



# Enhancing Dissemination of Soil and Water Research Outputs of SADC Universities



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## **Introduction**

Lack of information of appropriate soil and water management practices is a major factor limiting sustainable crop production amongst smallholder farmers in sub-Saharan Africa. Considerable research on soil and water management has been conducted by universities, national research organisations, CGIAR centres and non governmental organisations. Although some of the work has been published in national, regional and international journals and books, most of it remains unpublished - grey literature. Access to published information by extension workers, researchers and stakeholders is also limited. In addition most of the information is not written in a user-friendly manner to extension workers and farmers. Therefore there is need to provide a forum to publish grey literature which continues to pile up in many organisations so that it can be easily accessed by different stakeholders.

The linkage between research, extension and farmers is weak within SADC countries, and the linkage across countries almost non existent. The latter implies that soil and water practices developed in one country cannot be applied to similar agro-ecological and socio-economic conditions in other countries within SADC, a development that would result in major savings in financial resources meant for research. There is, therefore, need to deliberately enhance networking between universities at lecturer, student and even technician level to enable counterparts to share experiences.

It is in recognition of these that a workshop was organised to bring together Agricultural Research and Extension experts to review existing soil and water management information in the SADC region and package it in a form useful and easy to find by stakeholders. Target beneficiaries comprised university lecturers, students, Agricultural Extension workers, civil society organisations, private sector and smallholder and commercial farmers and the wider scientific community. Universities will benefit from increased visibility which, it is hoped will provide an advocacy tool for resource mobilization and increased participation in development processes in the region. By such networking through information-sharing, universities will be able to reduce duplication of research and development activities. Regional governments and their people will in the long term benefit from increased food security, greater economic growth, ecosystem health and reductions in land degradation and environmental damage.

This publication is a compilation of scientific papers reviewed in the Information-sharing workshop on “Enhancing Dissemination of Soil and Water Research Outputs of SADC Universities” held in Lilongwe, Malawi on 12-13 September 2010.

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# VALUATION OF AMELIORANTS FOR CORRECTING SOIL ACIDITY IN AN ACID SWAZILAND SOIL

G. N. Shongwe<sup>1</sup> and P Maseko<sup>2</sup>

## ABSTRACT

Soil acidity is a major limiting factor for agricultural production in many parts of the world and more particularly in the tropics and sub-tropics where the soils are extremely acid in reaction. The application of lime to acid soils is a commonly recommended agronomic practice to remove the acid-infertility factors. However, the beneficial effect of liming acid soils on phosphorus availability to plants has been brought to question in recent years. This is due to the inconsistent results often obtained where liming either increases, has no effect or decreases the availability of phosphorus to plants through a decrease in P concentration in the soil solution. Such observations were made in soils with high levels of exchangeable aluminium. The objective of this study, therefore, was to find the best liming material for correcting soil acidity in Swaziland soils on hypothesis that a combination of lime and manure is a better liming material than either amendment alone.

Greenhouse and laboratory studies were conducted using one acid soil collected from the experimental farm at Nhlanguano Research Station. The soil was collected from the top 0- 15-cm depth, air-dried and pulverized to pass through a 4 mm sieve for the greenhouse experiment and 2 mm sieve for the laboratory study. The soil received a fertilizer dressing of 500 kg of 2:3:2 (38 per hectare and five liming materials at three rates of application. The liming materials included cattle manure, dolomitic limestone, gypsum and a combination of cattle manure and lime as well as gypsum combined with cattle manure. The liming materials were applied at the following rates: cattle manure, 0, 15 and 30 t/ha; dolomitic lime, 0, 1.06 and 2.12 t/ha; gypsum, 0, 1.12, and 2.24 t/ha and cattle manure combined with dolomite and gypsum at the rates indicated above. After mixing, the soil samples were added by volume into circular plastic pots 15-cm in depth, twenty centimeter top diameters with 15-cm bottom diameters and tapped three times on the work bench and leveled to within 3 cm of the top. Twelve maize seeds (SC 701 hybrid seed) were planted in each pot and were thinned to three plants per pot two weeks after seedling emergence. The maize plants were allowed to grow for forty-five days. After harvesting, the plant material was dried at 65 C for seven days and weighed. The plant material was then ground and analysed for macronutrients as well as micronutrients using standard procedures.

In the laboratory experiment, 100-g soil samples were treated with five rates of each liming material. Manure was applied at the rates ranging from 0 to 30 t/ha, lime at the rates of 0 to 2.12 t/ha and gypsum at the rates of 0 to 2.24 t/ha and the combinations. The soil samples were incubated for 30 days under laboratory conditions. Thereafter, the soil samples were subjected to chemical analysis including soil pH, exchangeable Al, Ca, Mg, and K, extractable Zn and plant-available P.

In this experiment, dry matter yield was found to be higher in the manure treatment followed by lime and gypsum treatments respectively compared to the control. A combination of manure and any of the other treatments did not give higher dry matter yield than the manure only treatment but much higher yield compared to the control. The dry matter yield as influenced by the treatments was highly significant ( $P < 0.01$ ) compared to the control treatment. The total nutrient uptake was higher in all the treatments compared to the control. Total P uptake by the maize plants was higher in the manure as a single treatment than in the other treatments but the combination of manure and gypsum gave the highest total P uptake.

The laboratory data showed that cattle manure had a positive effect of soil acidity. There was both a significant increase in pH and decrease in exchangeable Al ( $P < 0.01$ ) upon the application of manure and lime as single treatments. However, a combination of manure and lime gave the greatest increase in pH and decrease in exchangeable Al. Cattle manure proved to be an important source of micronutrients where the content of micronutrients in the soil after manure application was above the sufficiency level. Therefore, cattle manure plus lime is a better liming material than either material alone.

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## INTRODUCTION

Soil acidity is considered a major limiting factor for agricultural production in many parts of the world and more particularly in the tropics and subtropics where the soils suffer from extreme soil acidity (Kamprath, 1985; Sanchez, 1976). Soil acidity controls the solubility of essential plant nutrients and thus nutritional disorders as well as possible toxicities of some elements including  $\text{Al}^{3+}$ ,  $\text{Mn}^{2+}$  and  $\text{H}^+$  (Kamprath and Foy, 1972). Aluminium toxicity has been singled out as the main culprit responsible for poor plant growth in acid soils with pH values less than 5.0 and where Al saturation is high (Foy, 1984; Farina *et al.*, 1980). Swaziland has more than a fair share of acid soils where the Highveld and Middleveld ecological zones are dominated by soils with extreme acidity (Jones, 1977; Shongwe, 1994; Jones and Murdoch, 1965; Mhlungu, 2006; Bulunga, 2006). Therefore, plant growth in these regions may be adversely affected by this soil condition.

The application of dolomitic limestone to acid soils in Swaziland has been shown to increase crop yields (Jones, 1977; Mhlungu, 2006; Shongwe, 1994). The application of lime to acid soils can stimulate plant growth by eliminating toxicities more particularly  $\text{Al}^{3+}$  and  $\text{Mn}^{2+}$  toxicity (Adams, 1984). Joann *et al.* (2000) reported that crop production on acid soils can be improved by the application of lime to increase the pH to near neutral. Barker (1999) emphasized the importance of proper mixing of the lime with the soil to realize the full benefit of liming.

In similar work, the application of gypsum to such soils has been shown to ameliorate the phytotoxicity of  $\text{Al}^{3+}$  (Horst, 2002; Farina *et al.* (2001). Farina *et al.* (2001) reported that gypsum was more effective in correcting subsoil acidity to a depth of 0.75m than lime. The authors further observed that even the highest rate of lime application had minimal effects on soil acidity below the depth of incorporation. However, White (2006) holds the view that gypsum has no value as a liming material despite the over whelming evidence in the literature that gypsum corrects soil acidity. According to Nguyen *et al.* (2001) the application of lime and gypsum to an acid soil in Hawaii reduced the toxicity of  $\text{Mn}^{2+}$  in the soil solution. The authors also found that a combination of lime and gypsum was more effective in correcting soil acidity than either amendment alone.

While lime application to acid soils has shown significant increases in crop yields, however, the beneficial effects of liming acid soils has been brought to question in recent years. This is due to the inconsistent results often obtained where lime either increases, has no effect or decreases the availability of phosphorus to plants through a decrease in the concentration of P in the soil solution (Friesen *et al.*, 1980; Haynes and Ludecke, 1981; Amarasiri and Olsen, 1973). Raising the pH of an acid soil with exchangeable  $\text{Al}^{3+}$  content above  $2 \text{ mmol kg}^{-1}$  soil ( $0.6 \text{ cmolc kg}^{-1}$ ) results in the reduction of the solubility of phosphorus in the soil solution between pH 4 and 6 (Haynes, 1982). Curtin and Syers (2001) reported decreases in both water-extractable and Olsen bicarbonate extractable P after lime application. The authors took the view that the lime induced decreases in extractable P were attributed to enhanced P adsorption following lime application. Even though the adsorption of P in acid soils has been shown to be correlated with many factors including Al, Fe, oxides, clay content and percent carbon (Syers *et al.*, 1971; Lopez-Hernandez and Burnham, 1974; Juo and Fox, 1977), the decrease in P solubility between pH 4.0 and 6.0 is attributed

mainly to  $\text{Al}^{3+}$ . Miles and Farina (1986) reported that liming some acid soils to pH values near 5.0 resulted in significant decreases in the amount of P extracted by three reagents the authors evaluated. They further reported that the amount of extractable P was at a minimum between pH 5.0 and 5.5. In a similar study Shongwe (1992) reported the same observations where P extracted by three reagents that are commonly used as indices for plant-available P, decreased with increasing pH of each soil from acid to neutral. In all these acid soils, the content of exchangeable  $\text{Al}^{3+}$  was above  $2.0 \text{ mmol kg}^{-1}$  soil ( $0.6 \text{ cmolc kg}^{-1}$ ). These findings raise a lot of concern with respect to acid tropical and subtropical soils which are very acid and are often limed to pH values around 5.5 where apparently the solubility of P is at a minimum.

While soil acidity has traditionally been ameliorated by the application of lime or gypsum, available evidence indicates that animal manure can also correct soil acidity. Joann *et al.* (2000) reported that animal manure amended soils had significantly higher pH than the unamended ones. The authors further observed that the highest rate of manure application increased the pH of the soils from 4.8 to 6.0. The authors noted that the manure amendment also increased the content of some macronutrients and that, in particular, the contents of P and K were three to four times higher at the highest rate of manure application compared to the control. The authors also noted a slight decrease in extractable Al and Fe after manure application. Tang *et al.* (2007) evaluated the effect of feedlot manure and poultry litter on soil pH and found that these organic amendments increased soil pH and reduced exchangeable  $\text{Al}^{3+}$  in the soils studied. In similar investigations, Cong and Merckx (2005) reported that the application of green manure to an acid soil increased the soil pH to between 5.6 and 6.1 while oxalate extractable  $\text{Al}^{3+}$  declined to almost zero during the 49-day incubation period. You *et al.* (2007) reported that the decomposition of organic residues causes a transitory increase in soil pH that can have contradictory effects on phosphate adsorption. The authors were of the opinion that if the increase in pH increases negative charges on Al and Fe oxide surfaces, less phosphate adsorption is expected. But if the increase in soil pH leads to enhanced hydrolysis of hydroxyl-Al associated with organic matter, more phosphate adsorption may occur. It is believed that lower molecular weight organic acids and soluble humic and fulvic acids released during the decomposition of organic residues reduce the adsorption of added phosphate by competing for binding sites on soil colloids as well as complexation of  $\text{Al}^{3+}$  (Sibanda and Young, 1986; Bhatti *et al.*, 1998; Haynes and Mokolobate, 2001).

The objective of this study, therefore, was to find the best liming material for correcting soil acidity in Swaziland soils on hypothesis that a combination of lime and manure is a better liming material than either amendment alone in soil with high levels of exchangeable  $\text{Al}^{3+}$

## **MATERIALS AND METHODS**

### **Soil and Manure used in the Study**

The soil used for the greenhouse and laboratory studies was a surface soil collected at a 0-15 cm depth from Nhlangano Agronomy Research Farm, Ministry of Agriculture and Cooperatives, where maize grew poorly due to low pH and Al toxicity (Mhlungu, 2006). The cattle manure was collected from a cattle kraal at Mafutseni. The soil was air-dried and passed through a 4-mm sieve while the soil sample for the laboratory

study was passed through a 2-mm sieve and analysed for the basic properties of the soils including exchangeable Al using standard methods. Soil pH was measured in a 1:2 soil/solution ratio (McLean (1982). Exchangeable Ca, Mg and K were extracted by 1 N NH<sub>4</sub>OAc at pH 7.0 (Lanyon and Heald, 1982) while P was extracted following the method proposed by Olsen and Sommers (1982).

Exchangeable Al was extracted as proposed by Barnhisel and Berstch (1982). The manure was treated in a similar manner. The pH of the manure was measured as outlined above for the soil samples. The content of Ca, Mg, K, Zn, Fe, and P in the manure was determined following the wet digestion method (Melsted, *et al.*, 1969).

## **Soil Treatments**

### **(a) Greenhouse experiment**

The study soil was divided into five twelve kg-samples where each received a basal fertilizer application at the rate of 500 kg/ha 2:3:2 (38). The soil samples were then amended with three liming materials which were cattle manure, dolomite and gypsum. The soil samples were also amended with a combination of manure and lime, and manure and gypsum. The manure was air-dried and ground to pass through a 2-mm sieve before addition to the soil samples. The application rates for cattle manure were 0, 15 and 30 t/ha, for lime 0, 1.06 and 2.12 t/ha while for gypsum were 0, 1.4 and 2.4 t/ha. These liming materials were mixed thoroughly with the soil in preparation for potting.

Brown circular plastic pots, fifteen centimetres in depth, twenty-centimetre top diameters with fifteen-centimetre bottom diameters were used in this study. The soil samples were added to each pot by volume. Each pot lined with a filter paper at the bottom was filled with soil and gently packed by tapping three times on a metal bench and leveled to within 3 cm of the top and weighed. Thirty pots were placed on each metal bench in a randomized complete block design with four replications. Twelve maize seeds variety SC 701 (hybrid) were planted in each pot. Each pot was watered using deionised water by capillary action where water was added on the saucers. Ninety to 100% seedling emergence occurred four days after planting. The greenhouse was not equipped with a temperature control system except for two large fans and running water along one wall which were used to minimize the effects of high temperatures. The water content in each pot was maintained close to field capacity by making sure that there was always water in the saucers. The seedlings were thinned to three per pot fourteen days after seedling emergence. The plants were grown for forty-five days.

The maize plants were harvested 45 days after seedling emergence by cutting each plant at the soil surface, cut into smaller pieces and put into brown paper bags. The plants were dried using a draft oven at 72° C for seven days. The plant material was then weighed and ground in a Christy and Norris Laboratory Mill fitted with a 2-mm sieve. The content of macronutrients and micronutrients of interest were determined using the wet digestion procedure. The amount of Ca, Mg, Zn Fe and Cu in the plant extracts were measured by atomic absorption spectrophotometry using a Varian Techtron Atomic Absorption Spectrophotometer (Model AA 20) at appropriate wavelengths for each element. Potassium was measured by flame photometry using a

Jenway Flame Photometer (model PFP7). Phosphorus was measured by a Biochrom Spectrophotometer (model Libra S12) at a wavelength of 730 nm. The contents of the elements were expressed as a percentage of the dry matter yield.

### (b) Laboratory experiment

In the laboratory experiment, 100-g soil samples were used. Each of the liming materials was applied at five levels. Cattle manure was applied at the rates of 0, 7.5, 15, 22.5 and 30 t/ha and lime at the rates of 0, 0.53, 1.06, 1.59 and 2.12 t/ha while gypsum was applied at the rates of 0, 0.6, 1.2, 1.8 and 2.4 t/ha. The soil samples were also treated with a combination of lime and gypsum with manure at the rates indicated above. After the treatments, the soil samples were incubated for 30 days with the moisture content kept at field capacity for the duration of the incubation period. After the incubation period the soil samples were oven-dried and pulverized to pass through a 2 mm sieve and subjected to chemical analyses. The contents of exchangeable Ca, Mg and K were determined following the methods recommended by Lanyon and Heald (1982), and exchangeable Al was determined following the method outlined by Barnhisel and Berstch (1982). The soil pH was determined by a modification of the method proposed by McLean (1982) and plant-available P was determined by the method proposed by Olsen and Sommers (1982). The amount of extractable Zn, Cu and Fe was determined by the method proposed by Baker and Amacher (1982).

The contents of Ca, Mg, K, Zn Cu, and Fe in the extracts were measured by atomic absorption spectrophotometry using a Varian Techtron Atomic Absorption Spectrophotometer (model AA 200) at the appropriate wavelength for each element. Potassium was measured by flame photometry using a Jenway Flame Photometer (model PFP7). Plant-available P was measured calorimetrically using a Biochrom Spectrophotometer (model Libra S12) at a wavelength of 730nm. Aluminium was determined by titration against a 0.01 M NaOH solution. The contents of Ca, Mg K and Al were expressed in cmolc kg<sup>-1</sup> soil and extractable Zn, Cu and Fe and plant-available P were expressed in mg kg<sup>-1</sup> soil.

## RESULTS AND DISCUSSION

The chemical properties of the soil and manure used in this study are shown on Tables 1 and 2 below.

Table 1. Basic properties of the soil used in the study

pH <sub>CaCl2</sub>	Exchangeable cations			Available Phosphorus (mg kg <sup>-1</sup> )
	Ca	Mg	K	
4.14	0.90	0.16	0.17	13.3
	1.42			

The soil has a low pH and high exchangeable Al. The content of the exchangeable cations Ca, Mg and K and plant-available P are below the sufficiency level (Table 1).

Table 2. The properties of manure used in the study

pH <sub>H2O</sub>	Content of cations					Content of Phosphorus (%)
	Ca	Mg	K (%)	Fe	Zn	
8.39	0.55	0.46	1.35	0.45	0.01	0.008

The pH of the cattle manure is very high at 8.39 as well as the content of K. The manure recorded the lowest content of P while Zn content was the lowest among the cations (Table 2).

### **Effect of amendments on maize dry matter yield**

All the amendments and the combinations significantly ( $P < 0.01$ ) increased maize dry matter yield compared with the unamended soil (Table 3). The maize plants showed the largest response to manure application compared with lime or gypsum which gave the second and third largest responses respectively. With regard to the combination of treatments, the manure plus lime treatment gave the highest maize dry matter yield compared with the manure plus gypsum treatment (Figs. 1, 2, and 3). It is worth noting the superiority of the manure treatment which gave the highest dry matter yield than all the other treatments including the combinations (Fig. 3). The data showed that there was a large advantage in combining lime and manure or gypsum and manure where dry matter yield was significantly ( $P < 0.01$ ) increased compared with these two amendments applied as single treatments (Fig. 3). There was also a significant ( $P < 0.01$ ) difference between dry matter yield and the treatments including their combinations. The high maize dry matter yield obtained with the manure only treatment, may be attributed to the capacity of the manure to increase soil pH and reduce the phytotoxicity of Al in the soil solution as well as supplying a wide range of essential nutrients (Fig.6 and Table 5). Manure increases soil pH through the neutralization of  $H^+$  ions in the soil solution by the large reserve of  $OH^-$  ions in manure as well as adsorption of  $H^+$  ions on the negative sites of organic colloids. The concentration of Al in the soil solution is reduced through complexation reactions with the various organic groups present in manure.

It is expected that the increase in dry matter yield after manure application is a result of the reactions and soil improvement cited above.

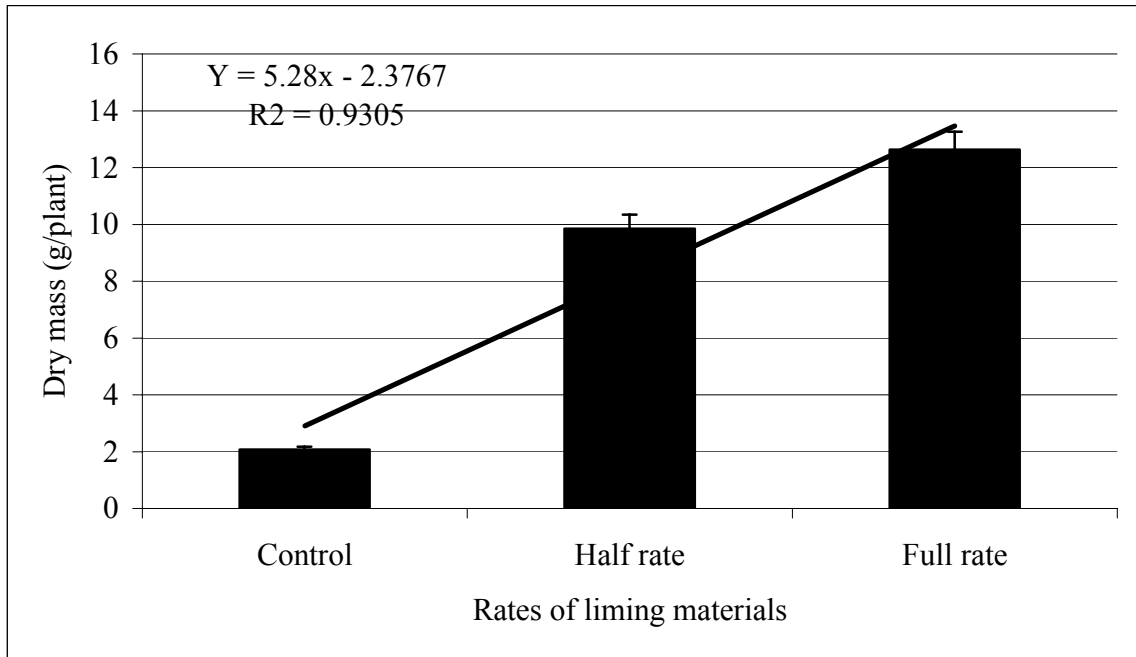


Figure 1. Dry mass (g/pot) of maize seedlings at three rates of application.

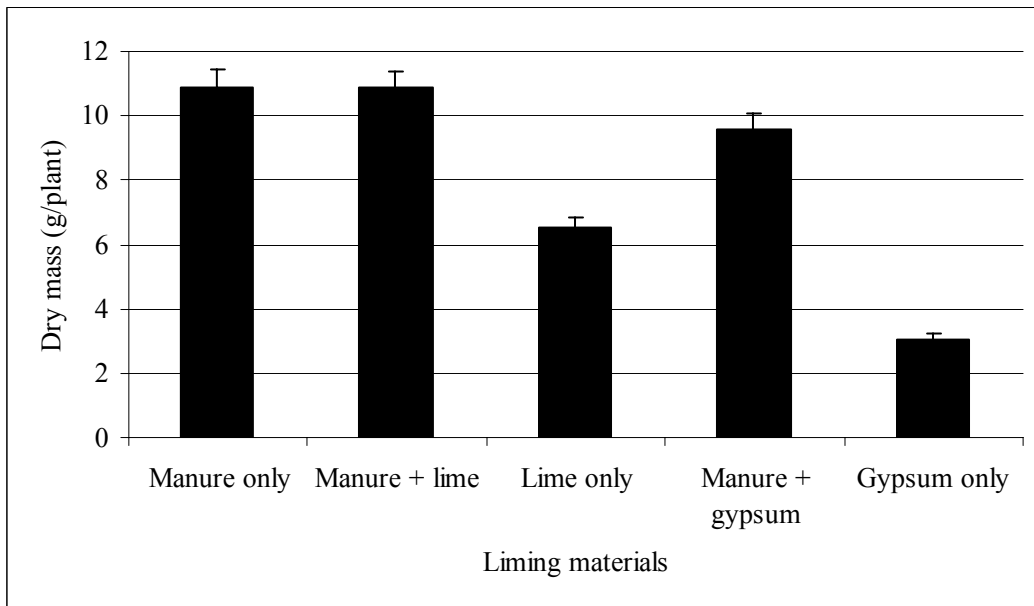


Figure 2. Dry mass (g/pot) of maize seedlings of five liming materials.

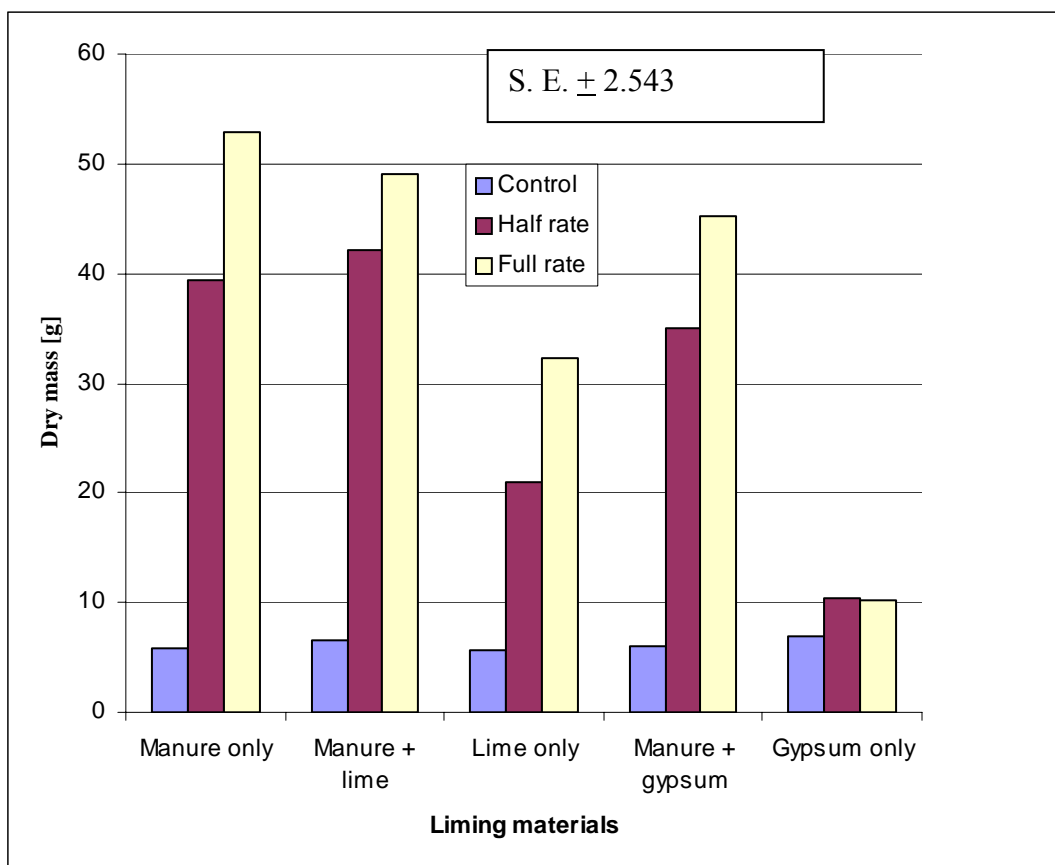


Figure 3. Dry mass of maize seedlings at five liming materials and three rates of application.

