwekanga	41.5	24.1	1.3	19	44.0	26.0	3.2	4.8	50.0	11.6	38.4	SC
	Malibwi	44.2	25.7	1.4	18	24.0	116.0	3.6	2.6	49.2	15.2	35.6	SCL
	Kwekame	48.9	28.4	1.4	20	32.0	84.0	3.2	2.4	26.0	15.6	58.4	Clay
	Migambo	47.0	27.3	1.5	18	60.0	66.0	2.4	4.4	55.2	23.2	21.6	SCL
	Milungui	71.0	41.3	1.9	22	28.0	120.0	2.0	3.4	43.2	17.2	39.6	CL
Mlalo	Mlalo	43.9	25.5	1.5	17	28.0	6.0	1.2	1.2	46.2	23.2	29.6	SCL
	Nyasa	33.0	19.2	1.0	19	36.0	6.0	1.6	2.2	30.0	19.6	50.4	Clay
	Zaizo	23.8	13.8	0.7	20	32.0	20.0	1.3	1.4	48.0	23.6	28.4	SCL
	Mhelo	44.6	25.9	1.2	22	28.0	3.0	0.4	2.0	58.0	21.6	20.4	SL
	Ngazi	47.8	27.8	1.3	21	32.0	60.0	1.2	2.6	49.2	21.2	29.6	SCL
	Handei	21.7	12.6	0.8	16	36.0	100.0	1.2	2.2	56.0	13.6	30.4	SCL
	Bungoi	41.5	24.1	1.3	19	50.0	160.0	8.8	4.8	35.2	21.2	43.6	Clay

[a)] CL = clay loam, SCL = sandy clay loam, SC = sandy clay.

ratio greater than 30 were in most cases N limited and could not support good plant and microbial growth. Practices that enriched soil organic carbon should be encouraged simply because as soil OC decreased it would become increasingly difficult to obtain yields equivalent to those expected from rich soils.

Total N

Total N in the soil ranged from 0.7 to 4.0 g kg^{-1} (Table II). The NSS (1990) proposed critical level for most crops in Tanzania of 2.0 g kg^{-1}, and 22 out of the 30 soils (73%) contained N below this recommended critical value. This meant that total N in most of the soils was not enough to support good plant growth or microbial activities and therefore, its application was necessary. However, the problem of N deficiency was expected to further intensify in the future because farmers in the WUM did not apply fertilizers on their farms. Since N is one of the essential elements for plant growth, for optimum crop production in the WUM the above soil N levels required application of organic and/or inorganic fertilizers.

Soil texture

The particle size analysis showed varying contents of sand, clay and silt (Table II). The textural classes varied from sandy clay loam (47%) to clay (23%), sandy clay (16%), sandy loam (7%) and clay loam (7%). The observed textural class variabilities were attributed to the original nature of the parent material in the study area that was characterized by metamorphic rocks consisting of gneiss, schist and granite (Wickama and Mowo, 2001). The higher sand fraction in most soils of the WUM was an indication that the soils were infertile and low in most minerals subjected to weathering, such as P, Mg, K, and Ca (Table I) (Grant, 1981). In addition, studies conducted by Whitlow and Campbell (1989) in Zimbabwe showed that sandy soils were very infertile and correlated with higher risk of erosion, a fact that was also seen to be a serious problem on the steep slopes of the WUM.

Available Cu, Fe, Mn, and Zn

Available Cu in the soil ranged from 0.4 to 8.8. mg kg^{-1} (Table I). For DTPA-extractable soil Cu, 0.2 mg kg^{-1} has been considered the limit below which plants are likely to suffer from Cu deficiency (Viets and Lindsay, 1973; Lindsay and Norvell, 1978). All soils were above the proposed critical value for Cu.

Available Fe in the soil ranged from 16.0 to 86.0 mg kg^{-1} (Table II). The proposed critical level for various crops varied from 0.3 to 10 mg kg^{-1} (Lindsay and Cox, 1985). In all soils studied, Fe levels were above the proposed critical levels and hence adequate for crops grown in the WUM. Nevertheless, Fe toxicity or deficiency could occur at low and high pH, respectively.

Available Mn in the soil ranged from 3.0 to 384 mg kg^{-1} (Table II). The proposed deficiency level for Mn (DTPA) in the soil varied from 2.0 to 5.0 mg kg^{-1} with values $>$ 140–200 mg kg^{-1} regarded as excess (Silanpää, 1982). In this study two sites had excessive Mn that could lead to toxicity in crops, and one was deficient.

Available Zn in the soil ranged from 1.2 to 6.8 mg kg^{-1} (Table II). The proposed deficiency level for Zn (DTPA) in the soil was 0.4–0.6 mg kg^{-1} and values greater than 10–20 mg kg^{-1} were regarded as excess (Silanpää, 1982). At all sites Zn levels in the soil were adequate.

CONCLUSIONS

The preliminary survey of 30 sites conducted in WUM in reference to the critical levels established by research in other areas showed important variations in soil nutrients. The results suggested that the major soil fertility constraint was P deficiency followed by inadequate N. Magnesium, K, and Ca also appeared limiting in some soils. A few soils were found to contain exchangeable Al, and metallic micronutrients (Cu, Fe and Zn) were adequate in all soils. Two sites had excessive Mn that could lead to toxicity in crops, and one was Mn deficient. Overall, these results have a clear implication for crop production in the WUM. In locations where mineral nutrients were found to be deficient, measures to correct the problem should be undertaken. This calls for participatory research interventions such as the use of nutrient stress tolerant crop varieties, farmyard manure, organic manure, inorganic fertilizers or combinations of all. Other strategic activities aimed at combating soil erosion must also be in the agenda. If such initiatives are neglected, the state of the soil that remains after nutrient mining will further grow to an acute stage whereupon its reverse might be very expensive.

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