Table 3. Maximum, minimum and mean values for dry matter yield (g/pot) in the soil studied.

Treatment	Maximum	Minimum	Mean
1. Control	2.51	0.96	1.93
2. 15 t/ha manure	15.95	11.14	13.12
3. 30 t/ha manure	19.04	15.79	17.60
4. Control	2.57	1.40	2.20
5. 15 t/ha manure + 1.06 t/ha lime	15.48	12.32	14.04
6. 30 t/ha manure + 2.12 t/ha lime	21.18	13.96	16.35
7. Control	2.44	1.32	1.90
8. 1.06 t/ha lime	7.91	5.11	5.88
9. 2.12 t/ha lime	14.84	8.27	10.74
10. Control	2.37	1.83	2.03
11. 15 t/ha manure + 1.2 t/ha gypsum	13.96	10.21	11.65
12. 30 t/ha manure + 2.4 t/ha gypsum	17.71	12.24	15.07
13. Control	3.06	1.73	2.29
14. 1.2 t/ha gypsum	4.38	2.34	3.48
15. 2.24 t/ha	5.79	1.78	3.41

## Effect of amendments on nutrient uptake

Similarly with total nutrient uptake, it was observed that the uptake of the elements measured in this study was enhanced to a greater extent by the application of all the three amendments including the combinations compared to the control. Total P uptake was higher in the manure as a single treatment compared with either the lime or gypsum as single treatments. However, the highest P uptake by the maize plants was obtained with the manure plus gypsum treatment combination than the manure plus lime combination (Table 4). The data indicate that manure enhanced the availability and uptake of P by the maize plants most probably through complexation of the soil materials responsible for its fixation (Al, Fe Mn), by blocking of P fixing sites on oxide surfaces by the organic acids in manure thus increasing its concentration in the soil solution or it contained available forms of P which were easily accessible to plant roots. The higher uptake of P in the manure and gypsum combination, may be due to the  $\text{SO}_4^-$  anion which may have improved plant health and thus better uptake of nutrients or this anion competed with P for adsorption sites thus resulting in more P in the soil solution. A number of workers have reported that cattle manure contains up to 84% inorganic P which is readily available to plants (Dou *et al.*, 2000). This may explain the enhanced P uptake upon manure application obtained in this study. Xiyang *et al.* (2008) reported P increases ranging from five to twelve times in the manured plots compared with the un-manured control plots. Akhtar *et al.* (2005) reported that  $\text{NH}_4\text{Cl}$ -extractable P in 0-15-cm manured soil was five times higher than in the un-manured control. These authors attributed the rather wide range of results to both the number of years and rates of manure application. The uptake of K by the maize plants was just as dramatic as that of P. The application of manure enhanced greatly the availability and uptake of K by the maize plants where K uptake was more than three times compared with the unamended soil (Table 4). The manure must have had a high content of available K. Again the positive influence of manure on nutrient availability has been demonstrated. The same trend was obtained with the uptake of Ca, Mg and Zn by the maize plants (Table 4).

Table 4. Total nutrient uptake by maize plants (mg/pot)

Treatment	P	K	Ca	Mg	Zn
1. Control	12.18	152.78	7.05	5.58	0.86
2. 15 t/ha manure	59.23	523.81	46.48	56.17	5.21
3. 30 t/ha manure	73.80	801.85	51.44	89.02	5.53
4. Control	14.49	193.88	4.06	5.82	0.99
5. 15 t/ha manure + 1.06 t/ha lime	74.51	572.51	45.67	80.63	5.88
6. 30 t/ha manure + 2.12 t/ha lime	77.67	737.98	47.59	95.42	3.82
7. Control	9.63	166.10	4.01	4.72	0.87
8. 1.06 t/ha lime	36.36	404.40	25.78	29.26	3.60
9. 2.12 t/ha lime	52.91	355.44	53.87	78.16	3.65
10. Control	13.46	200.80	3.84	5.19	0.99
11. 15 t/ha manure + 1.2 t/ha gypsum	77.44	487.70	70.20	70.79	5.93
12. 30 t/ha manure + 2.4 t/ha gypsum	79.04	661.69	124.06	71.93	5.00
13. Control	16.93	188.96	11.45	6.85	0.61
14. 1.2 t/ha gypsum	25.16	258.58	17.98	8.15	1.66
15. 2.4 t/ha gypsum	26.82	265.56	24.20	6.90	1.99

## **Effect of Amendments on soil pH, Aluminium and Phosphorus concentrations in the soil after incubation**

As single treatments, manure and lime significantly increased ( $P < 0.01$ ) soil pH compared with the unamended control (Table 5). The recommended rate of lime application increased soil pH to 4.56 while the highest rate of manure application increased the soil pH to 4.45 (Table 5). However, a combination of manure and lime at the highest rate of application increased soil pH to 4.90 which is higher than the values obtained when these amendments were applied as single treatments. The increase in pH with gypsum application was not significant compared with the control. Even though manure and lime applied as single treatments or in combination increased soil pH, they failed to raise the pH to the minimum of 5.5 recommended for optimum growth of most crop plants in acid tropical and sub-tropical soils. The increase in soil pH with lime application is due to the neutralization of  $H^+$  and  $Al^{3+}$  ions. In the case of manure, this amendment contains humic and fulvic substances which include carboxyl, phenolic and alcohol groups. These organic groups are known to consume or release protons depending on the pH of the soil. It is possible that the increase in pH with the application of manure to the acid soil studied may be explained by proton exchange between the soil and the manure added.

The unamended soil contained  $1.40 \text{ cmolc kg}^{-1}$  exchangeable Al (Table 5). Lime and manure amendments significantly decreased ( $P < 0.01$ ) the content of exchangeable  $Al^{3+}$  compared with the control while the gypsum treatment had very little effect on the content of this element. Manure alone decreased the content of Al from  $1.40 \text{ cmolc kg}^{-1}$  soil in the control to  $0.67 \text{ cmolc kg}^{-1}$  soil at the highest rate of application. Lime reduced the Al content to  $0.97 \text{ cmolc kg}^{-1}$  while gypsum decreased the Al content to  $1.13 \text{ cmolc kg}^{-1}$  soil. The greatest decrease in the content of Al was obtained with the combined treatment of manure and lime at the highest rate of application of each amendment where the Al content was decreased to a low of  $0.37 \text{ cmolc kg}^{-1}$  soil. The data indicate that as single treatments the amendments decreased Al content by 52%, 30.7% and 19% for manure, lime and gypsum treatments respectively. However, the combination of manure and lime treatment decreased the content of Al by 73.5%. The value of manure in reducing the concentration of Al in an acid soil has been demonstrated but it seems beneficial to add lime together with manure to an acid soil for maximum benefit.

The ability of manure to decrease exchangeable Al is through complexation reactions between the various organic groups in manure and Al in the soil solution resulting in the formation of an Al-Organic matter complex as well as neutralization reactions involving  $OH^-$  ions contained in manure. Lime reduces exchangeable Al through neutralization reactions which form  $Al(OH)_3^0$  solid while gypsum reduces Al through the formation of an aluminium sulphate solid ( $Al_2(SO_4)_3$ ).

All three amendments significantly increased ( $P < 0.01$ ) the concentration of phosphorus in the soil compared to the control treatment (Table 5). Manure as a single treatment increased the P content to  $63 \text{ mg kg}^{-1}$  soil while lime and gypsum increased the P content to only 47 and 53  $\text{mg kg}^{-1}$  respectively. Manure as a single treatment did better in increasing phosphorus concentration than the other amendments. It was also noted in this study that manure combined with lime or gypsum did not increase

the P content beyond 63 mg kg<sup>-1</sup> soil obtained with manure as a single treatment. The increase in P concentration with manure addition may be due to organic groups in manure which may have reacted with Al, Fe and Mn ions thus preventing the precipitation of P or the organic acids blocked some of the sites responsible for P fixation in soils. The manure itself may have supplied the P to the soil as it is a source of a wide range of essential elements including P. The lime influenced P concentration probably through the precipitation of elements responsible for P fixation and also through ligand exchange between H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and OH<sup>-</sup> ions in lime as well as competition between H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and OH<sup>-</sup> for adsorption sites in soils. Gypsum may also had a similar effect where the SO<sub>4</sub><sup>2-</sup> ion formed a precipitate with Al<sup>3+</sup>, (Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>)<sup>0</sup>, thus preventing the precipitation of P or the SO<sub>4</sub><sup>2-</sup> may have replaced P from the surfaces of oxides of Fe and Al through ligand exchange reactions. These reactions may explain the increase in P concentration in the soil with the application of the amendments. However, it was noted in this study that an increase in the rate of lime application resulted in a decrease in the content of P in the soil studied (Table 5).

Table 5. Soil pH, Aluminium and Phosphorus concentrations measured after 30 days incubation period

Treatment	pH	Exchangeable Al .....cmolc kg <sup>-1</sup> .....	Available P ...mg kg <sup>-1</sup> ..
1. Control	3.95	1.40	28
2. 7.5 t/ha manure	4.17	1.05	45
3. 15 t/ha manure	4.20	0.94	56
4. 22.5 t/ha manure	4.37	0.83	58
5. 30 t/ha manure	4.45	0.67	63
6. 7.5 t/ha manure + 0.53 t/ha lime	4.20	0.89	50
7. 15 t/ha manure + 1.06 t/ha lime	4.56	0.68	50
8. 22.5 t/ha manure + 1.59 t/ha lime	4.67	0.48	62
9. 30 t/ha manure + 2.12 t/ha lime	4.90	0.37	63
10. 7.5 t/ha manure + 0.6 t/ha gypsum	4.05 4.20	1.27 1.06	50 53
11. 15 t/ha manure + 1.2 t/ha gypsum	4.36 4.46	0.78 0.72	61 56
12. 22.5 t/ha manure + 1.8 t/ha gyps	4.01 4.12	1.30 1.17	47 45
13. 30 t/ha manure + 2.4 t/ha gypsum	4.17 4.56	1.09 0.97	45 42
14. 0.53 t/ha lime	3.91	1.34	42
15. 1.06 t/ha lime	3.92	1.13	48
16. 1.59 t/ha lime	3.96	1.22	50
17. 2.12 t/ha lime	3.94	1.24	53
18. 0.6 t/ha gypsum			
19. 1.2 t/ha gypsum			
20. 1.8 t/ha gypsum			
21. 2.4 t/ha gypsum			

## CONCLUSION

Under the conditions of this study and the soil used, it was found that all the liming materials significantly increased soil pH, maize dry matter yield and uptake of all the nutrients measured (P, K, Mg Ca, and Zn). These liming materials also significantly reduced exchangeable Al in the soil after 30 days incubation. A combination of lime and manure at the highest rate of application was found to be a better liming material than either amendment alone where the pH was raised from 3.95 to 4.90 and exchangeable Al reduced from 1.40 to 0.37 cmolc kg<sup>-1</sup> soil. However, total P uptake was higher in the manure and gypsum treatment combination compared to the other treatments either alone or in combination.

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# CONTENTS OF HEAVY METALS IN COAL AND ITS BY-PRODUCTS FROM THE SONGWE-KIWIRA MINE, TUKUYU DISTRICT, TANZANIA

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## ABSTRACT

Coals can be potent sources of heavy metal pollution upon their mining and utilisation. While Tanzania has many coal deposits, the coals have not been evaluated to determine their heavy metal contents and their potential to cause environmental pollution. Therefore, a study was undertaken to determine the heavy metal contents of the coal and its by-products from the Songwe-Kiwira mine, Tukuyu district, southern Tanzania. This is the area in the country where, currently, coal is being mined. The contents of lead (Pb), copper (Cu), chromium (Cr), cadmium (Cd), zinc (Zn), selenium (Se), and manganese (Mn) in different coal grades, in coal combustion by-products, and in various coal-derived sediments were determined by atomic absorption spectrophotometry (AAS) following aqua-regia digestion. The results showed the presence of heavy metals in the Kiwira coal. The highest levels of metals recorded in the different grades of coal were 6.8, 4.7, 7.9, 35.1, 72.4, 58.9, 59.5 and 801.1 mg/kg for Cr, Ni, Cd, Pb, Zn, Cu, Se and Mn, respectively. Long-term disposal of these coals will result in pollution of the surrounding environment. Some metal (Zn, Cr, Mn, Pb, Cd) levels in the coal indicated significant ( $p = 0.05$ ) differences with coal sampling periods, an indication that the metal contents of the Kiwira coal were not uniform along the coal seams or layers. The highest levels in the solid ash were 6.4, 5.2, 9.4, 33.3 and 60.4 mg/kg for Cr, Ni, Cd, Pb and Se, respectively. The highest levels for the fly ash were 7.1, 4.5, 10.8, 90.9 and 45.4 mg/kg, for Cr, Ni, Cd, Pb and Se, respectively. Long term accumulation of these metals will cause environmental pollution. Results showed variations in metal contents between the coal grades, its combustion by-products as well as between the sampling periods.

Key words: coal by-products, coal grades, heavy metals, Kiwira, sampling periods, Tanzania.

## INTRODUCTION

Tanzania is endowed with vast deposits of coal, mainly in the southern part of the country (Harris 1961), with minor deposits also known in other areas. In Tanzania, coal is presently mined only at the Songwe-Kiwira deposit, Tukuyu district, in the south-western part of the country. There is also a small, operational colliery at Ilima, only several kilometres away from the Songwe-Kiwira mine. The coal from Songwe-Kiwira is of the bituminous type, with about 1.5% sulphur, 16.8% ash, and with low levels of methane and other gases (Brian 1995).

The coal mined from Kiwira is sold for use in some industries within the country, e.g. the Mbeya Cement factory, and some of it is used onsite to generate electricity for the mining community at Kiwira, with the extra power so produced fed to the national electric power distribution grid. The mine at Kiwira has a design capacity for producing 150,000 tonnes of raw coal per year (Brian 1995), but currently produces about 108,000 tonnes (Dwasi; Simkoko, personal communications, 1998). At the design capacity, coal mining there will last for 65 years. As already pointed out, there are undeveloped coalfields in other localities within the southern part of the country. If the coals should

contain high concentrations of heavy metals, substantial quantities of these metals would be released to, and would thus pollute, the environment when the coal is exploited and used. Such pollution has been reported upon exploitation of coals in other countries (Bolton *et al.* 1975).

The waste products of coal combustion are solid ash and fly ash. The ashes so produced at Kiwira, and the waste coals left behind following the washing of raw coal prior to its combustion, are disposed of on an open waste heap or dump within the mining-processing complex. At the dumping site, the lighter components of these wastes together with the heavy metals they may contain are open to blowing by winds and, eventually, may cause environmental (soil, water, air, and vegetation/crops) pollution upon deposition and accumulation in the surrounding areas.

One problem associated with mining and processing of coal is that these activities lead to environmental pollution. Among the pollutants generated by coals are heavy metals. This is because the heavy metals, such as cadmium (Cd), nickel (Ni), chromium (Cr), lead (Pb), selenium (Se), arsenic (As), and copper (Cu) are usually found in coals from many countries (William and Barbara 1990), and the Kiwira coal may be no exception. The quantities of these metals vary widely between coal types. They usually also vary between mines, within a mine, and even within a single seam in a deposit (Kaakinen *et al.* 1975). Sabbioni *et al.* (1983) reported different quantities of metals in coals from different countries. For example, for coals from Great Britain, South Africa, and West Germany, the concentrations of Cr were 31.9, 140 and 17.5 mg/kg, respectively. For Se, the respective levels were 2.9, <3 and 1.5 mg/kg, while for Zn they were 57.3, 40.9, and 35.9 mg/kg.

Following combustion, the heavy metals remain in the ashes so produced: fly ash and solid ash. Fly ashes have been reported to contain higher levels of heavy metals as compared to solid ashes (Klein *et al.* 1975; Sabbioni *et al.* 1983; Lee 1984; Chen *et al.* 1997). For example, Klein *et al.* (1975) reported 1.1, 152, 6.2, 0.08, and 100 mg/kg Cd, Cr, Pb, Se, and Zn, respectively, in solid ash. The respective quantities in fly ash, on the other hand, were 8.0, 300, 80, 25, and 740 mg/kg. Continued release of such combustion wastes into the environment, with the concomitant levels of heavy metals that they may contain, will lead to heavy metal pollution of the receiving environment around the Songwe-Kiwira area and around those industries importing and using the coal. This has happened in the countries cited above, leading to closure of many such coal mining-processing operations.

So far, heavy metals have not been quantified in any of the Tanzanian coals. These coals are poised to become an important source of energy for the country in the future. Considering the need for coal exploitation for provision of energy, but also bearing in mind the potential for environmental contamination by the coals due to presence of heavy metals as has been recorded in other countries, the present study was undertaken with the objective of determining the heavy metal contents of Kiwira coal and its by-products, as proxy to possible subsequent environmental pollution, from the already operational mine at Songwe-Kiwira.

## **MATERIALS AND METHODS**

### **Location**

The Songwe-Kiwira coalfield of Tanzania lies about 32 km west of the northern tip of Lake Nyasa, in the valley of the Lower Kiwira River. The altitude in the coalfield area ranges from 600 to 1,158 metres above sea level (Harris 1961), and it is located between 8°5' and 9°5'S and 30° and 31°E. The Kiwira Coal Mine was developed in this area in 1988.

### **Sampling and chemical analysis**

Samples of different grades of coal were collected within the Kiwira coal-mining complex. The samples were taken in two sampling periods during December 1997 and January 1998. During each sampling occasion, four samples were taken in each of two consecutive days.

The freshly-mined raw coal, also called the Run of Mine (ROM), was sampled from the unloading area as the coal is brought in by rail wagons from deep in the mine. The waste and washed coal samples were taken from respective conveyer belts carrying these coal grades following the sorting and washing of the ROM coal.

The solid ash samples were taken at the ground floor of the power plant where the ash is initially deposited following combustion of the coal, prior to its eventual disposal within the Kiwira Complex compound.

The fly ash samples were collected within the boiler room of the power plant where the coal is combusted to generate steam. The fly ash settles by gravity onto the floor of the room. Immediately after sampling on the first day, the points where sampling had been done were wiped free of the remaining un-sampled fly ash, so that freshly deposited fly-ash samples would be taken from the same points the next day. The ash samples were taken in four replicates.

Sediments were sampled once, in four replicates, at the main adit leading out of the mine, and at the beginning of the drainage channels for conducting away wastewaters from the coal washing plant and the power plant.

All the samples were dried to at 100°C overnight and finely ground using a grinder in the laboratory of the Kiwira Coal Mine. The grinder was wiped clean in between the grinding of one sample and the next to avoid cross contamination of samples.

The total heavy metal contents of the ROM, waste coal, washed coal, solid ash and fly ash samples were determined at the Sokoine University of Agriculture (SUA) after aqua-regia digestion (Ure 1990; Jeng and Bergseth 1992). Into 2 g of the finely ground coal or ash sample contained in a 150 ml conical flask, 15 ml of concentrated HCl, followed by 5 ml concentrated HNO<sub>3</sub>, were added. The flask was covered using a watch glass and allowed to stand overnight. The mixture was gently boiled under reflux for two hours, and then evaporated to dryness at moderate temperatures, without being left to cake, and cooled. The residue was dissolved in 5 ml of concentrated HNO<sub>3</sub> and made up to 50 ml with distilled water. In this way, the heavy metals were finally contained in a matrix of 10% HNO<sub>3</sub>. The digests were filtered and Pb, Zn, Cd, Se, Ni, Mn, and Cu contents

determined by atomic absorption spectrophotometry (AAS), with appropriate standards prepared using the same matrix as that for the samples (i.e. 10% HNO<sub>3</sub>).

The data on heavy metal contents were analysed statistically using the completely randomized block design to evaluate the effects of coal (or by-product) grade and sampling time/date on heavy metal contents. The implication of sampling time/date is to assess the variations of heavy metals along different points on a coal seam, because sampling at different times is a reflection of sampling a different zone of the seam, which may have different levels of heavy metals as compared to other points of the seam mined previously.

## RESULTS AND DISCUSSION

### *Total heavy metal contents of different grades of coal*

The total heavy metal contents in the different grades of coal are presented in Table 1. The levels of Zn in each of the coal grades differed with period of sampling, and the highest (or lowest) level were not necessarily confined to a particular coal grade at any sampling time. There were significant differences ( $p = 0.05$ ) in the Cr, Cd, Pb and Mn contents of the coals sampled at different periods. However, the Se, Cu and Ni contents of all the three coal grades did not display significant ( $p = 0.05$ ) differences with respect to period of sampling.

Statistical analysis for comparing the coal grades revealed that some metals, namely Cr and Ni, did not display significant ( $p = 0.05$ ) differences between the coal grades at all sampling periods. For the rest of the metals, differences were observed between the coal grades during some sampling periods but not during other sampling times. For example, levels of Pb and Zn were different between the coal grades during the December 1997 sampling but not in the January 1998 period. Generally, there were variations in the contents of some metals with different sampling periods while for other metals the contents were similar ( $p = 0.05$ ) across sampling periods.

With the exception of Cd and Se, the levels of the other metals in the Kiwira coal were similar to those reported for European coals, that is within 6.4 - 260, 0.28 - 43.5, 9 - 50.7, 0.5 - 405 and 36 - 356 mg/kg for Cr, Cu, Pb, Zn and Mn, respectively (Klein *et al.* 1975; Sabbioni *et al.* 1983). The levels of Cd (0.01 - 0.56 mg/kg) and Se (0.3 - 5.1 mg/kg) in Kiwira coal were higher than those reported by Sabbioni *et al.* (1983) for coals from South Africa, implying greater potential for Cd and Se pollution from Kiwira coal.

The variations in metal contents with sampling periods, as presented in Table 1, have implications on uniformity of the metals within the beds or seams of the Kiwira coal. Differences in metal contents between different sampling times indicate that these metals were not uniformly distributed along the length and/or breadth of the seams. This was true of Zn, Cr, Mn, Pb and Cd, which showed significant ( $p = 0.05$ ) differences across sampling times. Harris (1961) reported that seams of the Kiwira coal were generally thin, contained many partings of mudstone and shale, and that the coal had all gradations between coal and shale or mudstone, implying considerable variation in the quality of the coal. Such variations seem to be displayed also in the different heavy metals in different zones of the coal seams, as indicated by the present data (Tables 1). Kaakinen *et al.* (1975) similarly reported variations in trace metal contents of coal between different mines and even within a single coal bed. The variations presently observed are

a reflection of differential concentrations of those metals in the original sediments that gave rise to the Kiwira coal. The Kiwira coal was derived from deposits of unmetamorphosed sediments of the Carboniferous-Jurassic geological time periods (Harris 1961).

This non-uniformity in metal contents in the Kiwira coal implies that the quantities of the metals in the by-products that would be left in the environment following combustion of different batches of the coal will not be the same. Therefore, continual monitoring of the heavy metal contents of the coal and its combustion by-products is necessary to be able to determine time wise metal inputs into the environment.

Therefore, continual disposal and long-term accumulation of coal and its by-products from the Kiwira coal mining and processing complex, and the associated accumulation in the environment of the heavy metals contained in these coals, will result in pollution of the surrounding environment, including water, soil and air. This may have negative human health impacts in the long term.

#### **Heavy metal contents in solid ash and fly ash sampled at different times**

The total metal contents in the two ash grades sampled in the two different time periods are shown in Table 2. The contents of Zn, Cu, Ni, Se, and Mn, both in solid ash and fly ash, were not different ( $p = 0.05$ ) between the sampling times. However, the Cr, Cd and Pb contents in both ashes differed ( $p = 0.05$ ) between the sampling periods. These variations in metal contents in the ash grades reflect, and further confirm, the non-uniform contents of these metals in Kiwira coal, as already discussed.

#### **Overall comparison of heavy metal contents between solid ash and fly ash**

A comparison of the heavy metal contents in the two types of ash is also displayed in Table 2. In the December 1997 sampling time, the contents of Cr, Ni, Cd, Se in solid ash were not significantly different ( $p = 0.05$ ) from those in fly-ash. However, Pb, Zn, Cu and Mn in solid ash were different ( $p = 0.05$ ) from those of the fly ash sampled in the same day. Similarly, some similarities as well as differences in metal contents were observed between the two ash grades sampled in the January 1998 period.

From Table 2, some heavy metal contents showed significant differences between the two ash grades. For those metals that did not exhibit significant ( $p = 0.05$ ) differences in content between the two coal grades, the metal levels in fly ash were nevertheless somewhat higher than those in the solid ash. In the case of Mn, Se and Ni, higher levels were observed in solid ash (even where the differences were not significant). On the other hand, Anders and David (1975) reported that about 68% of coal-derived Se was in the fly ash.

The data from the present study showed similar trends of variation as those reported by Sabbioni *et al.* (1983). However, the Cd levels in fly ash in the present study were much less than the 35 ppm (or mg/kg) reported by Wong and Wong (1986).

#### *Heavy metal contents of sediments of mine drainage water and washing plant and power plant wastewaters*

The total heavy metal contents of the various coal-derived sediments are given in Table 3. Some metals (Pb, Cd, Ni and Mn) showed significant ( $p = 0.05$ ) differences between

the three types of sediments, with the power plant sediments generally having the highest levels.

The high content of the metals in the power plant sediments is due to the fact that these sediments are admixed with the ashes coming out of the power plant following combustion of coal. These ashes were more enriched or concentrated with the heavy metals after coal combustion. These levels of heavy metals in these sediments would pollute the environment, including the Kiwira river that traverses the Kiwira area, if directly released without any treatment. However, these wastes are subjected to sedimentation treatment before clear water is discharged to the river. Pollution of the river by heavy metals via this clarified water would be minimal because the pH of the waters overlaying these sampled sediments, at the time of sediment sampling, was 6.7 for the mine drainage, 7.2 for the washing plant wastewater, and 10.0 for the power plant wastewater. It is presumed that these relatively high pH levels, in part, rendered the solubility of the metals to be low due to their precipitation at these high pH values. This led to the levels of the metals in these waters to be below detection using conventional flame AAS, as the precipitates settled into, and became retained by, the sediments, as was also reported by Kabata-Pendias and Pendias (1984). The other contributing factor is the fact that these samplings were undertaken during the rainy season. The rains had diluted these drainage/waste waters, contributing to the non-detection of the metals in the waters at that time period. In comparison, samples of the mine drainage at the main adit taken during the previous dry season (before dilution by the rains) contained detectable metal levels, namely 16.75 mg Se, 1.2 mg Pb, 6.3 mg Zn, 0.63 mg Cd, and 62.0 mg Mn per litre of the drainage water. The data in Table 3 was derived from only one sampling. It is conceivable that metal levels in mine drainage water sampled at different periods would result in variations similar to those observed in the case of the coal grades and coal combustion by-products, as already discussed.

### **General implications to human health**

While human health is not the subject of the research reported herein, it is instructive to point out that human exposure to high levels of heavy metals, as can be caused by pollution following the mining and processing of coal, can affect health negatively. Only a few examples are cited to here to illustrate this point. For example, Cd causes reproduction problems (WHO 1996) and is a potential carcinogen (Edmunds and Smedley 1996). Zinc can also cause problems in reproduction (Peereboom-Stegeman 1987). Lead poisoning can cause renal damage and hypertension (WHO 1996). This is why effective waste treatment and/or containment in respect of coal extraction/processing at Kiwira, as elsewhere, are important in order to minimise the extent of environmental pollution by heavy metals.

## **CONCLUSIONS**

In conclusion, the present studies have shown that the Kiwira coal, its combustion by-products, and coal-derived sediments contained substantial quantities of heavy metals, with the ashes containing generally higher contents. Therefore, indiscriminate disposal of large amounts of the coal and its by-products would, in the long-term, cause air, water and land pollution at this location and its surroundings if proper controls are not in place. This will be exacerbated by the presence of large quantities of waste coal, coal ashes and coal-derived sediments that have been disposed of, and have perennially piled up as

large mounds, within the area of the Kiwira Mine complex. The contents of the metals seem to vary along the coal seams, as indicated by variations in contents of the metals in the coals sampled at different sampling times.

## **ACKNOWLEDGEMENTS**

We are grateful for the financial support provided by the Norwegian Agency for Development Cooperation (NORAD) to the senior author, through the TAN 091 project in the Department of Soil Science at SUA. We also thank the then management of the Kiwira Coal Mine for permitting the senior author to undertake the research at their establishment.

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Table 1. Heavy metal contents in three coal grades sampled at different times.

Metal	Sampling period	ROM	Washed coal	Waste coal
Zinc	8 December, 1997	19.9c	48.1a	27.4b
	9 December, 1997	72.4a	16.1b	30.1b
	16 January, 1998	21.2c	15.6b	19.7b
	17 January, 1998	39.6b	34.0a	36.3a
Selenium	8 December, 1997	56.0a	21.6a	42.7a
	9 December, 1997	38.1a	59.5a	45.9a
	16 January, 1998	47.6a	26.3a	52.6a
	17 January, 1998	22.4a	25.4a	53.4a
Copper	8 December, 1997	22.1a	16.9a	28.4a
	9 December, 1997	27.5a	20.7a	30.6a
	16 January, 1998	58.9a	15.4a	24.2a
	17 January, 1998	26.7a	16.2a	25.6a
Chromium	8 December, 1997	6.0a	6.8a	6.2a
	9 December, 1997	3.8b	3.2b	5.0b
	16 January, 1998	5.7ab	4.3b	4.3b
	17 January, 1998	5.1ab	4.2b	3.9b
Lead	8 December, 1997	18.3b	12.8b	29.5a
	9 December, 1997	8.8c	2.4c	13.1b
	16 January, 1998	32.1a	22.6a	35.1a
	17 January, 1998	8.8c	1.5d	13.4b
Manganese	8 December, 1997	317.3a	241.1a	801.1a
	9 December, 1997	258.4a	163.5b	387.8b
	16 January, 1998	342.8a	146.9b	570.3ab
	17 January, 1998	153.0b	85.9b	247.5b
Nickel	8 December, 1997	3.3a	2.3a	4.0a
	9 December, 1997	3.3a	2.5a	3.3a
	16 January, 1998	4.7a	1.0a	2.6a
	17 January, 1998	2.9a	3.2a	3.2a
Cadmium	8 December, 1997	2.4b	3.6b	5.2b
	9 December, 1997	0.6c	0.3c	0.8c
	16 January, 1998	6.9a	6.6a	7.9a
	17 January, 1998	0.6c	0.4c	0.7c

For each metal, means within a column followed by the same letter are not significantly different ( $p = 0.05$ ) according to the Duncan's New Multiple Range Test.

Table 2. Total heavy metal contents in two ash grades sampled at different times

Metal	Sampling time	Content in solid ash, mg/kg	Content in fly-ash, mg/kg	Difference between solid ash and fly ash
Zn	8 December, 1997	28.7a	83.6a	*
	16 January, 1998	25.9a	56.9a	n.s.
Cu	8 December, 1997	23.3a	57.2a	*
	16 January, 1998	31.3a	53.5a	n.s.
Se	8 December, 1997	56.9a	39.5a	n.s.
	16 January, 1998	60.4a	45.4a	n.s.
Cr	8 December, 1997	6.4a	7.1a	n.s.
	16 January, 1998	3.9b	5.2b	*
Ni	8 December, 1997	5.2a	4.5a	n.s.
	16 January, 1998	3.5a	3.3a	n.s.
Cd	8 December, 1997	5.6b	6.1b	n.s.
	16 January, 1998	9.4a	10.8a	*
Pb	8 December, 1997	17.9b	50.4b	*
	16 January, 1998	33.3a	90.8a	n.s.
Mn	8 December, 1997	1225.3a	380.3a	*
	16 January, 1998	1198.0a	575.3a	n.s.

Means within a column, for each metal, followed by the same letter are not different ( $p=0.05$ ) between the two sampling times.

Table 3. Heavy metal contents of different types of coal sediments, mg/kg.

Heavy metal	Mine drainage sediments	Washing sediments	plant Power sediments	plant
Zinc	193.4a	87.3a	109.9a	
Copper	25.8a	26.6a	37.7a	
Lead	10.3b	20.2a	16.6a	
Chromium	3.1a	3.3a	3.2a	
Cadmium	1.3b	1.0b	2.9a	
Selenium	43.9a	51.3a	75.6a	
Nickel	5.3ab	2.5b	6.4a	
Manganese	809.1b	388.3b	4,716.7a	

Means within a row, for each metal, followed by the same letter are not different ( $p=0.05$ ) between the two sampling times.

# EFFECT OF CONSERVATIONAL TILLAGE ON SOIL LOSS AND PLANT NUTRIENT STATUS ON VEGETABLE YIELD, NORTHERN SLOPES OF ULUGURU MOUNTAINS, MOROGORO, TANZANIA

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## ABSTRACT

The study was conducted to evaluate effects of conservational tillage on vegetable production on the northeastern part of Uluguru Mountains in Tanzania. Six treatments such as control conservational tillage; conservational tillage with manure; conservational tillage with insitu composting; control traditional tillage; traditional terrace with manure and traditional tillage with in situ composting were examined. Nutrient levels were determined from soil before and after harvest and from plant samples after harvest. Soil losses were assessed by collecting runoff using polyethylene troughs for each treatment. Analysis of variance and Multiple range test ( $P=0.05$ ) was done to test the effect of the treatments. The differences ( $P=0.05$ ) on soil loss, plant nutrient status and vegetable yield were observed. All conservational treatments gave high fresh yield (4.3–44.7 ton/ha), high nutrient retention (N% 0.11–0.14, P% 5.17–16.33, K% 0.33–0.36) and experienced low soil losses (0.49, 0.54 to 0.65 ton/ha/season). While the opposite was true for traditional treatments lower fresh yield (0.9–13.9 ton/ha), low nutrient retention (N% 0.10–0.11, P% 0.91–4.00 and K% 0.29–0.32) and high soil losses (0.54, 0.83 to 1.26 ton/ha/season) at  $P=0.05$ . It was concluded from this study that the conservational tillage for vegetable production on sloping land ranging from 20 to 80 percent was the best practice resulting in increased crop yield, nutrient uptake, plant nutrient retention, and reduced soil loss.

**Key words:** *Conservational tillage, Soil loss, Traditional tillage and vegetable yield*

## INTRODUCTION

Conservation tillage is in focus of farmers and researchers who are working in areas prone to soil erosion because, in conservation tillage, crops are grown with minimal cultivation of the soil and most or all crop residues remain on top of the soil rather than being plowed or disked into the soil. New crops are planted into this stubble or in small strips of tilled soil (Peet, 2001, Sullivan, 2003). Many authors define tillage in different terms but all of them encompass many types of tillage and residue management systems. There are several definitions of conservation tillage, for example California's Conservation Tillage (CT) working group defined it as a crop production system that deliberately reduces or eliminates primary intercropping tillage operations such as plowing, disking, ripping, or chiseling, and that manages surface residues so as to permit efficient planting, pest management, and harvesting (Shresta *et al.*, 2007).

Tillage has long been a traditional agricultural system. In Tanzania fallowing and using organic matter are practices that farmers traditionally used to maintain or restore soil fertility. These practices have been used until 1950s, when the Government

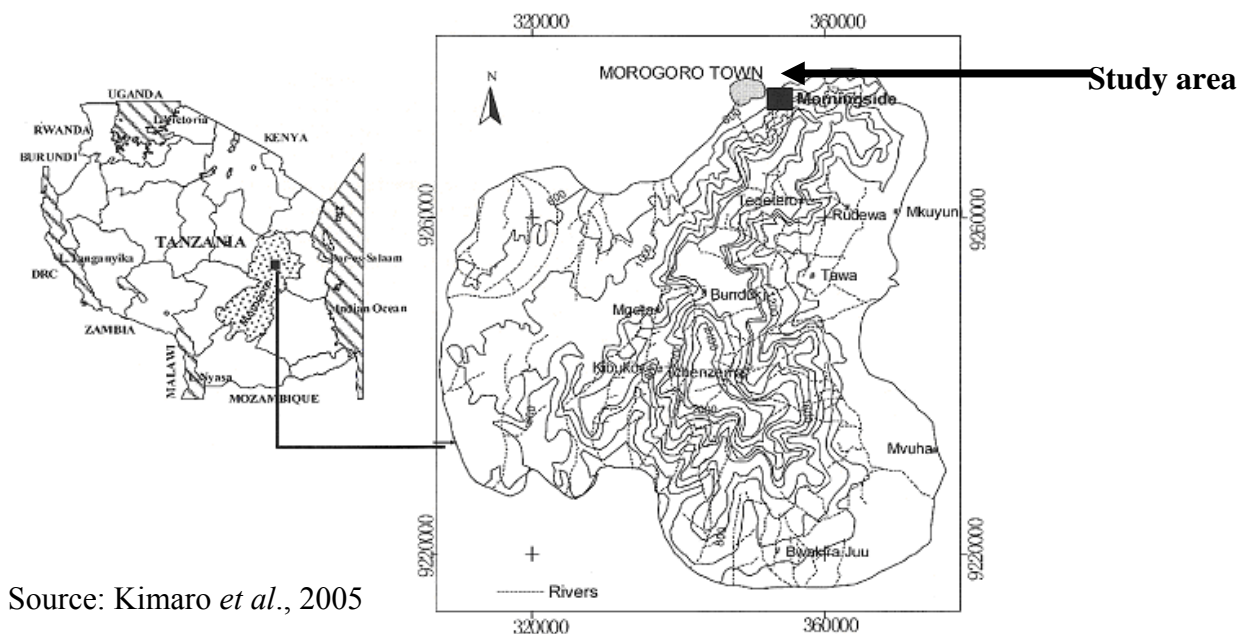
promoted soil and water conservation practices to control surface water runoff, such as stone and earth bunds, ridging, pitting, infiltration or cut-off drains, bench terraces and contours in mountainous areas (Shetto and Owenya, 2007). Many experiments demonstrated that conservation tillage generally reduces soil erosion (Leys *et al.*, 2007; Peet, 2001; Sullivan, 2003).

Tanzania recognizes that managing its natural resources sustainably needs to be an integral part of its agenda for agricultural productivity. Thus it is promoting conservation agriculture, especially in the regions that are potential in agriculture, as a combination of crop and crop–livestock production practices that make land more productive even as it improves the resilience of natural resources. Conservation agriculture is gaining recognition for its improved agricultural performance (Shetto and Owenya, 2007). Increased livestock and human activity has led to collapse of the soil conservation system and increased land degradation, thus caused compacted soils, depletion of nutrients and organic matter, low water-holding capacity and microbial activity. Strategies that aimed at combating land degradation through mechanical and biological measures: reforestation activities, agroforestry, protection of water catchments, improved land husbandry and environmental conservation in general were initiated in Tanzania in the late 1980 (Shetto, 1999). As a way to join the government efforts in addressing land degradation, Sokoine University of Agriculture initiated a Soil and Water Conservation program in Uluguru Mountain. One of its research aims was to assess the effect of conservational tillage on soil loss and plant nutrient status on vegetable yield in the project area.

## Materials and methods

### Description of the study area

The study was conducted in the northeastern part of the Uluguru Mountain between 350295E and 354368E and 9237500N and 9243697N UTM coordinates (Kimaro *et al.* 2005).



Source: Kimaro *et al.*, 2005

**Figure 1:** The location of study area

The area is dominated by metasediments mainly consisting of hornblende pyroxene granulites, with plagioclase and quartz-rich veins (Kimaro *et al.*, 2005). Based on the World Reference Base for Soil Resources (FAO, 1998), the soils on the mountain ridges are dominantly *Endoskeletal* and *Leptic Cambisols* with accessory surfaces of *Haplic* and *Chromic Phaeozems* and *Orthi-eutric Regosols*. While on the foothills the dominant soils are *Chromic Lixisols* and *Profondic Acrisols* associated with *Hyperferralic Cambisols*, and *Endoleptic Cambisols*. The soil surfaces are generally eroded. The area is mountainous comprising strongly with dissected mountain ridges and foothills with very steep slope of up to 80 percent and narrow valleys (Kimaro *et al.*, 1999).

The area is categorized as sub-humid savannah of the low latitude environment (Sharma, 1987). The mean annual rainfall varies with altitude, from 900 mm at 550 m above sea level to 2300 mm at more than 1500 m above sea level. The rainfall pattern is a bimodal with two distinct periods: a long rainy season which lasts from February to May and short rains from late October to December. The mean annual temperature also varies from 25°C at 550 m to 19°C at 1500 m above sea level (Kimaro *et al.* 2005).

In this area mountain ridges are mainly used for vegetable, bean (*Phaseolus spp*), short rain maize (*Zea mays L.*) and banana (*Musa spp*) production while on the foothills long rain maize is the main crop (Kimaro *et al.* 2005).

### **Experimental Design and cultural practices**

On farm field experiment was conducted for three years (2004 – 2006), on grass strip contours, following a complete Randomized Block Design (CRBD), six treatments were applied and replicated three times. The plot size was 2 x 3 m with one meter of polyethylene sheet laid at the end of the plot to the trough to collect run off. Seedlings of Chinese cabbage were transplanted at a spacing of 50cm x 25cm. The treatments were assigned to the replications randomly such as; T<sub>1</sub>: Conservational tillage + Insitu compositing (**CTG**), T<sub>2</sub>: Traditional terrace + Insitu compositing (**TTG**), T<sub>3</sub>: Conservational tillage + Manure (**CT**), T<sub>4</sub>: Traditional terrace + Manure (**TT**), T<sub>5</sub>: Control conservational tillage (**CCT**) and T<sub>6</sub>: Control traditional terrace (**CTT**). In situ composting means a mixture of green manure (mixture of *Gliricidia* and other farm residues at a rate of 5ton/ha), farmyard manure (10 ton/ha) and Minjingu Phosphate Rock (MPR) 100kg P /ha were left to decompose in situ on the soil. With this type conservation tillage the soil was ploughed upside down up to 50cm deep, the upper soil was laid followed by a mixture of green manure, farmyard manure and MPR then the stuff was sub soiled.. They were then left without physical disturbance by hand hoe throughout the experimentation period. Traditional terrace means normal tillage by hand hoe (30 to 50cm below soil surface) with complete incorporation of crop residues repeated each growing season. Nitrogen fertilizer in form of sulphate of ammonia was added to supplement nitrogen two weeks after transplanting at a rate of 100kgN/ha. Frequent weeding was done to maintain the experimental plots almost free from weeds, but on the conservation tillage plots, the weeded weeds were left on the soil surface to decompose.

### **Data Analysis**

The composite soil sample was taken before experimentation in the experimental plot and from each plot after each crop season through simple random sampling.

Sampling conditions were the depth between 0-50 cm, followed by normal sample preparation procedures. Plant samples were taken from the vegetable leaves, washed with water and then dried at 70<sup>0</sup>C, then grinded to obtain fine powder, which was used for analysis to determine plant nutrients which were taken up by the plants (Okalebo *et al.*, 2004, Van Reeuwijk , 2002).

The soil samples were analyzed for total N, available P and exchangeable K as well as organic carbon. Total nitrogen was determined by using micro Kjeldah distillation method (Van Reeuwijk 2002, Bremmer and Mulvaney, 1982). Phosphorus (P) was determined using Bray I method then the amount of P estimated by spectrophotometer (Van Reeuwijk 2002; Bray and Kurtz, 1945). Potassium (K) was determined using a flame photometer and Organic carbon was determined by Walkley and Black method (Van Reeuwijk 2002). The soil pH was determined potentiometrically with glass electrode (pH meter) in the 1:2.5 soils: water solution (Van Reeuwijk 2002; Moberg, 2001). Undisturbed core samples were also taken for bulk density was also determined (Van Reeuwijk 2002). Soil loss was estimated by taking soils from the plots through runoff and splash separately, air dried and weighed to determine the weights of soils lost on weekly basis. Then the values were statistically analysed to examine the significant difference at P=0.05, descriptive statistics was done using MSTAC and the Duncan Multiple Range test was used to separate the means. Plant samples were also analyzed for Total Nitrogen, Phosphorus and Potassium.

## RESULTS AND DISCUSSION

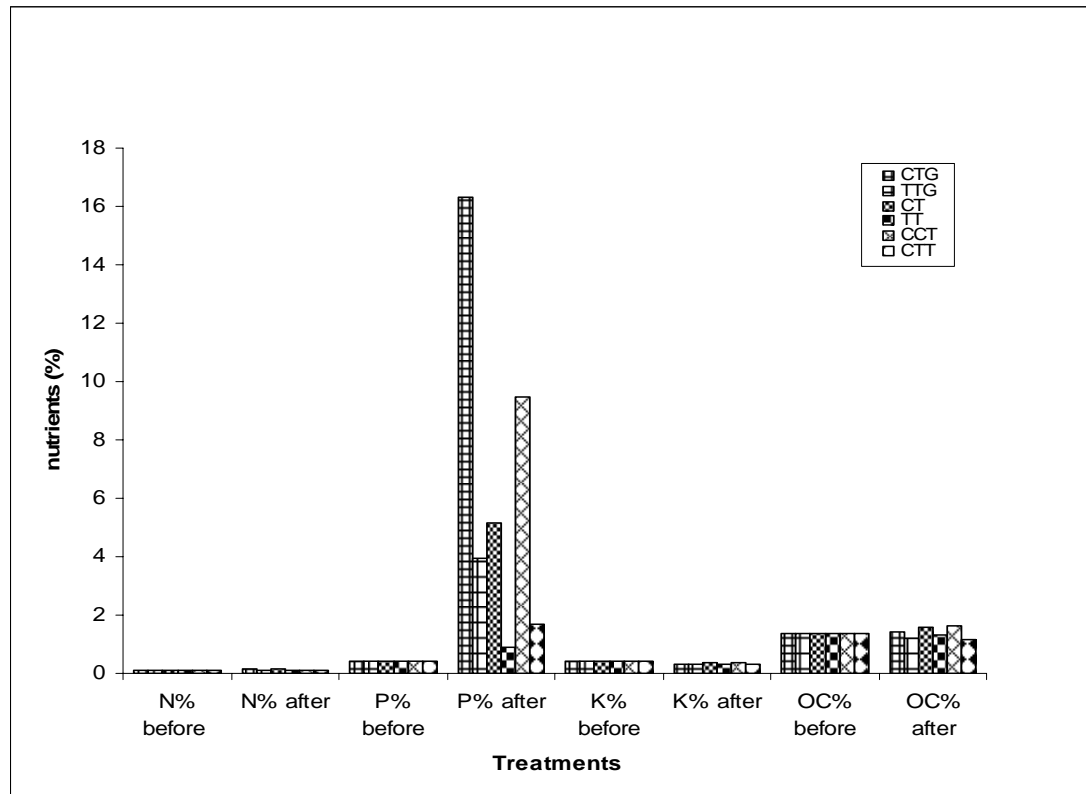
### Soil Nutrients

Soils in the study area were low in nutrients content N (0.11%), P (0.42%) and K (0.44%) (Table 1 and Figure 1) before treatment application (Landon, 1991). After treatment it showed that Nitrogen (0.10-0.14%) values did not change (P=0.05), phosphorus (0.91-16.33%) had increased (P=0.05) while potassium (0.29-0.36%) decreased (P=0.05), the decreased N and K may be due to heavy rains in the study area probably washed them down the slope while P was fixed in clay minerals. Furthermore, results indicated organic carbon to have decreased in all traditional tillage and increased in all conservation tillage treatments (Figure 1). Generally the conservational tillage provides higher values of nutrients available in soil with regard to N, P, K and OC elements. This is because SOM reserved in the conservation tillage contains large shares of the soil nutrients and other soil properties that are important for healthy plant growth, prevention of nutrient leaching and buffering soil from adverse pH changes (Hobbs, 2007). The same results were obtained by Guzman *et al* (2006) after long term of N application and conservation tillage (no till-NT) and conventional tillage (CT) that, Bray-1 extractable P was 20 mg/kg were higher, in the surface 2.5 cm of NT compared to CT. Organic carbon (OC) under NT was significantly higher in the surface 7.5 cm of soil compared to CT. Atreya *et al.* (2006) observed after two years of data indicated annual soil and nutrient losses to be significantly lowered by reduced till as compared to conventional till. Total annual soil loss from conventional and reduced till was 16.6 and 11.1 Mg/ha, respectively. Similarly, annual nutrient losses associated with the eroded sediment were 188 kg OC/ha, 18.8 kg

Soil pH	Textural class	N%	P%	K%	OC%
5.9	SCL	0.11	0.42	0.44	1.37

**Table 1:** Some soil properties before experimental layout

N/ha, 1 kg P/ha and 3.8 kg K/ha for conventional tillage and 126 kg OC/ha. 11.8 kg N/ha, 1 kg P/ha and 2.4 kg K/ha for reduced tillage. Soil OC and N losses were significantly higher in conventional till and this may be one of the major causes of fertility depletion in this area.



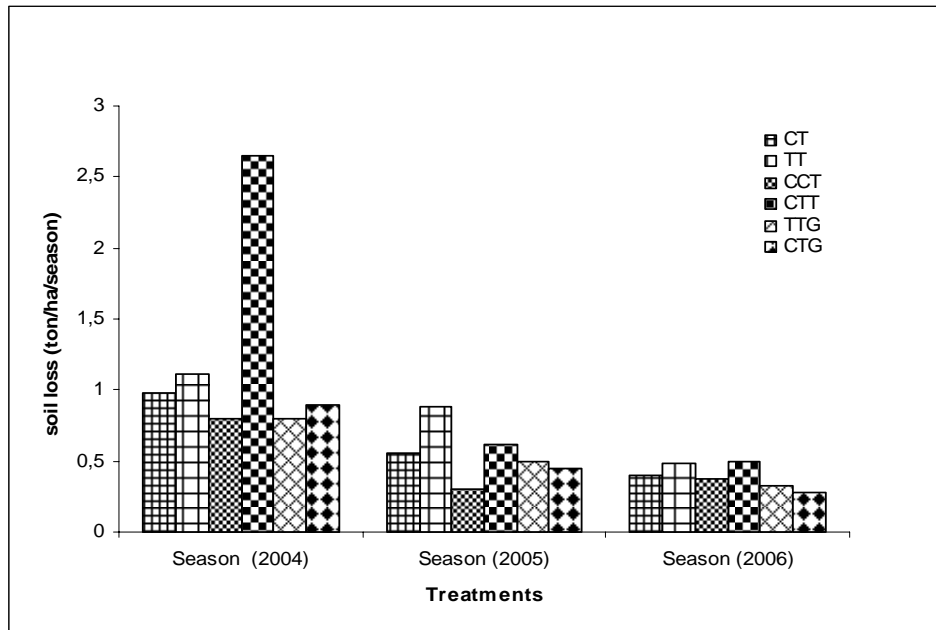
**Figure 1:** Comparison of nutrients levels in soil before and after three years (2004-2006) of treatment application (CV% N=22.61, P=52.69, K=15.53, OC=23.74)

The decrease of potassium may be due to the effect of nutrient balance whereby the increase of P and N application has influenced the negative balance of potassium without additional K fertilizer. Blaise *et al.* (2005) observed the negative K balance in spite of addition of K (PK, NK and NPK plots without FYM). The same results were reported by Dobermann *et al.* (1996) in the irrigated rice systems. Adamiak *et al.* (2002) at the end of 7 years observed a positive nutrient balance when both mineral K-fertilizers and manure were applied in combination. A positive nutrient balance indicates potential gains (soil storage), while a negative balance indicates the mining of the soil reserves.

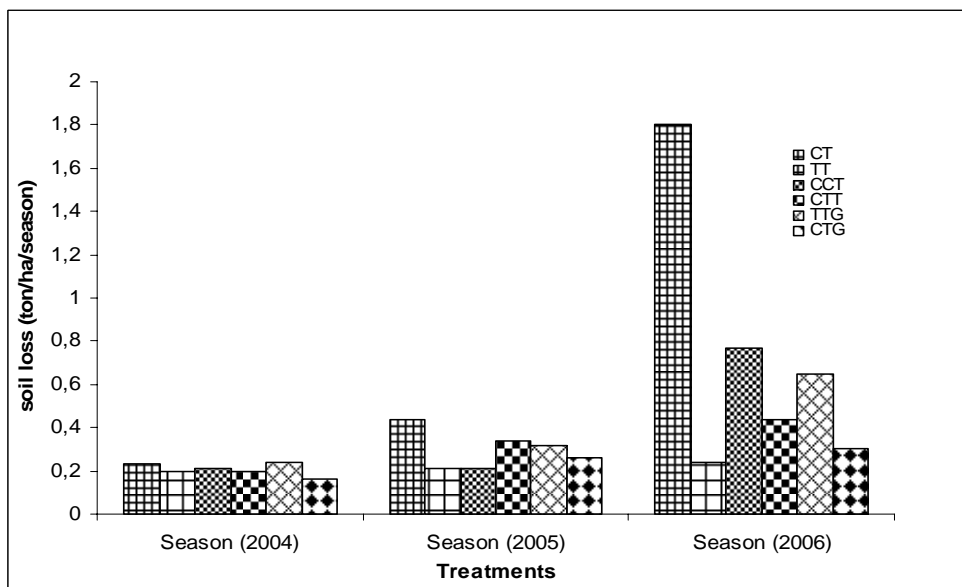
### Effect of conservational tillage on soil loss

The data indicate that soil loss through runoff was higher than soil loss by splashing (Figure 2 &3). It was further established that soil loss by runoff was gradually increasing from CCT, CTG to CT treatments by 0.49, 0.54 and 0.65 ton/ha/season respectively (Figure 2). The soil loss by runoff was decreasing from first season to third season in all treatments (Figure 2). The soil loss by splashing was increasing from first season to third season (Figure 3). This indicates that conservational tillage is effective in reducing soil loss due to run off. This could be due to the stability that was a result of lack of disturbing the soil every season (Arakeri and Roy, 1984). Accelerated erosion was most severe in the first season after land clearing due to the

kinetic energy of the raindrop surface that caused sealing, and crust formation leading to high runoff rate. High runoff velocity on long and undulating slopes, low soil strength of weak soil structure with high moisture content due to frequent rains followed immediately after land preparation, also led to high soil loss (Ral, 1981). Soil erosion control was more effective in conservation tillage due to the minimum soil disturbance applied on the soil surface in the second and third seasons, same results were observed by Lal 1976 and (1995). The soil erosion splash increased from season 1 to 3 due to increased soil crust on the soil surface in undisturbed soil (conservation tillage) than in the traditional tillage which is cultivated every season, same results were observed by Ohnuki and Shimizu (2004); Fox *et al.* (2007); Savat and Poesen (1981).



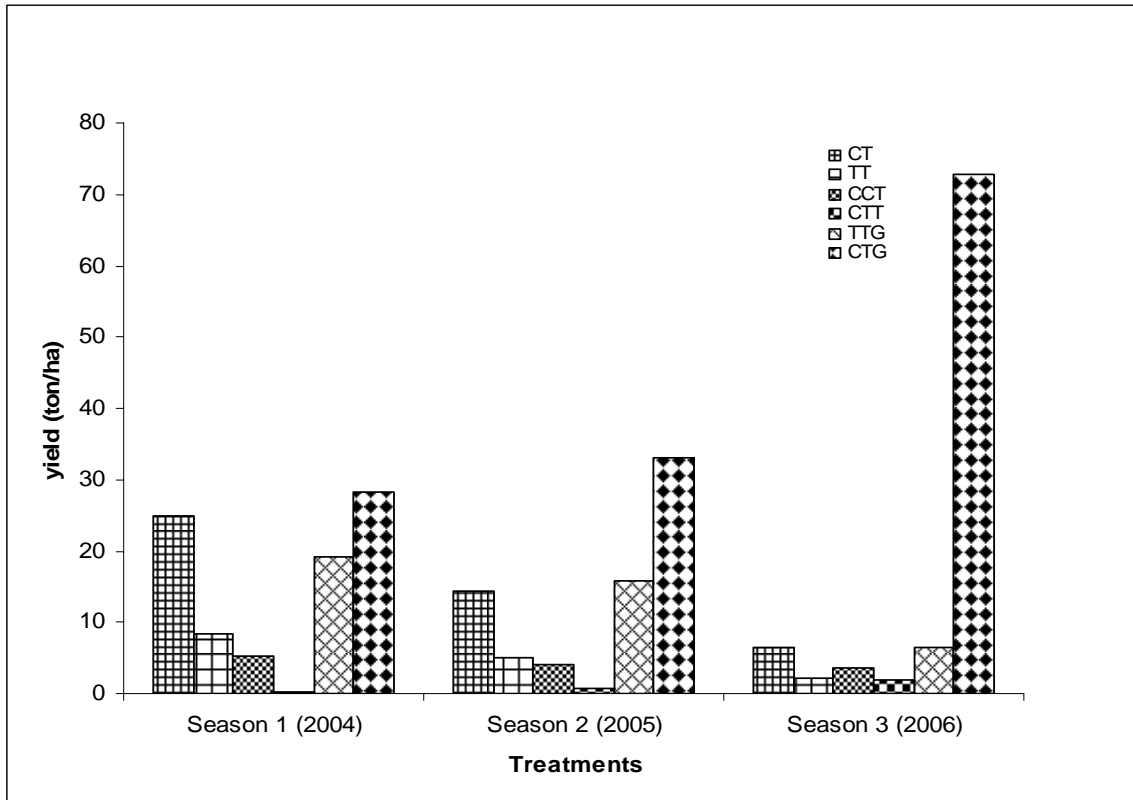
**Figure2:** Soil loss due to runoff during growing periods (October to January) in 2004 to 2006 (CV% season1=41.63, season2 = 19.96, season3 =42.59)



**Figure3:** Soil loss due to splashing during growing periods (October to January) in 2004 to 2006 (CV% season1 = 9.22, season2 = 18.56, season3 = 413.63)

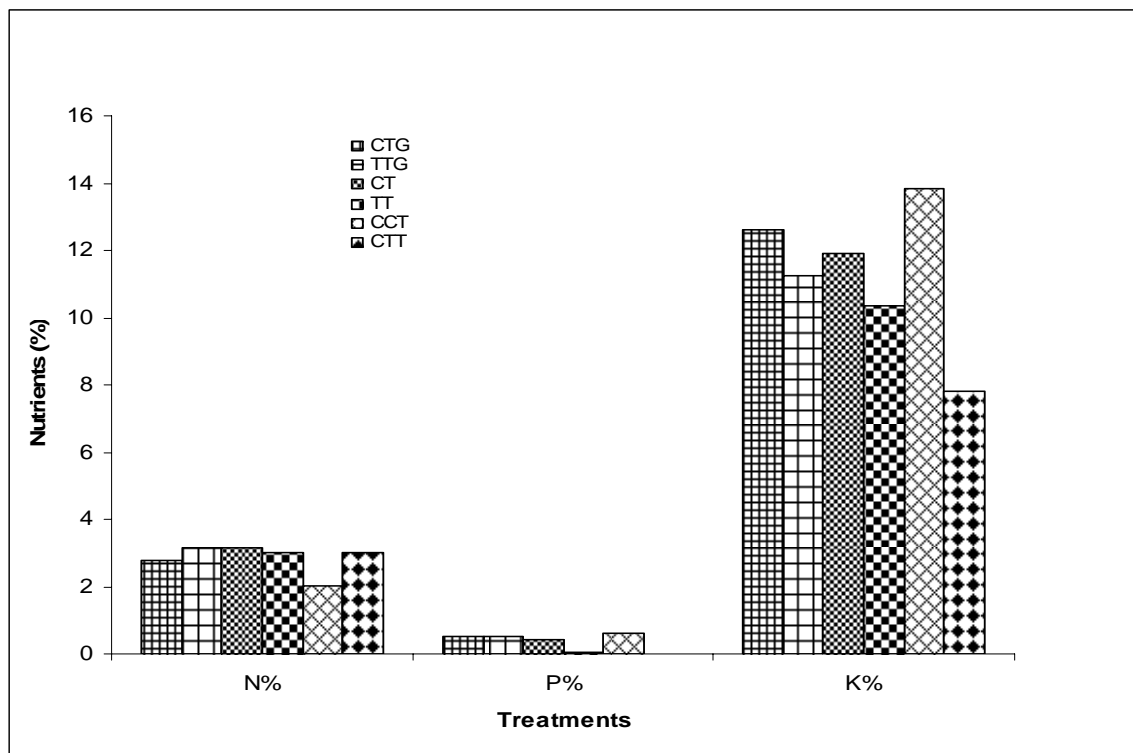
### Fresh yield and Plant Nutrient Contents

Figure 4 and 5 shows the fresh yield and plant nutrients contents respectively. On average, all conservational tillage treatments gave higher yield (CCT = 4.33, CTG = 44.68 and CT = 15.28 ton/ha), while traditional tillage had lower yield (CTT = 0.88, TTG = 13.85 and TT = 5.23 ton/ha) respectively. The yield levels corresponded to the nutrient uptake.



**Figure 4:** Fresh Yield of Vegetable of each season from 2004 to 2006 (*CV%* season1 =37.29, season2 = 28.07, season3 = 24.44)

The N% increased in the order: CCT (2.01) < CTT (2.99) =TT (2.99) <CTG (2.80) <TTG (3.14) <CT (3.15), but statistically there was no significant difference on the N% content ( $P=0.05$ ). The P% values were CTT (0.015) <TT (0.026) <CT (0.41) <TTG (0.50) <CTG (0.54) <CCT (0.63).



**Figure 5:** Plant nutrients uptake in the third year (2006) of treatment application (CV% N = 20.91, P = 12.77, K = 16.8)

On statistical analysis at alpha 0.05 there were significant differences among the treatments. The K% was in the order of CCT (7.80) <TT (10.35) <TTG (11.27) <CT (11.92) <CTG (12.62) <CCT (13.85). There was no significant difference between CT, TT and CTT, but there was significant difference between the three treatments and CTT which had no significant difference with TTG while significant difference was observed with CTG. The same trends were observed by Gangwar *et al.* (2004) whereby reduced tillage showed significantly greater available N, P and K content after three year of treatment application. Also similar results were observed by Ishaq *et al.* (2001) and Veenstra *et al.* (2006).

## CONCLUSION

All conservation tillage treatments gave higher fresh yield, higher nutrient retention and lower soil losses in the second and third season. While the opposite was true for traditional treatments lower fresh yield, lower nutrient retention and higher soil losses in the second and third season. It can be concluded from this study that the conservation tillage for vegetable production on slopping land is the best practice resulting in the highest sustained crop yield levels. , nutrient uptake, retain plant nutrients and reduce soil loss.

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# EFFECTS OF ROCK PHOSPHATE PLACEMENT METHODS AND RATES OF CO-APPLIED ORGANIC MATERIALS ON PHOSPHORUS AVAILABILITY AND MAIZE YIELDS FROM A DYSTROPEPT AND AN OXIC HAPLUSTULT IN TANZANIA

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Short running title: Effect of rock P and organics on maize yields

## ABSTRACT

Studies were conducted under pot and field conditions to evaluate the effects of Minjingu phosphate rock (MPR) placement methods and rates of organic residues on MPR dissolution, phosphorus (P) availability and maize yields from a Dystropept soil in Sasanda, Mbeya and from an Oxic Haplustult in Magadu, Morogoro, Tanzania. The treatments in the pot experiment were control, broadcasted MPR at the rate of 80 kg/ha, banded MPR on a 5 cm-wide strip, and 20-cm band MPR + OM applied together at 2, 4, or 8 t/ha and incorporated down to 20cm depth. In the field experiment an additional treatment, 20-cm wide MPR band incorporated to 20 cm, was included. The field experiment was laid out using the Randomized Complete Block Design with four replications while the pot experiment was laid out using the Completely Randomized Design with three replications. The results showed that MPR alone increased yields over those of the control treatments. Banding of MPR together with OM at the rates of 2, 4, or 8 t/ha significantly ( $P=0.05$ ) contributed to increased P availability from MPR and to higher maize dry matter and grain yields. In the pot experiment, MPR + OM at 2, 4 and 8 t/ha increased DM yields from 4.10 to 70.87 g/pot in Sasanda soil and from 14.14 to 76.17 g/pot in Magadu soil. In the field experiment at Sasanda, MPR + OM at 2, 4 and 8 t/ha increased extractable P in the soil from 0.18 to 0.47 mg/kg, and maize grain yields from 0.36 to 3.38 t/ha. The yield increases were proportional to the increasing rates of the OM applied.

Key words: Rock phosphate, placement methods, organic materials, Sasanda, Magadu, Tanzania

## INTRODUCTION

In most tropical soils low levels of phosphorus (P) is one of the most limiting factors in crop production, especially in weathered, leached and, consequently, acidic soils such as Ultisols, Oxisols, and in some volcanic soils. In order to increase the P content and availability in soils with low native P, fertilizer materials that contain P should be added to such soils. Due to high cost of water-soluble P fertilizers, research has been focused on possible use of agrominerals, namely phosphate rocks (PR), as sources of P to improve agricultural production, especially in acid soils. However, the PR has to undergo dissolution before it releases the P contained in it.

Placement methods have been reported to affect the solubility of PR in soil, hence its utilization by crops. Kanabo and Gilkes (1987) reported that the extent to which PR came into contact with soil was a key factor that affected PR dissolution, hence availability of P for plant uptake. The extent of contact of PR with soil, and its subsequent dissolution, will be governed by method of placement. Many researchers have reported inferior dissolution of PR upon band application. For example, Kanabo and Gilkes (1987) observed lower dissolution of PR in band application than where the PR was broadcasted. Also Kadoghola (2001) reported lower yields of maize from Sasanda (Mbeya) volcanic soils when the Minjingu Phosphate Rock (MPR), a sedimentary PR from northern Tanzania, was banded than when it was broadcasted, due to poor dissolution of the banded MPR. Mhagama (2003) reported improved availability of P and higher maize yields from this Sasanda soil when the MPR band was widened. No such work has been done using the Magadu soil.

Other researchers (Sanchez *et al.* 1997) have reported that organic materials applied in combination with MPR enhanced the availability of P from PR due to simple organic acids produced upon decomposition of the organic materials. But not much has been done to shed light on what rates of the organic materials should be applied to maximize the availability of P from PR.

Therefore, the studies reported here were conducted, using the Sasanda and Magadu soils, to evaluate the effects of MPR placement methods on its dissolution and availability of P from the soils, and to determine the effects of different rates of organic materials mixed with MPR on dissolution and availability of P from banded MPR.

## **MATERIALS AND METHODS**

Pot and field experiments were conducted to assess the effects of methods of PR placement, and rates of organic residues applied together with the PR, on P availability and maize yields. The soils used were a volcanic soil at Sasanda, Mbozi district, Mbeya region, and an ultisol from Magadu, Morogoro district, both in Tanzania. The Sasanda volcanic soil, classified as Dystrocept by Van Straaten *et al.* (1992), has a high P fixing capacity, with a P adsorption maximum of 4110 mg P/kg (Mwakisimba 1999). The ultisol from Magadu, classified as Oxic Haplustult (Kaaya 1989), has a medium P fixing capacity, with a P adsorption maximum of 466 mg P/kg (Mwakisimba 1999). The maize (*Zea mays*, L.) variety used as test crop was UH 615.

### **Soil sampling and preparation**

Composite soil samples (0 - 20 cm) were collected from Sasanda and Magadu. The Sasanda village is located at latitude 09° 16' S and longitude 33° 03' E, at an elevation of 1650 metres above sea level (masl), while Magadu is at latitude 06° 51' S and 37° 38' E, at the altitude of 530 masl. The soils were air-dried and ground to pass through a 6 mm sieve for a pot experiments or through a 2 mm sieve for routine soil analysis.

### **Soil analysis**

Soil pH was determined electrometrically in a 1: 2.5 soil:water ratio using a pH meter. Particle size distribution was determined by the hydrometer method (Ghee and Bauder 1986). Organic carbon was determined by the wet digestion method of Walkley and Black

(Nelson and Sommer 1982), while total nitrogen was by micro-Kjeldahl digestion followed by distillation (Bremner and Mulvaney 1982). Phosphorus was extracted using the Bray 1 method, and determined colorimetrically after colour development by the ascorbic acid method (Moberg 2000). The ammonium acetate saturation method was used in the determination of the exchangeable bases and CEC (Moberg 2000). DTPA-extractable zinc and copper were determined by atomic absorption spectrophotometry (AAS) (Moberg 2000).

### **Glasshouse pot experiments**

Four kg of the air-dried composite Sasanda or Magadu soil samples ground to pass through a 6 mm sieve were weighed into five-litre plastic pots, which were arranged in a Completely Randomized Design with three replications. The treatments were: 1) Control: No MPR added, 2) Broadcasted MPR incorporated into soil to about 5cm depth, 3) Strip banded MPR incorporated to about 5cm depth, 4) MPR+ OM banded (20 cm width band) at the rate of 2 ton/ha and incorporated to a depth of 20 cm within the pot, 5) MPR + OM banded (20 cm width band) at the rate of 4 ton/ha and incorporated to a depth of 20 cm depth within the pot, 6) MPR + OM banded (20 cm width band) at the rate of 8 ton/ha and incorporated to a depth of 20 cm within the pot. The organic materials used, indigenous to the sites of soil sampling, were *Ageratum conyzoides* for Sasanda soil and *Pycnanthemum tenuifolium* for Magadu soil. The organic materials, dried and cut to small (<1 cm) pieces, was thoroughly mixed with the soil within the 20-cm depth in the pot. The MPR was applied at the rate of 80 mg P/kg while N and Zn were applied at the rates of 200 and 5 mg/kg, respectively, and also thoroughly mixed with the soil. Thereafter, the pots were watered using distilled water.

Five maize seeds (varieties UH 615 for Sasanda and Kito for Magadu) were sown per pot and thinned to two plants per pot one week after emergence. The soils were maintained at about field capacity (0.3 bar) moisture content and weed-free during the whole period of the experiment. Plant shoots were cut at the height of 1 cm above the soil level after 42 days of plant growth, rinsed in distilled water and oven dried at 70°C to constant weight. The plant samples were finely ground using a Tecator Cyclotec 1093 sample mill for chemical analysis. The soils were left for two weeks to dry out. The soils were then excavated from the pots to a depth of 20 cm, ground, mixed and sieved through a 2 mm sieve for determination of post-harvest Bray 1 P.

### **Field experiment**

The field experiment was conducted only at Sasanda beginning December 2002. The treatments used were: 1) Control: (No MPR added), 2) Broadcasted MPR, ploughed down to a depth of 10 cm, 3) Strip banded MPR, incorporated to a depth of 5 cm, 4) MPR applied as a 20-cm wide band and ploughed down to a depth of 20 cm, 5) MPR+ OM banded at the rate of 2 ton/ha and incorporated down to a dept of 20 cm, 6) MPR + OM banded at the rate of 4 ton/ha and incorporated down to a depth of 20 cm, 7) MPR + OM banded at the rate of 8 ton/ha and incorporated down to 20 cm depth. The organic materials were the same as those for the pot experiments. The treatments were replicated four times and arranged in the Randomized Complete Block Design. The plot size was 5 m X 5 m. Maize seeds were sown at the spacing of 75 cm x 30 cm. The MPR was applied at planting at the rate of 80 kg P/ha while N and Zn fertilizers were applied at the rates of 100 kg/ha and 5 kg/ha, respectively. The nitrogen fertilizer, as ammonium sulphate, was applied in three splits, at planting, five weeks later, and at maize tasselling stage. Seedlings were thinned to one plant per hill two weeks after emergence. The plots were maintained weed-free during the entire plant growth

period. Maize cobs were harvested at maturity in July 2003, shelled, grain weighed and yields expressed as t/ha at 12.5% moisture content.

### **Plant sampling and analysis**

Three maize inner rows were randomly picked out of the six plant rows and used for leaf sampling. At 50% maize tasseling, fifteen representative flag leaves, five from each row, were randomly selected and harvested in each plot. The plant samples were rinsed in distilled water to rid them of dusts, dried at 70°C and ground using a Tecator Cyclotec 1093 sample mill for chemical analysis. The plant samples were digested using a mixture of HNO<sub>3</sub> and H<sub>2</sub>O<sub>2</sub>, and the contents of N, P, K, Mg Ca and Zn were determined. The content of P in the digests was determined using the ascorbic acid molybdenum blue method (Moberg (2000). Magnesium, calcium and zinc were determined using AAS, while potassium was determined using a flame spectrophotometer (Bremner and Mulvaney 1982). Total N was determined by micro-Kjeldahl digestion and distillation method (Bremner and Mulvaney 1982).

### **Statistical analysis**

The MSTATC computer program was used for analysis of variance (ANOVA) for the data obtained from post-treatment soil analysis, maize dry matter yields, maize grain yields, and plant nutrient concentrations. The Duncan's New Multiple Range Test was used for ranking the means.

## **RESULTS AND DISCUSSION**

### ***Some characteristics of the experimental soils and organic materials used***

Tables 1 and 2 show some chemical and physical properties of the experimental soils and characteristics of the organic materials, respectively. Based on the ratings as shown in Table 1, the experimental soils had an overall low soil fertility status in terms of P and other nutrient elements. The Bray 1 P in the Sasanda soil was especially low, and this is a significant limiting factor to crop production in that area. This is exacerbated by the high P fixation rate in this soil (Mwakisimba 1999). Therefore, all those nutrients that were in low levels were applied in order to overcome their deficiency in the course of the pot and field experiments.

The organic materials used in the present studies, with C:N ratios of 34 and 26 and C:P ratios of 205 and 263, for Sasanda and Magadu soils, respectively (Table 2), should undergo a relatively fast decomposition in the soil. Handayanto *et al.* (1994) observed fast decomposition of organic materials with narrow ( $\leq 30$ ) C:N ratios as compared with those with wider ( $>30$ ) C:N ratios. The C:N ratio of *Ageratum conyzoides*, at 34, is not very different from the cited cut-off point of 30. Tisdale *et al.* (1993) similarly reported fast decomposition of organic materials having C:P ratios  $<300$ .

### **Glasshouse pot experiment: Effects of MPR placement methods and rates of organic material on maize growth and yields**

Maize dry matter yields, phosphorus uptake, phosphorus concentrations, and post harvest Bray 1 P as influenced by methods of MPR application and rates of organic materials are presented in Tables 3 and 4 for Sasanda and Magadu soils, respectively. The control treatment gave the lowest dry matter yields. The MPR + OM banded at 2, 4, and 8 t/ha gave significantly ( $P=0.05$ ) higher maize dry matter yields than the other treatments, with the dry matter yields increasing as rate of OM was increased. Broadcasted MPR gave significantly ( $P=0.05$ ) higher dry matter yields than did the strip banded MPR. The trend of P uptake by the plants resembled closely those of the dry matter yields, plant P concentration, and post harvest Bray 1 P.

The lower DM yields in controls compared to MPR treatments are ascribed to low levels of P in these soils (Table 1) since no P source was applied in the controls. The higher DM yields from broadcasted MPR than from strip banded MPR were, therefore, due to higher P levels following increased MPR dissolution of the broadcasted MPR over the strip-banded MPR. Increased dissolution was a result of increased contact between P and soil in the broadcasted MPR, hence increasing the level of available P for plant uptake. Khaswaneh and Doll (1978), Hammond et al. (1986) and Mhagama (2003) have reported similar results. The decrease in available P in the strip banded MPR was a result of limited contact between the soil and the MPR. The further increase in DM yields as OM was increased is attributed to increased dissolution of MPR caused by increased supply of organic acids ( $H^+$ ) in the soil due to decomposition of the added organic material (Hammond et al. 1986). Kanabo and Gilkes (1987) and Robinson and Syers (1990) reported that a net supply of  $H^+$  in the soil, as would be supplied by organic acids produced when organic materials were decomposed, was a prerequisite for the dissolution of PR.

The higher yields in OM treated soil as observed in the present results may also be explained in terms of reduction of P fixation by the OM. Ikerra et al. (1994) noted that availability of P to plants was improved when soil was supplied with organic materials, as this reduced P sorption by the soil through binding of the organic matter/acids to the oxides and hydroxides on the surfaces of clay particles, thereby releasing more P into soil solution for plant uptake. From incubation experiments, Ikerra (2004) observed decreased P adsorption maximum, reduced bonding energy, and increased extractable P as a result of addition of OM. However, Ikerra (2004) found that organic acids did not increase dissolution per se of the MPR.

The lower P uptake in the control treatments was due to the inherently low P content and availability in the control soil (Table 1) since no P was added, coupled, especially in the Sasanda soil, with the high P fixing capacity of this soil for what little P was there (Mwakisimba 1999). This high P fixation, at 4110 mg P/kg soil (Mwakisimba 1999) implies possibilities of this soil immobilizing most applied P, especially when the rates of application are low, with implications on limiting crop yields. The lower P uptake in strip banded MPR than other MPR treatments was due to low P in the soil solution for plant uptake, as a result of low dissolution of strip banded MPR. The lower P uptake in the broadcasted MPR than in the MPR + OM at the rates of 4 or 8 t/ha was due to greater availability of P in those treatments, as a result of the OM-mediated mechanisms discussed above, following decomposition of the OM. The higher dry matter yields and P uptake in the MPR and OM treatments relatively to the control were consistent with increased concentration of P in the maize shoots in those treatments. This was also in line with

increased availability of P in those treatments, as reflected by the trends of post-harvest Bray 1 P levels in the soils.

The relatively higher values of dry matter yields, P uptake and concentrations, and post-harvest Bray 1 P in the Magadu soil as compared to the those in Sasanda soil is a reflection of the much lower P fixing capacity of the Magadu soil as compared to that of the Sasanda soil. This led to more P in soil solution in the Magadu soil and much lower P in the Sasanda soil.

### **Field experiment: Effects of MPR placement methods and rates of organic materials on maize grain yields**

The effects of MPR placement and rates of organic materials on maize grain yields, phosphorus concentrations and post harvest Bray 1 phosphorus in Sasanda soil are shown in Table 5.

The Maize grain yields ranged from 0.36 to 3.38 t/ha. The control treatment had the lowest ( $P=0.05$ ) maize grain yields. The maize grain yields from strip banded MPR were lower ( $P=0.05$ ) than the yields from the other treatments that received MPR. Broadcasted MPR gave significantly ( $P=0.05$ ) lower maize grain yields than those from the MPR + OM treatments. The MPR + 8 t/ha of OM gave the highest ( $P=0.05$ ) maize grain yields. The control treatment had significantly ( $P=0.05$ ) lower P concentration than that of the other treatments. There were no significant ( $P=0.05$ ) differences in ear leaf P concentration among all the treatments that received MPR. Only the broadcasted MPR and MPR + OM at 4 and 8 t/ha showed higher levels of post-harvest Bray 1 P ( $P=0.05$ ) than that of the control treatment.

The lower maize grain yields observed in the control treatment in this soil was due to the inherently low P status, leading to low levels of P in the soil solution and in plant tissues. Upon addition of P, maize grain yields increased. Kadogholo (2001) and Mhagama (2003) also reported increased maize grain yields due to MPR from the same soil. The lower maize grain yields in strip banded MPR compared to the other MPR treatments confirm, as observed in the pot studies, that there was poor dissolution of MPR when MPR was strip banded, which resulted in low levels of P in the soil solution for plant uptake. The increased maize grain yields with respect to the increased rates of organic materials were due to higher availability of P from MPR, as reflected by higher extractable P in the MPR treatments. Le Mare (1991) reported that dissolution of PR increased when it was mixed with organic materials, and that availability of P to maize was improved when soil was supplemented with organic matter, as this reduced P sorption by the soil.

The lower ear-leaf P concentration in the control was due the inherently low P status in this soil. The increase in ear-leaf P concentrations in the MPR + OM treatments was due to the P increment in soil upon dissolution of the added MPR (Hammond *et al.* 1986). It is interesting to note that such low levels of post harvest Bray 1 P observed in the present study, ordinarily rated as being low (Landon 1996), could lead to relatively high levels of maize yields. It may be revealing to monitor the Bray 1 P with time, from planting till harvest, to evaluate the trend of this index during the entire growing season.

The profile of post-harvest Bray 1 P (Table 5) was similar to that of the pH measurements taken after harvest (Table 6). All the treatments had significantly ( $P=0.05$ ) higher pH than that of the control. However, there were no significant differences in pH among the MPR + OM treatments. The rise in pH was a result of dissolution of MPR, releasing  $\text{Ca}^{2+}$  that increased pH through the liming effect of MPR. Similar results were reported by Chien *et al.* (1987) using an Oxisol and by Hu *et al.* (1995) working with an Ultisol. The rise in pH contributed to reducing P fixation, resulting in higher levels of soluble P in soil solution in the treatments that received MPR and OM.

In conclusion, this study showed that MPR placement methods and organic residues incorporation significantly ( $P=0.05$ ) improved P availability from MPR, leading to higher maize dry matter and grain yields. The MPR incorporated down to 20 cm in a hand hoe-width (20 cm) band led to significant ( $P=0.05$ ) improvement in availability of P as compared to that from strip banded MPR. This led to higher levels of P uptake by maize plants, higher plant P concentrations, grain/dry matter yields, post harvest extractable P, and pH in broadly banded MPR treatments than in strip banded MPR. Increasing rates of OM increased extractable soil P, plant P concentrations, P uptake, and dry matter and grain yields. Thus, organic residues found in the field can be a valuable resource in increasing the availability of P from added PR.

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Table 1. Some physical chemical and physical properties of the experimental soils

<b>Parameter</b>	<b>Sasanda soil</b>	<b>Magadu soil</b>
pH in water	5.6 M*	5.2 L
Total N (%)	0.37 M	0.10 L
Organic carbon (%)	4.34 M	1.17 L
Bray 1 extractable P (mg/kg)	0.81 L	7.14 L
Exchangeable Ca {cmol (+)/kg}	1.10 L	3.08 L
Exchangeable Mg {cmol (+)/kg}	0.56 L	2.15 H
Exchangeable K {cmol (+)/kg}	0.97 H	0.76 H
Exchangeable Na {cmol (+)/kg}	0.75 L	0.65 L
CEC {cmol (+)/kg}	16.8 M	28.9 H
Base saturation (%)	20.12 M	23.01 M
DTPA extractable Zn (mg/kg)	0.55 L	0.69 L
Sand (%)	67	55
Silt (%)	22	5
Clay (%)	11	40
Textural class	Sandy loam	Sandy clay

\*Ratings according to Landon (1996). L = Low, M = Medium, H = High.

Table 2. Some characteristics of the organic materials used

<b>Parameter</b>	<b><i>Ageratum conyzoides</i></b>	<b><i>Pycnanthemum tenuifolium</i></b>
N content (%)	1.33	1.75
P content (%)	0.22	0.17
Organic carbon content (%)	45.19	44.69
Ca content (%)	0.46	0.48
C:N ratio	34	26
C:P ratio	205	263

Table 3. Maize dry matter yields, phosphorus uptake, phosphorus concentration and post harvest Bray 1 phosphorus in Sasanda soil as influenced by MPR placement methods and rates of organic material in the pot experiments

Treatment	Dry matter yields (g/pot)	Phosphorus uptake (mg/pot)	Phosphorus Concentration (%)	Post harvest Bray1 P (mg/kg)
Control	4.10f	3.33d	0.08c	0.07d
Broadcasted MPR	40.53d	69.04b	0.17ab	0.75ab
Strip banded MPR	24.81e	31.79c	0.13bc	0.52c
MPR + OM at 2 t/ha banded to 20 cm depth	45.37c	66.20b	0.15ab	0.75ab
MPR + OM at 4 t/ha banded to 20 cm depth	58.37b	126.60a	0.22a	0.93a
MPR + OM at 8 t/ha banded to 20 cm depth	70.87a	126.00a	0.18ab	0.69bc
CV (%)	3.3	17.1	13.3	18.2

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

Table 4. Maize dry matter yields, phosphorus uptake, phosphorus concentration and post harvest Bray 1 phosphorus in Magadu soil as influenced by MPR placement methods and rates of organic material in the pot experiments

Treatment	Dry matter yields (g/pot)	Phosphorus uptake (mg/pot)	Phosphorus Concentration (%)	Post harvest Bray1 P (mg/kg)
Control	14.14e	16.87c	0.12c	2.60c
Broadcasted MPR	50.54c	114.60ab	0.23a	19.14a
Strip banded MPR	25.35d	44.02c	0.14c	10.36b
MPR + OM at 2 t/ha banded to 20 cm depth	54.30c	99.12b	0.18ab	19.83a
MPR + OM at 4 t/ha banded to 20 cm depth	60.23b	140.10a	0.20ab	20.33a
MPR + OM at 8 t/ha banded to 20 cm depth	76.17a	127.70ab	0.17ab	11.86b
CV (%)	6.5	19.5	21.2	6.9

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

Table 5. Maize grain yields, phosphorus concentration and post harvest Bray 1 phosphorus in Sasanda soil as influenced by MPR placement methods and rates of organic material in the field experiment

Treatment	Grain yield (t/ha)	Ear leaf P Concentration (%)	Post harvest Bray 1 P (mg/kg)
Control	0.36g	0.10b	0.18c
Broadcasted MPR	2.12d	0.20a	0.41ab
Strip banded MPR	1.39f	0.18a	0.23bc
MPR banded to 20 cm depth	1.72e	0.20a	0.32abc
MPR + OM at 2 t/ha banded to 20 cm depth	2.67c	0.21a	0.35abc
MPR + OM at 4 t/ha banded to 20 cm depth	3.02b	0.22a	0.44ab
MPR + OM at 8 t/ha banded to 20 cm depth	3.38a	0.23a	0.47a
CV (%)	9.5	9.1	37.9

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

Table 6. pH trends in Sasanda soil as influenced by MPR placement methods and rates of organic materials

Treatment	pH
Control	5.2d
Broadcasted MPR	5.8b
Strip banded MPR	5.5c
MPR banded to 20 cm depth	5.5c
MPR + OM at 2 t/ha banded to 20 cm depth	6.9a
MPR + OM at 4 t/ha banded to 20 cm depth	6.0ab
MPR + OM at 8 t/ha banded to 20 cm depth	6.1ab
CV (%)	2.5

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

# THE EFFECT OF PARENT MATERIAL AND TOPOGRAPHY ON SOIL MORPHOLOGY, MINERALOGY, AND CLASSIFICATION OF SOME SOIL PROFILES ON A SELECTED TRANSECT IN MOROGORO DISTRICT, TANZANIA

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## ABSTRACT

Soil associations on a transect west of Mindu mountains in Morogoro District were studied in order to establish the effect of parent material and topography on soil morphology and mineralogy of some soil profiles in Morogoro District based on their catenary relationships. Eight soil profiles were described, sampled, and analyzed in the laboratory. From the upper to the lower parts of the landscape, the profiles included: well drained soils formed from quartz rich muscovite biotite gneisses and migmatites; well drained soils weathered from hornblende biotite gneiss; and imperfectly drained 'mbuga' soils developed from old and recent fluvial materials on the Wami-Mkata plains.

The study revealed that changes in soil properties along the transect were abrupt particularly the degree of soil profile development, soil depth, soil colour, clay content, soil mineralogy, cation exchange characteristics, and accumulations of carbonates or Fe-oxides. This demonstrates clearly that the soil properties along this transect are mainly controlled by the nature of the parent materials and their position on the landscape. Soils developed from the quartz rich muscovite biotite gneisses and migmatites in the upper parts of the landscape are moderately weathered, shallow to moderately deep, light coloured sandy soils with mixed clay mineralogy, and are classified as Oxic Ustropets (Chromic Cambisols). The soils from the hornblende biotite gneiss on the middle slope are highly weathered, deep red soils with high kaolinitic clay contents and are classified as Rhodic Kandistalfs (Haplic Lixisols) and Kandic Paleustalfs (Haplic Lixisols). Soils on the lower landscape position are mainly black soils, with high clay contents dominated by smectite, and most of them are characterized by accumulation of carbonates in their subsoils and are classified as Fluventic Ustropepts (Calcic Fluvisols), Petrocalcic Calciusterts (Calcic Vertisols) and Chromic Haplusterts (Eutric Vertisols).

**Key words:** Parent material; Topography; Soil mineralogy; Mineral transformations; Pedogenic processes; Geomorphic processes.

## **INTRODUCTION**

The spatial distribution of soil characteristics is determined by the factors of soil formation including parent material, climate, organisms, relief and time as proposed by Jenny (1980). These factors including human activities determine the nature and intensity of pedogenic processes in soils, and consequently the soil properties. Topography and parent materials are among the important factors affecting soil development (Jenny, 1980). In Morogoro, little information is available about the extensive soils of the flat Wami-Mkata plains and their catenary relationship with the adjacent soils on the gently sloping to strongly sloping topography. Investigations by Kaaya (1997) indicated that the soil characteristics on the western slopes of Mindu mountains differ from those of the western slopes of the neighbouring Uluguru mountains. Detailed soil classification and characterization provide better understanding and prediction of soils' behaviour when utilized under different management practices. This study was therefore carried out in order to study the effect of the nature of soil parent material and the landscape position of the soil profile on soil morphological and mineralogical characteristics of some soil profiles based on their catenary relationships in the study area. The study was carried out on a selected transect west of Mindu mountains towards Mkata River Plain in Morogoro District, Tanzania.

The results would provide better understanding of the soils of the Wami-Mkata plains. Such an understanding is required for making recommendations on sound soil management practices, not only for the area, but also elsewhere in Morogoro where similar soils and environmental conditions exist. The generated information would also add to soil resources inventory data, which is required for land use planning at district and regional levels.

## **NATURE OF THE STUDY AREA**

### **Location**

The transect selected for this study extends from the western slopes of Mindu mountains to Mkata River Plain in Morogoro District, Tanzania between Longitude 37° 20' E and 37° 33' E, and Latitudes 6° 43' S and 6° 54' S.

### **Geology and Geomorphology**

The salient geomorphological and geological features of the studied transect have been reported by Sørensen and Kaaya (1998), and are summarized in Fig. 1. The Mindu mountains, where this study was carried out, are among the famous isolated chains of block faulted mountains called the Eastern Arc Mountains, which extend from Kenya to Tanzania (Newmark, 2002). Runoff from the Mindu mountains flows into Ngerengere and Mkata rivers, which further drain into Wami River and enter the Indian Ocean to the east.

The bedrocks consist of high grade metamorphic rocks that belong to the Mozambique Belt, which stretches in a N-S direction from Ethiopia through Kenya and Tanzania to Mozambique (Sommer et al., 2003). It is believed to have formed by the collision of East and West Gondwana between 640 and 550 Ma (Tenczer et al., 2006). Geologically, the rocks in this Belt are polymorphic and have experienced intensive folding with granitization and migmatization (Newmark, 2002). The studied soil profiles are underlain by two contrasting rocks: i) muscovite biotite gneisses and migmatites with granitic composition around Mindu mountains, and ii) biotite-hornblende gneisses dominating the rest of the area.

## **Climate and Vegetation**

The climate in the area is of sub humid type with well-defined wet and dry seasons. However, there is a marked local variation of climatic factors, which has been associated with variation in the relief features of the study area (Sampson and Wright, 1964; Msanya et al., 2003). According to Soil Survey Staff (1996), the soil moisture regime is classified as ustic, and the soil temperature regime as iso-hyperthermic.

## **MATERIALS AND METHODS**

### **Field and Laboratory Methods**

The studied transect and the soil profiles were identified and selected during soil mapping and characterization in the area (Kaaya, 1997). The soil profiles and their relative positions on the landscape are shown in Fig. 1. However, four of these profiles were selected to represent the dominant soil types along the transect and, hence, only their morphological and physico-chemical data are presented. Freshly dug profiles were described and sampled according to the 'Guidelines for soil profile description' (FAO, 1990). Soil samples were taken from each horizon for the physical, chemical, and mineralogical analysis. Standard methods were used for physical and chemical analyses and these have been described in the soil mapping and characterization report (Kaaya, 1997). Mineralogical analysis of clay, silt and sand fractions were by X-ray diffraction, after removal of free oxides by buffered dithionite-citrate-bicarbonate solution (Mehra and Jackson, 1960). Quantification of minerals in each fraction was based on the X-ray peak intensities as described by Kaaya et al. (1998).

## **RESULTS AND DISCUSSION**

### **Morphological Properties**

Some physical and other salient morphological properties relevant to the genesis and development of the selected soil profiles have been summarized in Table 1.

### **Soils developed on quartz rich muscovite biotite gneisses and migmatites**

These soils are found on the western foot slopes of the Mindu mountains. They are relatively shallow, well-drained, moderately developed soils with sandy loam to sandy clay loam texture. Soil profiles KIP 1 and KIP 3 (Fig. 1) with A-Bw-C horizon sequence, typical of Cambisols (Inceptisols) represent the dominant soils surrounding Mindu mountains. The profiles show moderate weathering with no observable clay illuviation. They contain some slightly weathered and unweathered feldspar gravels throughout their depths. The saprolite thickness is < 1 m. The type of the underlying bedrock, and considerable high rate of surface soil erosion account for the observed shallow soils in the area.

### **The soils developed on the hornblende-biotite gneiss**

These soils occupy the middle part of the studied transect. They are deep, well drained, strongly weathered red clay soils, and mainly formed in situ. The subsurface horizons show low silt:clay ratios reflecting advanced weathering. Although Sampson and Wright (1964)

referred to these soils as deep red earth of Neogene Period, recent studies by Sørensen and Kaaya (1998) revealed that most of the soils were developed during the Quaternary. Profiles LUB 5, LUB 4 and LUB 3 (Fig. 1) with horizon sequence of A-Bt-C, are typical of the soils developed on the hornblende-biotite gneiss along the studied transect. Most of the soil materials have developed from the underlying biotite-hornblende gneiss rocks. The saprolite thickness is > 1 m. The soils are red, a property which must be associated with weathering of the underlying hornblende biotite gneiss. Often biotite gneiss and hornblende weathering result in red staining of soil particles by Fe-oxides (Allen and Hajek, 1989). Presence of clay cutans, blocky structure, and higher clay content in the B horizon than the overlying horizon indicate that these soils are still actively evolving by weathering of primary minerals and translocation of clay (Young, 1976). These profiles might have started their development under previous climate, which was wetter than the present one, but with alternating wet and dry seasons as indicated by the occurrence of ferricretes in the lower part of profile LUB 3.

### **The complex soils developed from fluvial materials on hornblende-biotite gneiss**

These are found in the lower part of the studied transect where slopes are  $\approx$  0% on the flat Wami-Mkata plains. The typical soil profiles are LUB 1 and MK 2 (Fig. 1). The parent materials for these soils could be a mixture of the saprolite weathered from the underlying hornblende-biotite gneiss and pre-weathered fluvial materials of different ages. Various dated materials indicate that the age of soil material range from < 3,800 years on the bank of Mkata River tributary to > 47,000 years near profile LUB 1 (Sørensen and Kaaya, 1998). This observation suggests that fluvial deposition, which occurred on the river plains during the Holocene, have resulted in the formation of very young Vertisols of < 3,800 years near river valleys, whereas relatively much older Vertisols occur elsewhere on the Wami-Mkata plains. This was also demonstrated by the clay mineralogy of these profiles (Table 3). The soils are therefore, complex with very young soils formed during the Late Holocene and relatively 'older' in situ weathered soils, but most likely formed during the Late Pleistocene (Sørensen and Kaaya, 1998).

The soils are imperfectly drained, with very sticky and very plastic (when wet) consistence indicating the presence of significant amounts of expanding-lattice clay minerals as confirmed by clay mineralogy of soil profiles LUB 1 and MK 2 (Table 3). Due to local variation in relief, some local geomorphic processes including slight erosion and accumulations are moderately active. The micro-relief is dominantly gilgai, typical of most Vertisols.

The profiles have high clay contents throughout the depth and they show minimum horizon differentiation due to pedoturbation. All the subsoils in this area are characterized by Ca-concretions, which have developed into a petrocalcic horizon in some subsurface horizons as observed in profile LUB 1. Decalcification in upper horizons and subsequent calcification in the subsoil are the main pedogenic processes which have resulted in pedogenic accumulations of carbonates in the subsurface horizons of these soils, and subsequent development of petrocalcic horizons in some profiles. Pedogenic accumulations of  $\text{CaCO}_3$  normally occur in semi arid climates and this might have been formed during the previous arid climates. The process involves dissolution and leaching of  $\text{CaCO}_3$  from the overlying horizons during humid seasons, and their subsequent accumulation and hardening in the dry seasons. The sources of high contents of Ca in these soils could be enrichment of Ca by lateral soil water movements, Ca-rich eolian deposits during the dry and windy periods in

tropical Africa (Talbot, 1981) and surface erosion of the Ca-rich eolian deposits from the upper slope positions.

## **Chemical and Mineralogical Properties**

### **Soils developed on quartz rich muscovite biotite gneisses and migmatites**

These soils (profiles KIP 1 and KIP 3) have fairly low CEC ranging from 8.6 to 14.0 cmol(+)/kg dry soil (Table 2). This is mainly due to their low clay and organic matter contents. Their clay CEC values are moderate to high and range from 18.5 to 51.1 cmol(+)/kg clay suggesting presence of some 2:1 expanding types of clays. The soil reaction is medium acid to neutral with pH values ranging from 5.9 to 6.6 and base saturation > 50% throughout.

The clay mineralogy (Table 3) shows that the clay fractions in profiles KIP 1 and KIP 3 are composed of various minerals including illite (dioctahedral and trioctahedral), kaolinite, smectite, mixed illite-smectite, and traces of quartz and feldspars. These minerals are at proportions that allow for both profiles to be classified under the mixed mineralogy class (Soil Survey Staff, 1996). The silt and sand fractions are mainly composed of feldspars and quartz with small amounts of mica and kaolinite in the silt fraction. Presence of considerable amounts of weatherable minerals (such as feldspars and mica) in all fractions indicates that the soils are relatively young. The mineralogical compositions of the silt and sand fractions are closely associated with the nature of the underlying parent rock and the mineralogical composition of the clay fractions suggesting that most of the clay minerals have formed as a result of in situ weathering.

### **The soils developed on the hornblende-biotite gneiss**

The soils developed on the hornblende-biotite gneiss (profiles LUB 5, LUB 4 and LUB 3) have low CEC with values between 8.5 and 14.1 cmol(+)/kg dry soil, and < 16 cmol(+)/kg clay indicating their low nutrient reserves. However, their base saturation is > 50%, and their soil reaction range from medium acid to mildly alkaline with pH values within 5.4 to 7.4 (Table 2).

The clay mineralogy is dominated by kaolinite (Table 3) and, therefore, the soils belong to the kaolinitic soil mineralogy class (Soil Survey Staff, 1996). This is an indication that they were formed under strong leaching environments of high humidity, which resulted into strong weathering. Unexpectedly, the clay fractions of these soils contain small amounts of smectite which are relatively higher in the surface than in the subsoil. A possible source of smectite in these soils could be wind-blown dust from the smectite-rich Wami-Mkata plains. Silt and sand fractions are dominated by quartz, with relatively small amounts of K-feldspars and plagioclase and some ilmenite (Table 4). Dominance of kaolinite in the clay fraction, the low silt:clay ratio, dominance of quartz, relatively low contents of feldspars, and presence of ilmenite in the silt and sand fractions are all indicators of advanced weathering in these profiles. Since amphiboles have been observed in some fresh rocks earlier (Sørensen and Kaaya, 1998) as shown in Fig. 1, their absence in the silt and sand fractions of these soils is another indication that these soils are at advanced stage of weathering. Presence of the highly resistant ilmenite (FeTiO<sub>3</sub>) could be a result of relative accumulation during

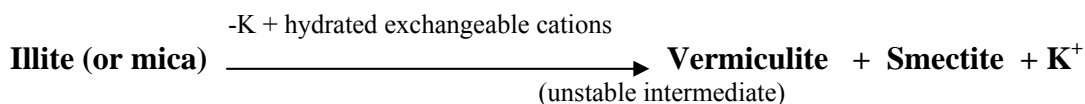
weathering of the parent rock. The higher contents of some weatherable minerals especially feldspars in the surface horizon compared to the immediately underlying horizons could be due to deposition and slight accumulation of less weathered materials brought by surface erosion from the upper parts of the transect. The deposition must have occurred on the already in situ weathered materials.

### **The complex soils developed from fluvial materials on hornblende-biotite gneiss**

These soils (profiles LUB 1 and MK 2) are alkaline with high base saturation of > 90%, and are characterized by high cation exchange capacities (CECs) of > 28 cmol(+)/kg dry soil, and > 48 cmol(+)/kg clay throughout the profiles (Table 2). The clay mineralogy is dominated by smectite (Table 3) hence classification of these soils under the smectitic mineralogy class (Soil Survey Staff, 1996). Other clay minerals in these soils include kaolinite, illite (mainly dioctahedral) and some hydroxyl-interlayered vermiculite (HIV). The high amounts of smectite dominated clays account for the soils' high CECs.

Genetic interpretation of the soil development processes in this part of the transect is difficult because in situ weathering and geomorphic processes such as addition/accumulation of pre-weathered fluvial materials resulting from sheet erosion in the middle and sloping parts of the transect are taking place simultaneously. However, the source of high contents of smectite could be one or more of the following:

- a) **Formation from solution:** this is one of the main sources of smectite in these soils. Genesis and preservation of smectite in a soil environment requires restricted drainage conditions and accumulation in the solum of its elemental constituents including basic cations such as Ca and Mg (Borchardt, 1989). Imperfect drainage conditions of these profiles, and possible accumulation of basic cations leached from the middle parts of the transect provide a suitable environment for precipitation of smectite from solution.
- b) **Transformation from mica:** smectite can also be formed from micaceous minerals by de-potassiation process as follows:



The flat Wami-Mkata plain provides a suitable environment for transformation of clay-size mica (illite) to smectite. The environment include low K<sup>+</sup> and Al<sup>3+</sup> and, high Ca<sup>2+</sup> and Mg<sup>2+</sup> contents in soil solution, high soil pH of > 7.0, imperfect drainage, presence of illite, and wetting and drying conditions (Borchardt, 1989; Fanning et al., 1989).

- c) **Inherited smectite:** some of the smectite could be inherited from the fluvial materials deposited in this part of the landscape. Since most soils of the extensive Wami-Mkata plains are smectitic, deposition of smectite containing wind-blown dust could be an additional source.

The silt and sand fractions of profiles LUB 1 and MK 2 are mainly composed of quartz, plagioclase and K-feldspars (Table 4). They also contain some amphiboles, which must be associated with their presence in the underlying rocks (Sørensen and Kaaya, 1998).

## **Soil Classification**

Classification of the soil associations on the studied transect according to the US Soil Taxonomy (Soil Survey Staff, 1996) and the FAO-Unesco system (FAO, 1988) is presented in Table 5. The soil temperature and moisture regimes throughout the transect are isohyperthermic and ustic, respectively (Soil Survey Staff, 1996). The profiles were classified to family level in the US Soil Taxonomy and to soil unit level in the FAO-Unesco system. Since most of the diagnostic horizons and characteristics are related to pedogenic processes, the results of soil classification reflect to a large extent the genesis and degree of weathering of the studied profiles.

## **CONCLUSIONS AND RECOMMENDATIONS**

The investigated soil profiles represent typical soil associations transect in the area. Abrupt changes in the morphological, physico-chemical and mineralogical characteristics of the studied soil profiles are mainly due to lateral variations of the initial parent materials along the transect as demonstrated by the properties of soils developed on quartz-rich muscovite biotite and migmatites with granitic composition towards the soils developed on micaceous and hornblende gneisses. The most affected soil properties include degree of soil profile development, soil depth, soil colour, clay content, soil mineralogy, cation exchange characteristics and accumulations of carbonates or Fe-oxides in the soil profiles along the transect.

Also, the results demonstrate that the landscape positions greatly influence pedogenic processes and, consequently, the morphological, physico-chemical and mineralogical soil properties in the area. The combined influence of parent material and landscape position has also affected the average saprolite thickness, which was found to increase considerably from the slopes of Mindu mountains towards the Wami-Mkata plains.

Weathered materials including hydrous mica (illite) and kaolinite are transported from the upper and mid-slopes and subsequently, they are deposited in the lower terrain where they undergo transformation to smectite. Also, weathering of Fe-rich hornblende-biotite gneisses in the well-drained environments release basic cations into the soil solution, which are then subjected to leaching. Their translocation and accumulation in the imperfectly drained lower terrain positions accounts for the alkaline soils in the Wami-Mkata plains. Accumulation of basic cations especially  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in the high pH and Si-rich environment accounts for smectite formation and accumulation in the Wami-Mkata.

With exception of minor exceptions, the two classification systems used in this study seem to provide fairly adequate groupings of the studied soil types, which is useful for land suitability evaluation. The information generated from this study forms the basis for further interpretations in terms of land suitability evaluation of the soils of the Wami-Mkata Plains and the surrounding undulating plains. The results are also useful for developing sustainable soil management technologies for the area, and elsewhere in Morogoro District where similar soils and environmental conditions exist.

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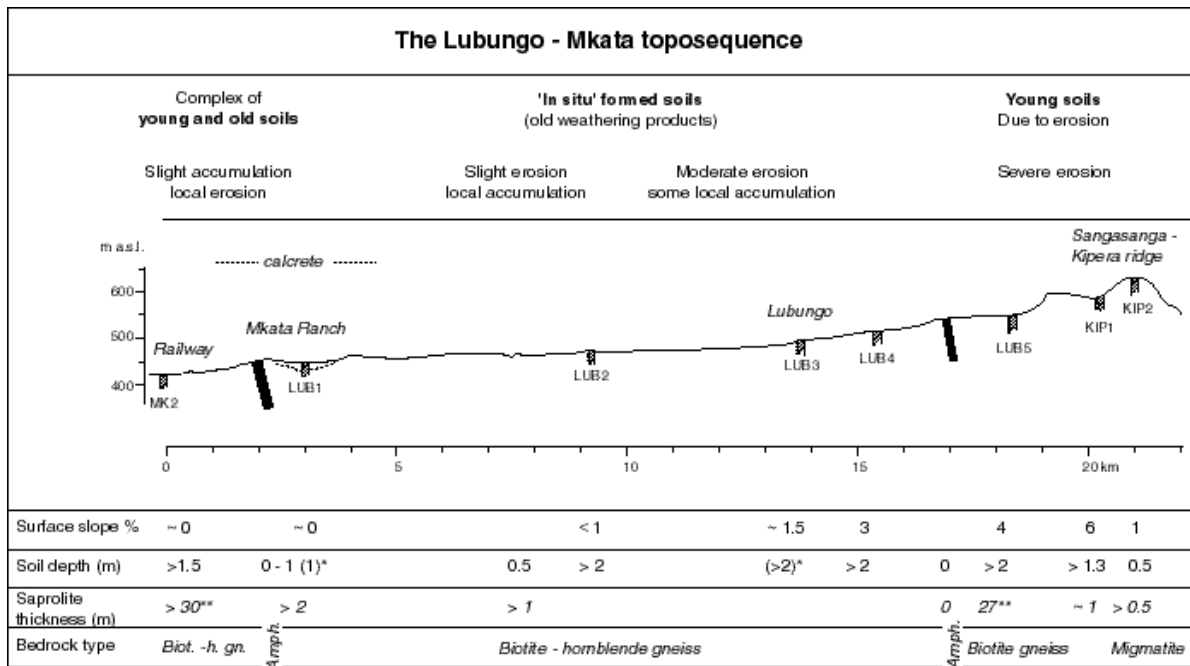


Fig. 1 Some geomorphic and geological features of the studied transect from the Sangasanga ridge to Mkata River Plain. (Adopted from Sørensen and Kaaya, 1998).

Table 1 Some morphological and physical characteristics<sup>§</sup> of the studied soil profiles

Horizon	Depth (cm)	Munsell soil colour		Particle-size analysis			Texture	Structure	Consistence			Other features	Horizon boundary
		Moist	dry	clay (%)	silt (%)	sand (%)			dry	moist	wet		
<i>Profile KIP 3: Shallow, well drained, overlying mica gneiss and migmatites, in situ weathering at 640 m asl</i>													
Ah	0 - 8	10YR 3/2	10YR 5/4	18.2	13.2	68.6	SL	MO,FM,GR	SHA	FR	NST,NPL		C,S
Bw	8 - 18	2.5YR 3/4	2.5YR 4/6	33.6	8.2	58.2	SCL	MO,ME,AB	HA	FI	ST,PL		C,S
BC	18 - 55/65	2.5YR 3/4	2.5YR 4/4	34.2	15.7	50.1	SCL	MO,FM,AB	HA	FR	ST,PL		C,W
C	55/65 - 92+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	slightly weathered gravels and stone	--
<i>Profile LUB 5: Very deep, well drained, in situ weathering from underlying biotite-hornblende gneiss at 580 m asl</i>													
Ah	0 - 20	5YR 2.5/2	5YR 3/3	47.8	10.8	41.4	C	MS,FI,GR	HA	FR	ST,PL		C,S
BA	20 - 38	2.5YR 2.5/4	2.5YR 3/6	69.1	4.2	26.7	C	MS,FI,SB	HA	FR	ST,PL		C,S
Bt1	38 - 134/138	10R 3/6	10R 4/8	76.4	4.8	18.8	C	MO,FI,SB	SHA	FR	SST,SPL	clay cutans, very few Fe-Mn nodules	G,W
Bt2	134/138-200+	10R 3/6	10R 4/8	73.4	7.0	19.6	C	MO,FI,SB	SHA	VFR	SST,SPL	clay cutans, very few Fe-Mn nodules	--
<i>Profile LUB 1: Moderately deep, imperfectly drained, developed from old alluvial deposits and in situ weathering from amphibole-containing biotite-hornblende gneisses at 445 m asl</i>													
Ah	0 - 25	5Y 2.5/1	5Y 3/1	50.2	12.2	37.6	C	ST,FI,AB	VHA	FI	VST,VPL		C,W
Bck1	25 - 65	5Y 2.5/1	5Y 2.5/1	55.3	9.9	34.8	C	ST,CO,PR	VHA	FI	VST,VPL	slickensides, carbonate concretions	G,W
Bck2	65 - 90	5Y 2.5/1	5Y 2.5/1	55.2	12.2	32.6	C	ST,CO,PR	VHA	FI	VST,VPL	slickensides, calcareous (Ca concretions)	C,S
Ckm	90 - 110+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	cemented (Petrocalcic horizon)	--
<i>Profile MK 2: Deep, imperfectly drained, developed from old alluvial deposits and in situ weathering of underlying amphibole-containing biotite-hornblende gneisses at 400 m asl</i>													
Ah	0 - 12	2.5Y 4/1	2.5Y 4/1	44.4	12.5	43.1	C	MS,FM,SB	VHA	FI	VST,VPL		G,S
Bw1	12 - 102	2.5Y 4/1	2.5Y 4/1	48.2	11.5	40.3	C	ST,MC,PR	EHA	VFI	VST,VPL	slickensides	G,S
Bw2	102 - 159+	2.5Y 5/4	2.5Y 6/4	50.8	13.0	36.2	C	MO,ME,SB	VHA	VFI	VST,VPL	slickensides, Fe-Mn concretions	--

<sup>§</sup> Abbreviations used for texture, structure, consistence and horizon boundaries are from the 'Guidelines for Soil Profile Description' (FAO, 1990)

Table 2 Some chemical properties of the soil profiles along the studied transect

Hor- zon	Depth (cm)	pH (H <sub>2</sub> O)	Organic Carbon	Sum of bases	Exch. Al <sup>3+</sup>	ECEC		CEC (NH <sub>4</sub> OAc)		Base saturation (%)
						soil	clay	soil	clay	
			(%)	(cmol(+)kg <sup>-1</sup> )					(%)	
Profile KIP 3: (on gneiss and migmatites)										
Ah	0 – 8	6.5	1.00	6.20	0.60	6.80	18.42	7.86	24.24	78.9
Bw	8 – 18	5.9	0.83	6.27	0.40	6.67	11.33	10.80	23.63	58.1
BC	18 - 55/65	6.2	0.26	5.32	0.50	5.82	14.40	7.22	18.49	73.7
Profile LUB 5 (on biotite-hornblende gneiss)										
Ah	0 -20	5.9	1.60	9.21	1.20	10.41	10.24	13.20	16.07	69.8
BA	20 – 38	5.8	0.92	6.82	2.10	8.92	8.32	11.20	11.62	60.9
Bt1	38 134/138	- 5.4	0.31	5.73	3.00	8.73	10.03	9.80	11.43	58.5
Bt2	134/138- 200+	5.6	0.23	5.37	3.20	8.57	10.60	8.62	10.66	62.3
Profile LUB 1 (on old alluvial deposits overlying amphibole-containing biotite-hornblende gneisses)										
Ah	0 – 25	7.6	1.47	42.98	0.00	42.98	75.52	47.60	84.72	90.3
Bck 1	25 – 65	8.4	1.05	47.39	0.00	47.39	79.15	52.40	88.21	90.4
Bck 2	65 – 90	8.5	1.11	56.98	0.00	56.98	96.29	57.60	97.41	98.9
Cck	90 - 110+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Profile MK 2 (on alluvial deposits overlying amphibole-containing biotite-hornblende gneisses)										
Ah	0 – 12	7.5	1.89	27.32	0.06	27.38	46.99	28.02	48.43	97.5
Bw1	12 – 102	8.0	1.38	31.89	0.00	31.89	56.29	31.96	56.44	99.8
Bw2	102 - 159+	8.3	0.45	34.32	0.00	34.32	64.50	34.92	65.69	98.3

Table 3 Mineralogical composition of the clay fractions of the soil profiles along the studied transect

Profile	Hori- zon	Depth (cm)	Smect- ite (wt %)	Illite/ Smectite	Illite	Kaol- inite	HIV	K-Feld- spars	Plagio- clase	Quartz
KIP 3	Ah	0 – 8	0	5	54	38	0	0	0	3
	Bw1	8 – 18	0	5	42	51	0	0	0	2
	BC	18 - 55/92	0	0	36	63	0	0	0	2
LUB 5	Ah	0 – 20	2	0	10	89	0	0	0	0
	Bt1	38 - 134/138	2	0	10	89	0	0	0	0
	Bt2	134/138-200	0	0	6	94	0	0	0	0
LUB1	Ack	0 – 25	74	0	0	6	9	2	2	8
	Bck1	25 - 65	83	0	0	4	7	1	1	4
	Bck2	65 - 90	83	0	0	4	7	1	1	4
MK 2	Ah	0 – 12	42	0	18	20	0	8	9	3
	Bw1	12 - 102	44	0	12	19	0	11	11	3
	Bw2	102 - 159	25	0	13	22	0	13	15	12

Table 4 Mineralogical composition of the silt and sand fractions of the soil profiles along the studied transect

Profile	Hori- zon	Depth  (cm)	Silt fractions									Sand fractions				
			Qua- rtz	K- Feld- spars	Plagio- -clase	Mica	Kaoli- nite	Illite/ Smectit e	Amphi- bole	Sme- ctite	Ilmenite	Quartz	K- Feldspars	Plagio- clase	Amphi- bole	Ilmen- ite
			(%)									(%)				
KIP 3	Ah	0 - 8	32	12	43	10	3	0	0	0	0	36	10	55	0	0
	Bw1	8 - 18	31	14	39	11	5	0	0	0	0	45	10	46	0	0
	BC	18 - 55/92	52	17	20	8	3	0	0	0	0	66	16	18	0	0
LUB 5	Ah	0 - 20	67	10	14	3	4	0	0	0	2	73	5	16	1	5
	Bt1	38 - 134/138	84	4	4	0	1	0	0	0	2	83	5	9	0	4
	Bt2	134/138-200	76	3	7	3	7	0	0	0	2	84	5	7	0	4
LUB1	Ack	0 - 25	73	1	22	0	0	0	3	1	0	64	5	27	4	0
	Bck1	25 - 65	77	1	18	0	0	0	2	2	0	59	5	33	4	0
	Bck2	65 - 90	64	1	32	0	0	0	2	1	0	61	4	32	4	0
MK 2	Ah	0 - 12	46	16	37	1	0	0	0	1	0	86	5	9	0	0
	Bw1	12 - 102	49	16	35	0	0	0	1	0	0	73	7	19	1	0
	Bw2	102 - 159	58	11	29	0	0	0	2	1	0	62	8	28	3	0

Table 5 Classification of the studied soil profiles along the transect

Profile No.	Soil classification	
	USDA Soil Taxonomy(Soil Survey Staff, 1996)	FAO-Unesco (1988)
KIP 3	Oxic Ustropepts, fine, mixed, iso-hyperthermic	Chromic Cambisols (CMx)
KIP 1	Typic Ustropepts, fine, mixed, iso-hyperthermic	Chromic Cambisols (CMx)
LUB 5	Rhodic Kandustalfts, very fine, kaolinitic, iso-hyperthermic	Haplic Lixisols (LXh)
LUB 4	Kandic Paleustalfts, fine, kaolinitic, iso-hyperthermic	Haplic Lixisols (LXh)
LUB 3	Kandic Paleustalfts, fine, kaolinitic, iso-hyperthermic	Haplic Lixisols (LXh)
LUB 2	Fluventic Ustropepts, fine, mixed, iso-hyperthermic	Calcaric Fluvisol (FLc)
LUB 1	Petrocalcic Calciusterts, fine, smectitic, iso-hyperthermic	Calcic Vertisol (VRk)
MK 2	Chromic Haplusterts, fine, smectitic, iso-hyperthermic	Eutric Vertisols (VRe)

# RETENTION OF MACRONUTRIENTS IN A SANDY SOIL AMENDED WITH VERMICULITE UNDER TANZANIAN FIELD CONDITIONS

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## Abstract

*The study assessed the ability of vermiculite to enhance the retention of extractable nitrogen (N), phosphorus (P), and potassium (K) in arable Tanzanian soils. Raw and expanded vermiculites pre-heated at 600 °C were mixed with a sandy soil in varying amounts. Inorganic fertilizers N, P and K were added to the soil-vermiculite mixes and buried at 0-15 and 15-30 cm depth in litter bags for three months during the rainy season. After that period, extractable N, P and K retained in the mixes were determined. The result showed that less than 10% of the applied N was retained whereas for K it was 26-48%. Phosphorus was highly retained and in part fertilized from vermiculite over the control. The maximum extractable fertilizer P retained in soil amended with expanded vermiculite was 78%, whereas in soil with raw vermiculite it was 141%, suggesting that vermiculite also retains soil P mineralized over the course of the experiment. More retention of N, P and K occurred at 15-30 cm than at 0-15 cm and increased with the amount of vermiculite mixed with the soil. Thus, use of vermiculite enhances soil productivity by retaining extractable essential macronutrients which could be used for crop production.*

**Key words:** Fertilizer; Nutrients; Retention; Sandy soil; Vermiculite

## INTRODUCTION

Crop productivity in many tropical countries, particularly in Africa, is generally low. Among the factors behind this low productivity is the poor capacity of some soils under crop production to retain adequate plant-available nutrients (Sanchez, 2002). Many tropical soils weather while losing their capacity to retain plant nutrients, resulting in poor soil fertility (Kellman, 2002). This problem is alleviated usually by manure and/or mineral fertiliser addition, but not all applied nutrients are effectively retained in the soil and made available to plants. Some nutrients are lost easily by leaching or lateral flow, whilst others volatilize as gases or get fixed in soil constituents (Sanchez, 2002). Thus, the application of plant nutrients alone is not a solution to the decline in crop yields and fertility status experienced in most tropical soils.

Many tropical soils generally have low organic carbon (C) and total nitrogen (N) contents because of low biomass production and a high rate of decomposition (Mokwunye *et al.*, 1996). The low concentration and solubility of phosphorus (P) in soils frequently makes it a limiting

factor in plant nutrition. Fixation of fertilizer P by many tropical soils is also another factor that is lowering its availability for plant uptake (Van der Eijk *et al.*, 2006). Phosphorus deficiency is widespread in East Africa and the Sahel (Sanchez, 2002), including Tanzania, where this study was conducted.

Loss of plant nutrients in tropical agricultural soils is high. For instance, it is estimated that 4.4 million tonnes of N, 0.5 million tonnes of P, and 3 million tonnes of potassium (K) are lost each year from cultivated land in Africa (Sanchez *et al.*, 1997). That loss of nutrients is above the estimated rate of Africa's annual fertilizer consumption (FAO, 1995). The consequence of that trend is a decline in crop productivity and food security (Sanchez *et al.*, 1997).

The main objective of this study was to investigate the role of vermiculite as a soil amendment in enhancing the retention of extractable N, P and K in the Tanzanian soils. Studies indicate that vermiculites have a high cation exchange capacity (CEC), broadly ranging between 50 and 150  $\text{cmol}_{(+)}\text{kg}^{-1}$  (Van Straaten, 2002). Field experience shows that a medium characterized by a high CEC can retain nutrients from leaching during irrigation (Tisdale *et al.*, 1993), but it is not known to what extent vermiculite from Tanzania can do so. Nitrogen, P and K were selected because they are the dominant macronutrients required for plant growth. Of these, N and P are the most limiting nutrients in most tropical soils of Africa (Kwabiah *et al.*, 2003).

## **MATERIALS AND METHODS**

### **Source of vermiculite**

Vermiculite (MK1) from Mikese area ( $06^{\circ} 47' 08''$  S and  $37^{\circ} 54' 35''$  E) in the Neoproterozoic Mozambique Belt of Tanzania was used. Semi-quantitative X-ray analysis of this vermiculite indicates that it is composed of about 74% by weight R1 hydrobiotite and 25% by weight vermiculite and a small amount of apatite and monazite as inclusions (Marwa, 2009). Thus, it is essentially hydrobiotite rather than vermiculite in mineralogical sense, but commercially all are regarded as vermiculite (Frank and Edmond, 2001).

At the site, approximately 50 kg of MK1 were excavated from 2-2.5 m depth and air-dried in a glasshouse at the Sokoine University of Agriculture in Tanzania to a constant weight. Half of the sample was exfoliated by heating for one hour at  $600^{\circ}\text{C}$  at the Southern and Eastern African Mineral Centre (SEAMIC) Laboratories in Tanzania. Both the unheated (raw) and heated (expanded) vermiculites were ground by hand to avoid structural degradation and sieved through an 8 mm sieve before mixing with a sandy soil.

### **Site description and soil classification**

The study was carried out at Mazimbu area in Morogoro Urban District, Tanzania from March to June 2007, during the long rainy season, locally known as '*Masika*'. Most crops in the country are grown during that period. The site is situated at latitude  $06^{\circ} 47' 02''$  S and longitude  $37^{\circ} 37' 34''$  E. It is well drained, undulating, colluvial plain with a uniform gentle slope of 2-3%. The site is known for its poor fertility potential and crop yield (personal communication with the local residence). Cassava and maize are some of the crops that are usually grown in the area. During 2005 and 2006, the area was under fallow.

The soil at the site was studied and its physical and chemical properties were established. A 170 cm depth soil profile was made at the site and a Mussel Colour Chart was employed in describing the soil horizons. Soil samples were taken from each horizon, air-dried at a room temperature to a constant weight, and sieved through a 2 mm sieve for laboratory analysis. Analysis of the soil properties was done at the Soil Science Laboratories of the Sokoine University of Agriculture, in Tanzania, using the methods of Okalebo *et al.* (2002) and Møberg (2001). The physiochemical properties of the soils found are located in Table 1. The soil was classified as *Ustic Quartzipsamment* based on the Soil Survey Staff (1996) and *Orthidystric Arenosol* according to FAO (1998). The soil was ideal for the study because of its poor status in plant nutrients and, thus, less interference with the treatments.

**Table 1:** Initial properties of the soil at the site

Soil parameter	Soil horizon			
	Ap	AB	Bw1	Bw2
Depth (cm)	0 – 20	20 – 33	33 – 133	133 – 170+
Texture: Clay (%)	7	7	6	5
Silt (%)	7	18	10	4
Sand (%)	86	75	84	91
Textural class	LS	LS	LS	S
pH in H <sub>2</sub> O (1:2.5)	6.56	6.55	6.30	6.05
Organic carbon (%)	0.75	0.31	0.12	0.04
Total nitrogen (%)	0.06	0.02	0.01	0.01
EC (mScm <sup>-1</sup> )	0.11	0.11	0.10	0.10
Bray 1 available P (mg kg <sup>-1</sup> )	3.90	5.51	1.03	0.67
CEC NH <sub>4</sub> OAc (cmol <sub>(+)</sub> kg <sup>-1</sup> )	13.6	6.8	7.3	8.2
Exchangeable cations (cmol <sub>(+)</sub> kg <sup>-1</sup> ):				
Ca <sup>2+</sup>	2.48	1.54	1.08	0.95
Mg <sup>2+</sup>	1.14	0.87	0.75	0.60
K <sup>+</sup>	0.55	0.44	0.26	0.07
Na <sup>+</sup>	0.34	0.33	0.34	0.34
TEC (cmol <sub>(+)</sub> kg <sup>-1</sup> )	4.51	3.18	2.43	1.96
Cation saturation (%)	33.2	46.8	33.3	22.7

LS = loamy sand, S = sand, EC = electrical conductivity, CEC = cation exchange capacity, P = phosphorus, NH<sub>4</sub>OAc = ammonium acetate, Ca<sup>2+</sup> = calcium cation, Mg<sup>2+</sup> = magnesium cation, K<sup>+</sup> = potassium cation, Na<sup>+</sup> = sodium cation, and TEC = Total exchangeable cations

### Site preparation and experimental design

The soil adjacent to the site, 0-30 cm depth from the surface, was sampled, air-dried to a constant weight at room temperature, and sieved through an 8 mm sieve. The soil was mixed with raw vermiculite and pre-heated vermiculite MK1 (600 °C) in varying amounts. Amounts of vermiculite added to the soil were 0, 10, 20, 30, 40, and 50% volume by volume (v/v). A total of 12 treatments was obtained, 6 treatments of soil mixed with raw vermiculite and another 6 treatments of soil mixed with pre-heated vermiculite. Each treatment was replicated three times, giving a sum of 36 samples.

Two sets of samples were made, each with 36 samples. The first set comprised 36 samples from 12 treatments for burying at 0-15 cm from the surface while another set of 36 samples were for burying at 15-30 cm depth. Thus, the total samples used were 72. Each sample weighed one kg of dry weight. Sulphate of ammonia ( $240 \text{ mg N kg}^{-1}$  soil), triple super phosphate (TSP) ( $160 \text{ mg P kg}^{-1}$  soil), and sulphate of potash ( $200 \text{ mg K kg}^{-1}$  soil) were applied to each soil/vermiculite mix, mixed well by hand, and packed into labelled sample bags. The TSP was ground before mixing.

The experimental site (10 m by 30 m) was cleared, ploughed, and harrowed to remove all vegetation in order to avoid interference from plant nutrient uptake. Two main plots were made, one for burying the samples at 0 -15 cm and another plot for burying the samples 15 -30 cm from the surface. Each plot was further subdivided into two sub-plots. One sub-plot was for replicated samples mixed with raw vermiculite and another sub-plot for replicated samples applied with pre-heated vermiculite.

Sample burial holes were made using a hoe. A ruler was used to check for the maximum depths (15 and 30 cm from the surface). In each hole, a small litter bag (polyethylene net) with a capacity of carrying about 2 kg of soil/vermiculite mix was inserted. The prepared samples were put into the litter bags and covered by soil. Sample locations were marked using labelled plastic pegs. The samples were spaced 150 cm apart in each of the sub-sub plots and were buried for 90 days. Weeding was done regularly by hand.

Rainfall and soil moisture at the site were recorded daily during the entire period of the field experiment. The rainfall was recorded using a rain gauge while soil moisture at 0-15 cm depth from the surface was automatically measured using time domain reflectometry (TDR) probes. The instruments were installed at the site by the Department of Soil Science of the Kyoto University from Japan.

After 90 days, the buried samples were carefully excavated, ground by hand, and sieved through a 2 mm sieve for laboratory analysis. Analysis of extractable nutrients retained by the soil/vermiculite mix was carried out at the University of Aberdeen, Department of Plant and Soil Science, in the United Kingdom. The samples were analysed for ammonium and nitrate after digestion with 1M KCl (Allen, 1989) by flow injection analysis (Tecator FIAstar 5010 Analyser). The samples for extractable P and K were digested by using acetic acid (Allen, 1989). Extractable P was determined by flow injection analysis (Tecator FIAstar 5010 Analyser), while the K was analysed by flame emission spectrometry (Perkin Elmer Aanalyst 100). All instruments are from International Scientific Instruments (ISI) of Europe.

### **Data analysis**

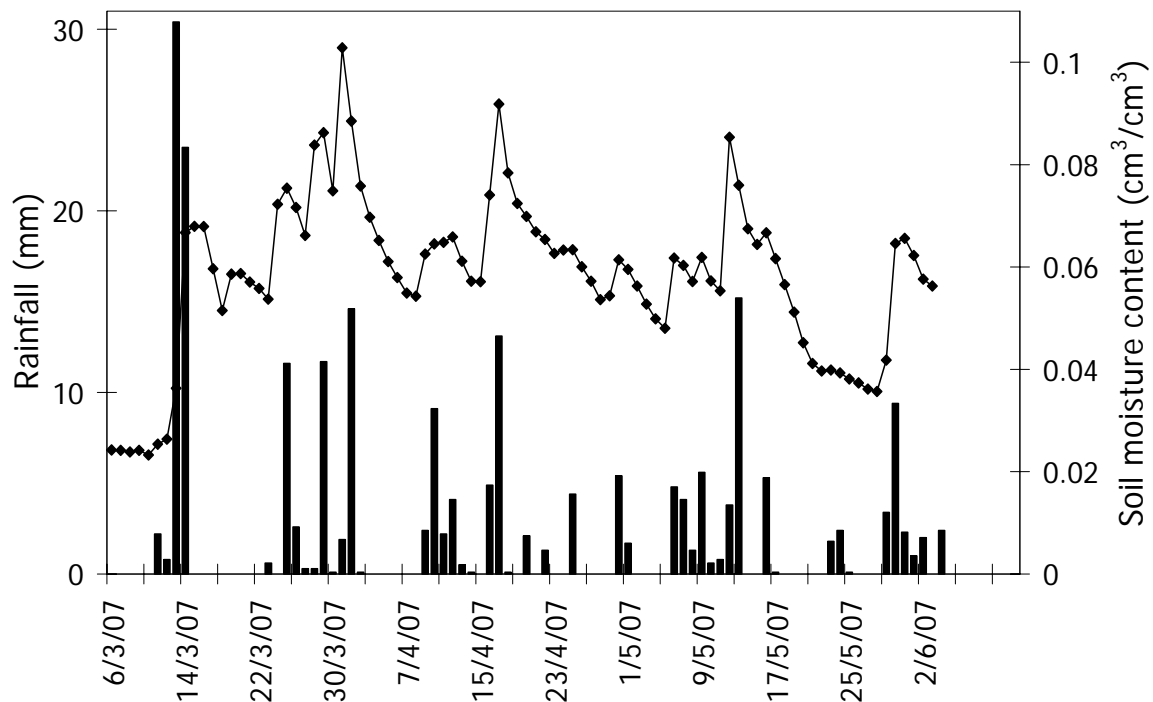
Analysis of variance (ANOVA) was done using the MSTATC software and separation of the treatment means were carried out using the Duncan's multiple-range test at the 5% level of significant (Freed *et al.*, 1991).

## RESULTS AND DISCUSSION

### Site rainfall and soil moisture

Rainfall recorded at the site was low and unevenly distributed with several days of dry spells (Fig.1). The total precipitation was 216 mm. Daily rainfall distribution was between 0 - 30 mm, with 0.1 mm as the median. The total amount received was far below the average annual rainfall of 1042 mm received in the country (Agrawala *et al.*, 2003). The low and erratic rainfall during growing seasons with periods of dry spells is a common phenomenon in most parts of Tanzania (Mapande and Reason, 2005).

Volumetric soil moisture content at the site was also low and ranged between 0.02 and 0.1  $\text{cm}^3/\text{cm}^3$  (Fig.1). The moisture content corresponded closely to the magnitude of precipitation, with high values obtained immediately after heavy rainfall. Although the soil texture influences moisture content, the short duration and low intensity of precipitation experienced at the site might have been the main contributing factors for the low moisture content. A similar observation has also been reported by Pan *et al.* (2008).



**Fig.1.** Site rainfall and soil moisture recorded from 6/3/07 to 6/6/07 during the field experiment in Tanzania. The curve represents the soil moisture content at 0-15 cm depth from the surface, while histograms denote the rainfall received at the site.

(Source: Department of Soil Science, Kyoto University, Japan).

## Retention and fertilization of plant nutrients in soil

Vermiculite burial depth caused a significant difference ( $P < 0.05$ ) in the retention of extractable nitrate, K and P but not ammonium (Table 2). The retention of those nutrients was more at 15-30 cm than at 0-15 cm due to the variation in temperature and soil moisture from rainfall. Temperature and soil moisture from rainfall are the factors that enhance the solubility and mobility of the nutrients and are usually higher at the surface than at depth. The temperature enhances P solubility (Kwari and Batey, 1991), while more soil moisture increases the degree of P saturation and mobility (Casson *et al.*, 2006) and, thus, more leaching of P at the surface than at depth. Similarly, more soil moisture from rainfall at the surface dissolves water soluble  $K^+$  and transport it down the soil profile. In addition, surface temperature enhances both the availability of exchangeable  $K^+$  (Grava *et al.*, 1961) and the intensity of leaching during rainfall.

**Table 2.** Effect of burial depth on the retention of ammonium, nitrate, extractable P and K in soil amended with vermiculite

Burial depth, cm	Ammonium mg kg <sup>-1</sup> soil	Nitrate mg kg <sup>-1</sup> soil	P mg kg <sup>-1</sup> soil	K mg kg <sup>-1</sup> soil
0-15 (Control)	2.2 <sup>a</sup>	3.1 <sup>b</sup>	51.3 <sup>c</sup>	50.2 <sup>c</sup>
15-30 (Control)	2.1 <sup>a</sup>	2.6 <sup>b</sup>	51.3 <sup>c</sup>	50.0 <sup>c</sup>
0-15 (All vermiculite)	2.3 <sup>a</sup>	3.6 <sup>b</sup>	94.3 <sup>b</sup>	64.0 <sup>b</sup>
15-30 (All vermiculite)	2.1 <sup>a</sup>	11.4 <sup>a</sup>	114.8 <sup>a</sup>	70.4 <sup>a</sup>
Standard error	0.3	0.4	2.7	2.1
CV, %	44.1	54.9	10.1	14.9

Means in a column followed by the same superscript letter are not significantly different at  $P < 0.05$  according to the Duncan's multiple-range test. CV = Coefficient of variation.

The applied N-fertilizer dissolves easily when there is sufficient soil moisture and undergoes hydrolysis to ammonium, via nitrification it leads to denitrification (Bijoor *et al.*, 2008). Apart from nitrification and denitrification, N is also lost from agricultural soils by ammonia volatilization, a phenomenon that is enhanced with the increase in temperature and soil moisture (Sigunga *et al.*, 2002). Also the mobility of nitrate is increased with the increase in soil moisture (Sánchez-Martín *et al.*, 2008). Since there were no plants grown at the site for plant off take, leaching by infiltrating water might have been the main mechanism through which P and K were lost, whereas leaching as nitrate and emission to the atmosphere as gas might have been the mechanism behind the loss of the applied sulphate of ammonia.

The soil at the site is loamy sand (Table 1). Loamy sands have a high proportion of drainage pores and, thus, are permeable (Haygarth and Jarvis, 1999). When it rains, rainwater and dissolved plant nutrients are rapidly lost from the upper layers. Interception of some of the infiltrating rainwater by the upper soil horizon and loss through evaporation reduces the amount of water at 15-30 cm depth and, thus, reduction in loss of nutrients at that level. A similar observation was made by Cai *et al.* (2002) when studying N losses from buried fertilizers.

Burial depth for the control did not cause any difference in the retention of the applied macronutrients (Table 2). In addition, the amount of nutrients retained in the control was significantly lower than that retained in soil applied vermiculite, with the exception of ammonium. Retention of nitrate, P and K increased with the increase in the amount of vermiculite added to the soil (Table 3). This indicates that vermiculite contributed to enhancing nutrient retention in the sandy soil.

Extractable P was highly retained in soil amended with raw vermiculite than expanded vermiculite (Table 4). The high P in soil mixed with raw vermiculite might be due to the contribution of extractable P from apatite and monazite, which was significantly suppressed in expanded vermiculite as a result of heating (Marwa, 2009). Contrary to P, extractable K was marginally higher in soil amended with expanded vermiculite than in soil with raw vermiculite, probably due to the increased availability of exchangeable  $K^+$  caused by heating vermiculite (Marwa, 2009). According to Marwa (2009), the exchangeable  $K^+$  in expanded vermiculite MK1 heated at 600 °C is 10 fold more than in raw vermiculite, but the observed difference in the amount of K retained between the two products was quite small. Probably, part of the exchangeable  $K^+$  in expanded vermiculite was lost by leaching or fixation.

**Table 3.** Effect of amount of vermiculite added to the sandy soil on the retention of ammonium, nitrate, extractable P, and K

Vermiculite added, % v/v	Ammonium mg kg <sup>-1</sup> soil	Nitrate mg kg <sup>-1</sup> soil	P mg kg <sup>-1</sup> soil	K mg kg <sup>-1</sup> soil
0	2.1 <sup>abc</sup>	2.8 <sup>c</sup>	51.3 <sup>f</sup>	50.1 <sup>e</sup>
10	1.6 <sup>c</sup>	3.5 <sup>c</sup>	61.5 <sup>e</sup>	56.1 <sup>de</sup>
20	1.8 <sup>bc</sup>	5.3 <sup>bc</sup>	83.4 <sup>d</sup>	61.8 <sup>cd</sup>
30	2.1 <sup>abc</sup>	6.9 <sup>b</sup>	97.2 <sup>c</sup>	65.9 <sup>bc</sup>
40	2.6 <sup>ab</sup>	8.0 <sup>b</sup>	119.5 <sup>b</sup>	74.0 <sup>ab</sup>
50	2.9 <sup>a</sup>	13.8 <sup>a</sup>	161.3 <sup>a</sup>	78.2 <sup>a</sup>
Standard error	0.3	1.1	2.8	2.8
CV, %	44.1	54.9	10.1	14.9

Means in a column followed by the same superscript letter(s) are not significantly different at  $P < 0.05$  according to the Duncan's multiple-range test. CV = Coefficient of variation.

**Table 4.** Overall retention of ammonium, nitrate, extractable P, and K in a sandy soil as influenced by the added raw and expanded vermiculites

Type of vermiculite	Ammonium mg kg <sup>-1</sup> soil	Nitrate mg kg <sup>-1</sup> soil	P mg kg <sup>-1</sup> soil	K mg kg <sup>-1</sup> soil
Control	2.1 <sup>a</sup>	2.8 <sup>c</sup>	51.3 <sup>c</sup>	50.1 <sup>c</sup>
Raw vermiculite	2.2 <sup>a</sup>	8.6 <sup>a</sup>	126.3 <sup>a</sup>	60.6 <sup>b</sup>
Expanded vermiculite	2.3 <sup>a</sup>	6.4 <sup>b</sup>	82.8 <sup>b</sup>	73.9 <sup>a</sup>
Standard error	0.2	0.6	1.6	1.6
CV, %	44.1	54.9	10.5	14.9

Means in a column followed by the same superscript letter are not significantly different at  $P < 0.05$  according to the Duncan's multiple-range test. CV = Coefficient of variation

Retention of nitrogen as nitrate and ammonium showed a different pattern from that of P and K. The amount retained was very low as compared to P and K. In addition, retention of ammonium did not show any significant difference among the treatments. In proportion, nitrate in soil amended with expanded vermiculite was slightly lower than in soil that was applied raw vermiculite (Table 4).

The results of the combined effects of the burial depth with the type and amount of vermiculite added to the soil on the retention of the applied nutrients are summarized in Table 5. From that table it shows that retention of applied nutrients increased with the depth of burial and the amount of vermiculite added to the soil. Ammonium and nitrate were much less retained than the other nutrients. The maximum ammonium retained was 4 mg kg<sup>-1</sup> in the soil mixed with 50% expanded vermiculite and buried at 0-15 cm. The amount retained was less than 2% of the original 240 mg kg<sup>-1</sup> of N-fertilizer applied. For the nitrate, maximum retention was 23.8 mg kg<sup>-1</sup> and was found in soil amended with 50% expanded vermiculite and buried at 15-30 cm. Similarly, this retention was insignificant (< 10%) when compared to the 240 mg kg<sup>-1</sup> of N-fertilizer applied.

In the soil environment, ammonium and nitrate ions are very mobile and biologically labile. When applied as mineral fertilisers in soils they are easily lost by leaching or lost into the atmosphere in gaseous forms (Cai *et al.*, 2002), thus explaining the low recovery. The loamy sand at the site has a high permeability which would have favoured leaching. Nitrate in agricultural soils is commonly depleted by leaching to the deeper layers below the rooting zone where it accumulates or enters the saturated phase (Fang *et al.*, 2006). From this study, it is clear that vermiculite is incapable of prolonging the retention of appreciable amount of N as ammonium or nitrate in the soil for plant growth for more than 90 days.

Although K retained in the soil increased with the amount of vermiculite applied, the overall fraction retained was slightly low as compared to the original 200 mg K kg<sup>-1</sup> applied to the soil. Potassium in the control regardless of the burial depth was about 25%. In the soil which raw vermiculite was added, the K retained ranged between 26-34%, whilst in soil applied expanded

vermiculite was 29-48%. The observed low K in both treatments might have been caused by leaching or fixation in vermiculite as a result of climate-controlled wetting and drying cycles (Carter and Singh, 2004). Contractions of the interlayer space in vermiculite on drying can lead to the entrapment of the K (Sparks and Huang, 1985) and, thus, reduction in extractable fractions.

The amount of P-fertilizer applied (TSP) to the soil was 160 mg P kg<sup>-1</sup>. The fraction retained in the control at 0-15 cm depth was 25-26%, whilst at 15-30 cm was 38-39%. In soil amended with raw vermiculite, P retained at 0-15 cm ranged from 33 to 111%, while at 15-30 cm was 51-141%. It is obvious that raw vermiculite not only retained the applied P, but also fertilized the soil by adding more extractable P. Fertilization might have been attributed to the extractable P from apatite and monazite as mentioned earlier. Phosphorus recovered from the soil applied with expanded vermiculite was 29-74% at 0-15 cm and 41-78% at 15-30 cm. Thus, in comparison with N and K, P was more retained and in some cases fertilized by applied vermiculite. Vermiculite should preferably be buried at 15-30 cm from the surface for better performance.

Phosphorus dynamics in soils is complex. It undergoes slow sorption (fixation) and desorption (release) processes (Sanchez *et al.*, 1997). The presence of organic matter enhances its mobility while the presence of Fe and Al oxides and hydroxides reduces its mobility by fixation (Kwabiah *et al.*, 2003). However, it is considered to be less mobile particularly in fine-textured soils, but leaches in a substantial amount when applied to sandy soils (Humphreys and Pritchett, 1971). Since P was applied to the sandy soil and a substantial amount was retained by the soil for more than 90 days over the control, it is a proof that vermiculite enhanced its retention and fertilization. Thus, from this study we can conclude that this Tanzanian vermiculite has a marked ability of enhancing the retention of extractable P when applied to the sandy soil under a tropical climate.

## CONCLUSIONS

The study has established that vermiculite is incapable of adequately enhancing the retention of N as ammonium and nitrate in a sandy soil for more than 90 days under the tropical Tanzanian climate. Potassium was slightly retained but the fraction retained was less than 50% of the originally applied amount. In addition, part of the exchangeable K<sup>+</sup>, which is 10-fold more in expanded vermiculite than in raw vermiculite was also lost. In comparison with N and K, P was more retained and in part fertilized by vermiculite applied to the soil. The maximum P retained in soil applied with expanded vermiculite was 78%, whereas in soil amended with raw vermiculite the amount retained and fertilized was 141%. Fertilized P came from apatite and monazite, which are accessory minerals in vermiculite. Thus, it was concluded that vermiculite when added to a sandy soil under tropical condition has a marked ability of enhancing the retention and fertilization of P followed by K. More retention occurs when vermiculite is buried at 15-30 cm from the surface than at 0-15cm. Effective utilization of vermiculite can reduce the burden of replenishing tropical soils with the same amount of P and K-fertilizers.

## ACKNOWLEDGEMENT

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**Table 5.** Combined effects of the burial depth, amount, and type of vermiculite applied to the soil on the retention of ammonium, nitrate, extractable P, and K

Vermiculite added to the soil % v/v	Soil mixed with raw vermiculite and buried at 0-15 cm			
	Ammonium mg kg <sup>-1</sup> soil	Nitrate mg kg <sup>-1</sup> soil	P mg kg <sup>-1</sup> soil	K mg kg <sup>-1</sup> soil
0	2.3ab	1.6e	40.3j	49.1f
10	1.8b	1.5e	52.3hij	51.9f
20	2.0b	3.0de	88.8f	57.6ef
30	2.1ab	4.4cde	112.5e	60.0def
40	2.4ab	4.7cde	132.9cd	60.0def
50	2.4ab	4.9cde	176.9b	64.2def
	Soil mixed with raw vermiculite and buried at 15-30 cm			
0	2.0b	4.5cde	62.3hi	51.3f
10	2.1ab	8.8bcde	81.3fg	53.9f
20	2.4ab	11.2bc	121.2de	60.3def
30	1.7b	12.9b	128.3cde	62.5def
40	2.5ab	13.1b	143.3c	67.2cdef
50	2.6ab	21.3a	225.9a	67.9cdef
	Soil mixed with expanded vermiculite and buried at 0-15 cm			
0	2.1ab	1.9e	41.5j	49.3f
10	1.4b	1.7e	47.0ij	57.2ef
20	1.5b	2.8de	57.0hij	62.7def
30	2.7ab	3.6de	66.9gh	65.3cdef
40	3.0ab	4.3cde	91.1f	77.4bcd
50	4.0a	5.2cde	118.0de	83.8abc
	Soil mixed with expanded vermiculite and buried at 15-30 cm			
0	2.0b	3.3de	61.0hi	50.6f
10	1.2b	2.1e	65.3ghi	61.6def
20	1.2b	4.1cde	66.6gh	66.7cdef
30	2.2ab	6.7bcde	80.9fg	75.7bcde
40	2.7ab	10.0bcd	110.6e	91.3ab
50	2.7ab	23.8a	124.2de	96.9a
Standard error	0.6	2.1	5.6	5.5
CV, %	44.1	54.9	10.1	14.9

Means in a column followed by the same superscript letter(s) are not significantly different at  $P < 0.05$  according to the Duncan's multiple-range test. CV = Coefficient of variation.

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# ORGANIC MATTER AND HUMUS CHARACTERISTICS OF SOME VOLCANIC ASH SOILS OF SOUTH WESTERN TANZANIA

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## ABSTRACT

This study was done on soils developed from volcanic parent materials including pumice and ashes originating from various volcanoes in and around the Rift Valley of South Western Tanzania. The soil moisture and temperature regimes in the area are udic and isothermic respectively. One pedon close to Lake Nyasa (Mwaya) had aquic SMR and isohyperthermic STR. Soil OC content varied widely among and within pedons, with surface horizons generally having higher values (high to very high). N levels also varied similarly and correlated very well with OC. C:N ratios were very variable and increased with increasing OC. Based on the distribution of OC, N, C:N ratios and the relationship among these parameters, the Tanzanian volcanic ash soils compare quite well with known Japanese volcanic ash soils, although the absolute values of OC were much higher for Japanese than for Tanzanian soils. Results on humic acid studies indicate that the soils predominantly contain **A type** humic acids particularly in the surface A horizon, buried A, AB and BA horizons. These horizons are characteristically humus-rich with intense dark colors. UV-VIS absorption spectra revealed in some soils the presence of **Pg** fraction with absorption bands around (280), 450, 570 and 615 nm, which are normally associated with the presence of dihydroxyperylenequinone (**DHPQ**) nuclei responsible for the absorption bands at those wavelengths. On the basis of  $\Delta\log K$ , RF, HE, PQ values and the UV-VIS absorption spectra, the characteristics of HAs of the Tanzanian volcanic ash soils compare very well with Japanese volcanic soils.

Key words: Organic matter, humus characteristics, volcanic ash soils, Tanzania

## INTRODUCTION

The area in and around the Rift Valley of South western Tanzania between Mbeya town and Lake Nyasa is dominated by soils developed from volcanic parent materials. The main underlying bedrock type is basalt which is covered by thick blankets of pumice and ashes (Karlsson and Messing, 1980). Although there are several volcanoes in the area, the origin of the pumiceous and ash pyroclastics in the area is more attributed to Mts. Rungwe and Poroto, the two largest volcanoes (Stockley, 1948; Harkins, 1960). These volcanoes produced ejecta which is believed to have been wind-blown south-eastwards and got deposited to form many tephra layers over the geomorphologically stable plateau of Southern Highlands. The morphology of the soils in the area is typical of volcanic ash soil profiles found in other countries like Japan; showing clear strata of volcanic ash/pumice alternating with buried soil materials (Msanya *et al.*, 2002, 2007). Most of the soils in the study area have very dark colored thick, humus-rich surface horizons. Dark buried A, AB, and BA horizons are also common. These soils are generally classified as Andosols (FAO, 2006) or Andisols (Soil Survey Staff, 2006). Among the mineral soil orders, Andosols contain the largest amounts of soil organic matter (SOM) equivalent to about 5% of the global soil carbon (Dahlgren *et al.*, 2004; Eswaran *et al.*, 1993; Nierop *et al.*, 2007), implying that they contribute immensely to the global C cycle. Organic matter and its characteristics are very useful attributes used in the characterization of Andosols. Quite a lot of literature exists on characterization of

organic matter in Andosols mainly dealing with humic acid fractions, but most of these studies are from Japan. Rather limited studies have been done on the soils of the study area apart from the pedological characterization work by Msanya *et al.* (2007). The objective of the current study was to investigate the content and nature of the organic matter fractions of the soils with special emphasis on the characterization of their humic substances.

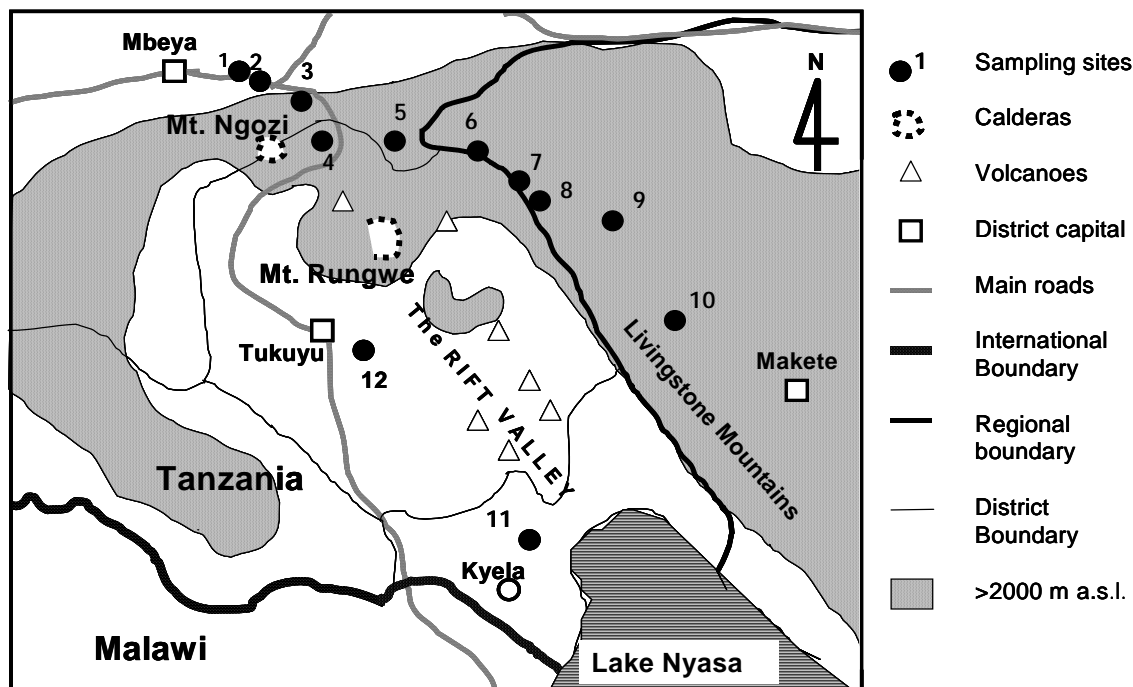


Fig. 1. Location of the studied pedons

## MATERIALS AND METHODS

Soil samples from 12 pedons were used in this study (Fig. 1). Detailed description in terms of their morphological, physical and chemical characteristics has been presented elsewhere (Msanya *et al.*, 2002, 2007). The soils were classified according to the USDA Soil Taxonomy (Soil Survey Staff, 1999). Table 1 gives some salient characteristics of the study area. The mean annual rainfall ranges from 900 to slightly > 2000 mm and temperatures range from slightly < 10 to about 20 °C. The altitude varies from 480 m (Lake Nyasa) to 2900 m (Southern Plateau).

Organic carbon was determined by the Walkley and Black wet oxidation method (Nelson and Sommers, 1982) and converted to organic matter by multiplying by a factor of 1.724. Kjeldahl method (Bremner and Mulvaney, 1982) was used to determine total nitrogen. Melanic index (the ratio of the humic and fulvic acids) was determined according to the method of Honna *et al.* (1988) by dividing the absorbance at 450 nm by the absorbance at 520 nm.

Table 1. Site characteristics of the studied soils

Pedon no.	Site name	Location	Altitude (m asl)	Vegetation / land use	STR	SMR	Soil name (USDA Soil Taxonomy)
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1	Uyole 1	<b>S 08°54'25"</b> E 33° 31' 33"	1792	Maize, wheat, beans	isothermic	udic	<i>Vitrandic</i> <i>Hapludoll</i>
2	Uyole 2	S 08° 55' 16" E 33° 32' 06"	1836	Grazing land (grasses mainly <i>Cynodon spp.</i> , <i>Chloris gayana</i> , <i>Digitaria spp.</i> , <i>Hyperrhenia spp.</i> )	isothermic	udic	<i>Vitrandic</i> <i>Eutrudept</i>
3	Galijembe	<b>S 08°57'43"</b> <b>E 33°36'02"</b>	2180	Irish potatoes, wheat, maize, peas, pyrethrum	isothermic	udic	<i>Pachic</i> <i>Melanudand</i>
4	Isyonje	<b>S 09°00'16"</b> E 33° 37' 37"	2313	Irish potatoes, maize, cabbage, pyrethrum	isomesic	udic	<i>Hydric Pachic</i> <i>Melanudand</i>
5	Nyalwela	<b>S 09°00'10"</b> E 33° 43' 26"	2657	Forest reserve with <i>Hagenia</i> <i>abyssinica</i>	isomesic	udic	<i>Hydric Pachic</i> <i>Melanudand</i>
6	Ilala	<b>S 09°01'17"</b> E 33° 49' 01"	2792	Grazing land (grasses mainly <i>Cynodon spp.</i> , <i>Chloris gayana</i> , <i>Digitaria spp.</i> )	isomesic	udic	<i>Vitric</i> <i>Melanudand</i>
7	Kitulo Comworks	<b>S 09°03'35"</b> E 33° 52' 10"	2870	Grazing land (short grasses locally called <i>Wasumba</i> )	isomesic	udic	<i>Vitric</i> <i>Melanudand</i>
8	Kitulo Central	<b>S 09°05'27"</b> E 33° 54' 30"	2749	Grazing land with scattered Cypress trees ( <i>Cupressus spp.</i> )	isomesic	udic	<i>Hydric</i> <i>Melanudand</i>
9	Ujuni	S 09° 07' 07" E 33° 59' 45"	2607	2 years fallow (normally under potatoes, maize; peas)	isomesic	udic	<i>Hydric Pachic</i> <i>Melanudand</i>
10	Luvulunge	S 09° 14' 49" E 34° 04' 22"	2348	Planted pines ( <i>Pinus patula</i> ), bamboo ( <i>Oxytenanthera abyssinica</i> )	isomesic	udic	<i>Acrudoxic Hydric</i> <i>Melanudand</i>
11	Mwaya	S 09° 34' 25" E 33° 52' 34"	480	Paddy rice	isohyper- thermic	aquic	<i>Aquandic</i> <i>Epiaquept</i>
12	Pakati	S 09° 17' 30" E 33° 40' 26"	1260	Banana	isothermic	udic	<i>Typic</i> <i>Hapludand</i>

STR= soil temperature regime

SMR= soil moisture regime

Humus composition analysis was carried out using modified Kumada *et al.* (1967) method. Humic acid (HA) and fulvic (FA) acid fractions were extracted using 0.1N NaOH and 0.1N 0.1 N Na<sub>4</sub>P<sub>2</sub>O<sub>7</sub> (formulated at the ratio of 1:1) to soil samples which were heated, cooled, centrifuged and filtered. The separation of the two acids was done by adding concentrated H<sub>2</sub>SO<sub>4</sub> which precipitated out HA and left the FA in solution. The HA precipitate was dissolved using 0.1N NaOH. The UV-VIS spectra of HA solutions were analyzed within 2 hours of dissolution for absorbances at 230 to 700 nm using a JASCO-V530 UV-VIS spectrophotometer.  $\Delta\log K$  values were calculated using the formula:  $\Delta\log K = \log (K_{400}/K_{600})$ , where  $K_{600}$  and  $K_{400}$  indicate the absorbance at 600 and 400 nm respectively. The amounts of HA and FA were determined by permanganate titration following the method by Ohba (1964). Extracted humus (HE) was taken as the sum of 0.1 N KMnO<sub>4</sub> ml consumed by HA and FA fractions of the two extracts per 1 g soil. **a** and **b** were the amounts of HA and FA respectively, calculated as ml of 0.1 N KMnO<sub>4</sub> consumed by the fractions of each extract corresponding to 1 g of soil sample. PQ, the % of HA in extracted humus =  $\{a/(a + b)\} * 100$ . RF =  $K_{600} \times 1000 / \text{ml of } 0.1 \text{ N KMnO}_4 \text{ consumed by } 30 \text{ ml of the HA used for determining the absorption spectra}$ . The type of humic acid was determined using Kumada's classification scheme (Kumada, 1987).

## RESULTS AND DISCUSSION

### Organic carbon, total nitrogen and C:N ratio

The OC content of the studied soils varied widely among and within the studied pedons. Generally the OC contents of surface horizons were higher than those in the subsurface horizons. Except for pedons 1 and 2 (Uyole 1 and 2) the OC levels in the surface A horizons can be rated as high to very high, with values ranging between 4.4 to 10.2 (Table 2). This corresponds well with the intense dark colors of these horizons, with color values and chromas as low as 2 and 1 respectively. In the surface horizons of pedons 1 and 2, the OC levels were low and medium respectively. OC content was highest (10.2%) in pedon 5 (Nyalwela) which is under natural forest reserve. N levels were also widely variable among and within pedons and correlated very well with OM content ( $Y = 0.043X - 0.0064$ ,  $R^2 = 0.98$ ) (Fig. 2). The values ranged from 0.04 (very low) to 0.57 (high). The C:N ratios were also very variable among and within pedons with values ranging between 6 and 26 (Table 2). According to Landon (1991) and Baize (1993) the quality of OM for most horizons can be rated as moderate (C:N values of 14 to 20). On the basis of OC and N contents and C:N ratio, the inherent fertility of most soils can be rated as moderate. Fig. 3 and 4 show the relationship between OC and C:N ratio respectively for Tanzanian volcanic ash soils and Japanese volcanic ash soils (database from Wada, 1986). The distribution pattern and values for C:N ratios look quite similar although the absolute values of OC were much higher for Japanese soils than for Tanzanian soils. Generally, the C:N ratios increased with OC for both Tanzanian and Japanese volcanic ash soils. Similar observation was made by Otsuka *et al.* (1988) for volcanic ash soils of the Phillipines.

Table 2. Organic matter content and some related data of 36 selected horizons of the studied soils

Pedon	Horizon	Depth cm	OC %	OM %	Moist color	TN %	C:N
1	Ap	0 - 33	1.9	3.3	10YR3/1	0.14	14
	3Bwb	56 - 131	1.0	1.7	10YR4/4	0.06	16
	3BCtb	131 - 185+	0.8	1.3	10YR4/3	0.04	19
2	Ap	0 - 41/45	3.2	5.5	10YR2/2	0.18	18
	2Bwb	50 - 115	1.2	2.1	7.5YR2.5/1	0.08	15
	3BCtb	>200	0.8	1.3	10YR4/3	0.05	15
3	Ap	0 - 54	7.1	12.2	10YR2/1	0.48	15
	AB	54 - 80/95	3.8	6.6	10YR3/1	0.23	16
	2Ahb	80/95 - 155	3.2	5.5	10YR2/1	0.20	16
4	Ap1	0 - 18	7.0	12.1	10YR3/3	0.42	17
	Ap2	18 - 78/82	8.2	14.2	10YR2/1	0.52	16
	2Bwb	88/90 - 134	2.7	4.7	10YY3/6	0.20	13
5	Ah1	0 - 12/18	10.2	17.5	10YR2/1	0.57	18
	Ah2	12/18 - 77/92	8.8	15.2	10YR2/2	0.44	20
	C	77/92 - 175	0.3	0.6	10YR5/6	0.05	6
6	Ap	0 - 33/50	6.4	10.9	10YR2/1	0.34	19
	C	33/50 - 53/60	1.7	3.0	7.5YR5/6	0.15	11
	3Ab	90 - 122/140	1.6	2.7	10YR2/1	0.11	14
7	Ah	0 - 32/42	6.7	11.6	10YR2/1	0.38	18
	2Cb	80/89 - 100/105	1.5	2.6	10YR2/1	0.08	19
	3Ab	100/105 - 141	1.5	2.5	10YR3/4	0.08	17
8	Ap	0 - 40/47	6.4	11.0	10YR2/1	0.35	18
	2Ab	55/60 - 75/89	5.0	8.6	10YR2/1	0.38	13
	4Ab	174/180 - 190/202	2.6	4.4	10YR3/2	0.10	26
9	Ap	0 - 38/51	6.8	11.7	10YR2/1	0.31	22
	2Ab	98 - 110	3.9	6.7	10YR3/2	0.25	15
	2BAtb1	110 - 145/154	3.5	6.0	10YR3/3	0.19	18
10	Ah	0 - 30/35	7.6	13.1	10YR2/1	0.49	16
	2Ab	49 - 98	5.3	9.1	10YR3/3	0.31	17
	2BAb	98 - 120/125	3.4	5.8	7.5YR3/4	0.18	19
11	Ap	0 - 17/20	4.4	7.6	10YR2/1	0.37	12
	Bwg1	17/20 - 30	0.8	1.4	10YR5/3	0.05	15
	Bwg2	30 - 80+	0.7	1.2	10YR 6/3	0.05	13
12	Ap	0 - 27	7.7	13.3	10YR2/1	0.52	15
	Ah	27 - 50	1.2	2.0	10YR2/1	0.09	13
	CB	50 - 100+	1.1	1.9	10YR6/8	0.07	17

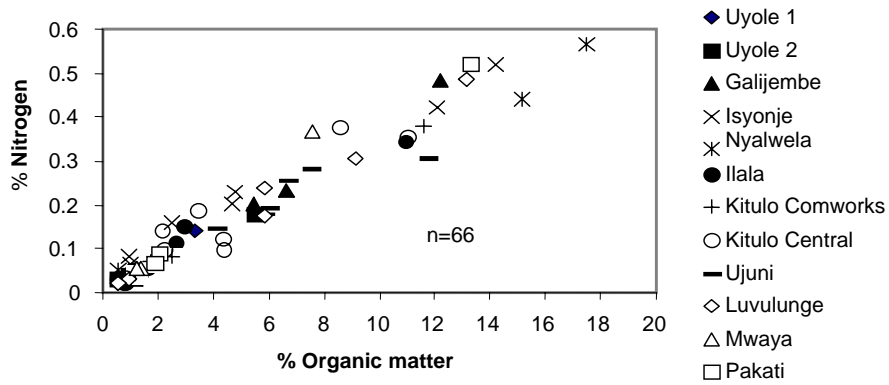


Fig. 2. Relationship between nitrogen and organic matter for Tanzanian volcanic ash soils

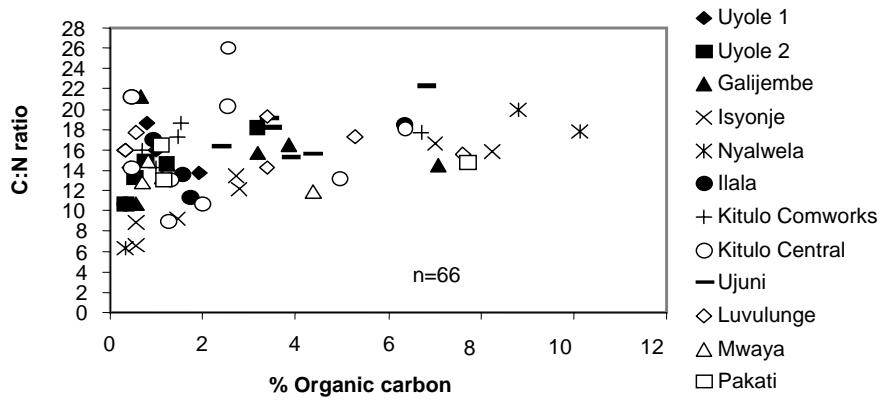


Fig. 3. Relationship between organic carbon and C:N ratio for Tanzanian volcanic ash soils

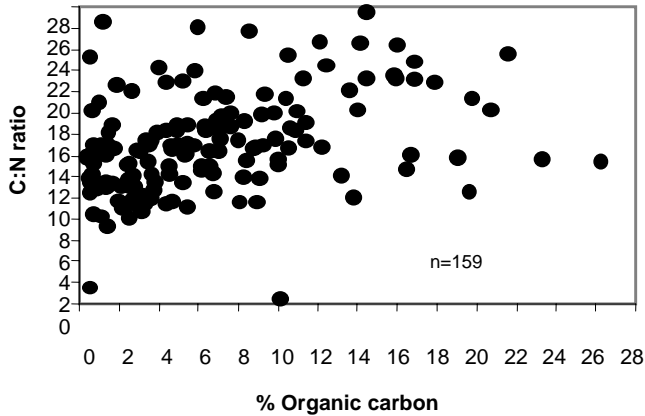


Fig. 4. Relationship between organic carbon and C:N ratio for Japanese volcanic ash soils

## Humus composition

Table 3 gives the humus composition analysis of the studied soils. HE (extracted humus) values for the studied pedons range from 1.3 (Bwg1 horizon of pedon 11- Mwaya) to 103.6 (surface A horizon of pedon 8- Kitulo Central). It was generally observed, that, the HE values were highest in the topsoils and decreased with depth, although the PQ (% of HA in extracted humus) values did not always decrease correspondingly. Similar observations were made by Wada (1986) and Kumada (1987) for Japanese soils and Otsuka *et al.* (1988) for soils of the Philippines. The PQ ratios ranged from 10 to 67 and most values were distributed between 30 and 67. Among the PQ values for the different horizons, most of those representing surface A, buried A, AB and BA were the highest.

The classification of the humic acids was done using Kumada *et al.* (1987) method based on  $\Delta \log K$  and RF values (see Fig. 5 and Table 3).  $\Delta \log K$  (color tone) values ranged between 0.469 (horizon 2Cb of pedon 7- Kitulo Comworks) and 0.663 (horizon C of pedon 5- Nyalwela). Such a narrow range was observed for volcanic ash soils of Japan (Wada, 1986) and for similar soils in the Phillipines (Otsuka *et al.*, 1988). On the basis of Kumada's classification (Kumada, 1987), the studied Tanzanian soils predominantly contained A type humic acids particularly in the surface A, buried A, AB and BA horizons. Twenty seven out of 36 horizons (75%) have this type of humic acids. Other types of humic acids observed in the soils are B and P which are found mostly in the subsoils (B and C horizons). Rp type humic acid was not detected in the studied soils. Rp type humic acids normally represent early stages in the humification process, whereas the P, B and A types represent stable forms of humic acid (with stability increasing from P to B to A). Worthwhile noting is the observation that in all the horizons with A type humid acid, the melanic index is 1.7 or less, whereas in the cases where B and P type humic acids appear the melanic index is  $>1.7$ . This can serve as a valid criterion of differentiating the latter two from A type humic acid. The appearance of P type humic acids in surface A horizon of pedon 4 (Isyonje) was unexpected. However, this could be explained by the fact that this pedon is situated near a homestead, from which it could be receiving fresh organic materials being disposed as household refuse.

Table 3. Humus characteristics of selected horizons of the studied soils

Pedon	Horizon	Depth (cm)	a	b	HE	PQ	$\Delta \log K$	RF value	Melanic index (MI)	HA type
1	Ap	0-33	6.6	9.1	15.6	42	0.564	82	1.6	A
	3Bwb	56-131	3.3	2.5	5.8	57	0.547	67	1.8	P
	3BCtb	131-185	1.1	2.0	3.1	35	0.527	59	1.8	P
2	Ap	0-41/45	22.4	10.9	33.3	67	0.534	83	1.6	A
	2Bwb	50-116	4.7	3.6	8.4	57	0.541	105	1.6	A
	3BCtb	>200	1.1	1.2	2.3	46	0.529	62	1.8	P
3	Ap	0-54	27.0	23.8	50.8	53	0.548	114	1.7	A
	AB	54-80/95	14.6	16.8	31.4	46	0.521	96	1.6	A
	2Ahb	155-178	18.9	11.2	30.1	63	0.548	145	1.5	A
4	Ap1	0-18	21.2	21.8	43.0	49	0.587	52	1.7	P
	Ap2	18-78/82	33.6	32.5	66.1	51	0.542	163	1.6	A
	2Bwb	88/90-134	6.3	9.6	15.9	40	0.521	101	1.7	A
5	Ah1	0-12/18	42.4	33.8	76.1	56	0.578	103	1.7	A
	Ah2	12/18-77/92	20.9	31.3	52.2	40	0.546	124	1.7	A
	C	77/92-175	0.3	2.7	3.0	10	0.663	21	2.2	P
6	Ap	0-33/50	39.3	43.1	82.4	48	0.505	106	1.7	A
	C	33/50-53/60	4.3	10.0	14.3	30	0.512	75	1.9	B
	3Ab	90-122/140	11.2	12.9	24.1	46	0.492	108	1.5	A
7	Ap	0-32/42	18.4	50.2	68.6	27	0.498	179	1.5	A
	2Cb	80/89-100/105	5.4	7.7	13.0	41	0.469	121	1.6	A
	3Ab	100/105-141	1.3	2.7	4.0	32	0.505	98	1.7	A
8	Ap	0-40/47	47.8	55.8	103.6	46	0.498	122	1.6	A
	2Ab	55/60-75/89	20.6	31.9	52.4	39	0.481	136	1.6	A
	4Ab	174/180-190/202	13.6	9.6	23.2	59	0.486	82	1.6	A
9	Ap	0-38/51	45.3	43.6	88.9	51	0.526	115	1.5	A
	2Ab	98-110	16.9	18.4	35.3	48	0.523	131	1.6	A
	2BAtb1	110-145/154	17.2	9.8	27.0	64	0.520	133	1.6	A
10	Ah	0-30/35	29.9	43.2	73.1	41	0.577	89	1.7	A
	2Ab	49-98	14.1	23.7	37.8	37	0.518	108	1.7	A
	2BAb	98-120/125	11.7	13.1	24.8	47	0.546	108	1.7	A
11	Ap	0-17/20	21.2	18.7	39.9	53	0.524	118	1.6	A
	Bwg1	17/20-30	0.6	0.7	1.3	49	0.533	34	2.0	P
	Bwg2	30-80+	0.6	2.0	2.6	24	0.524	46	2.2	P
12	Ap	0-27	34.6	29.6	64.2	54	0.586	112	1.7	A
	Ah	27-50	10.4	13.5	23.9	44	0.557	119	1.7	A
	CB	50-100+	2.1	6.1	8.2	25	0.606	58	1.9	B

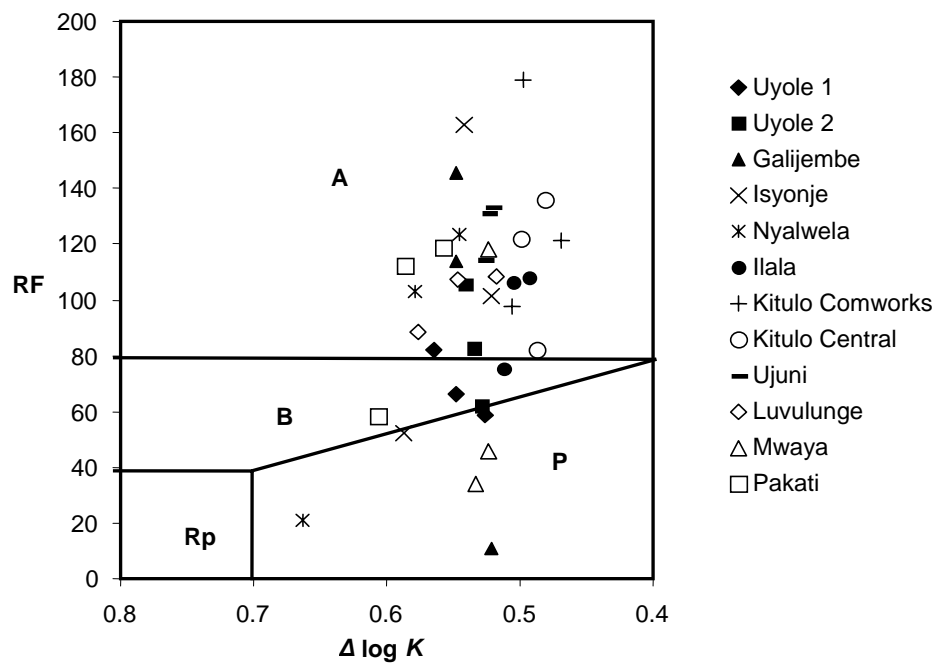
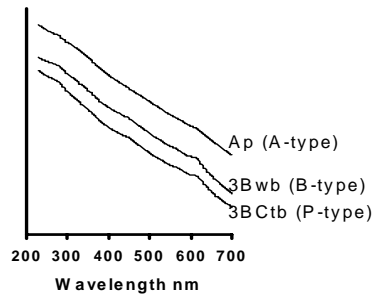


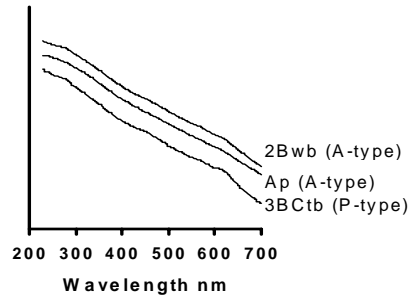
Fig. 5. Classification of humic acids extracted from selected horizons of Tanzanian volcanic ash soils

### UV-VIS spectroscopy

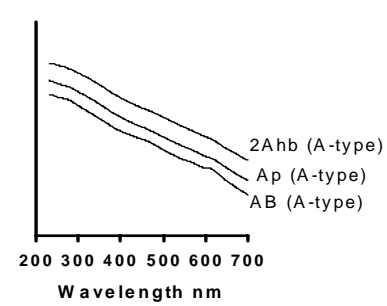
Fig. 6 presents the UV-VIS spectra of the humic acids extracted from selected samples of Tanzanian volcanic ash soils using a mixture of NaOH and  $\text{Na}_4\text{P}_2\text{O}_7$  solutions. The configurations of the UV-



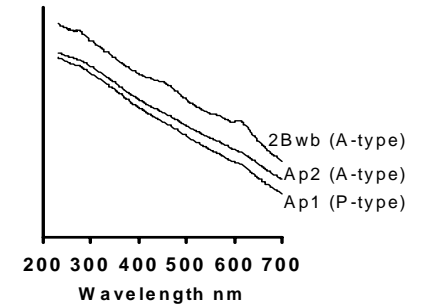
1. Uyole-1



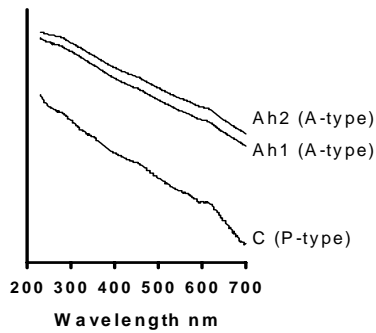
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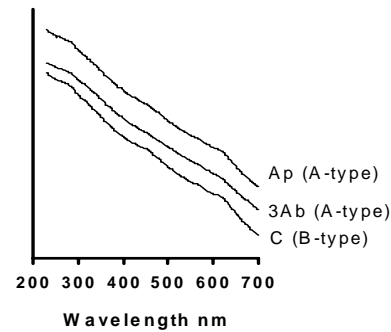
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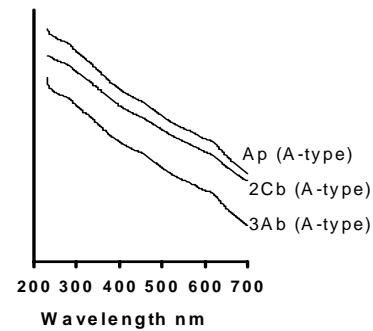
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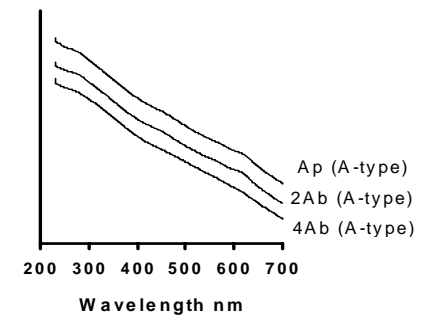
5. Nyalwela



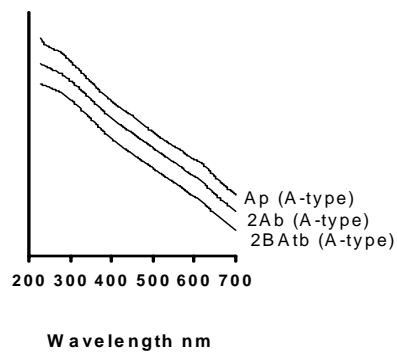
6. Ilala



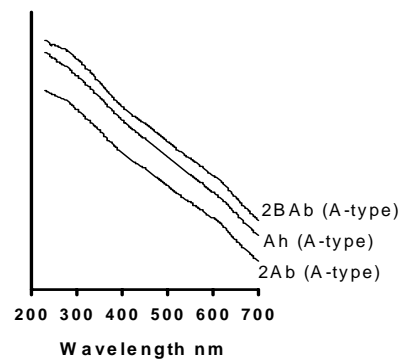
7. Kitulo Comworks



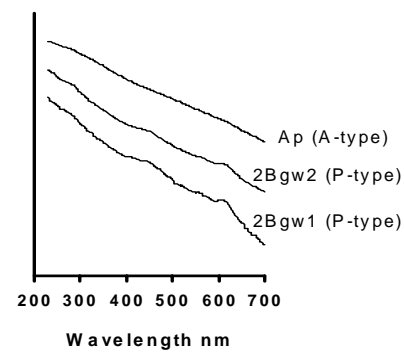
8. Kitulo Central



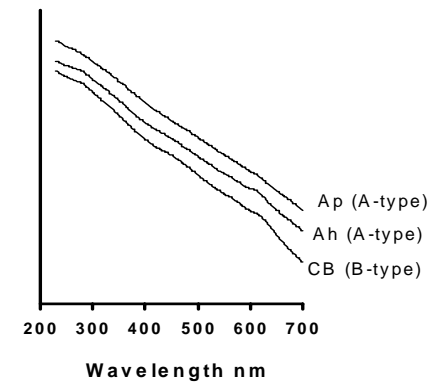
9. Ujuni



10. Luvulunge



11. Mwaya



12. Pakati

VIS spectra and the spacing between spectral lines of humic acids vary among the pedons in function of the type of humic acids. Generally, the spectral lines for A type humic acids particularly for topsoils were rather smooth. However, some B type humic acids showed some weak absorption bands at around (280), 450, 570 and 615 nm (pedons Uyole-1, Ilala and Pakati), commonly referred to in literature as Pg absorption (Kumada, 1987; Otsuka *et al.*, 1988; Fujitake *et al.*, 1999). The P type humic acids had also Pg absorption at the same wavelengths (pedons Uyole-1, Uyole-2 and Mwaya), which is commonly the case according to Kumada's definition of P type humic acid (Kumada, 1987). An interesting observation is the appearance of Pg absorption for A type humic acid in buried horizon 2Bwb of Isyonje pedon, with quite clear absorption bands around 280, 450, 570 and 615 nm. Wada (1986) reported the presence of Pg (green fraction) in A type humic acids for some Japanese Andosols. According to Kumada and Sato (1962) and Sato and Kumada (1967), Pg absorption bands are normally associated with P type humic acid which contains dihydroxyperylenequinone (DHPQ) nucleus responsible for the absorption bands at those wavelengths. Although Pg absorption is commonly associated with soils developed under forest vegetation (Coleman *et al.*, 1989), in this study it that was not the case as the phenomenon was observed in both forest (e.g. Nyalwela pedon) and normal cultivated soils (e.g. Isyonje and Mwaya pedons).

## CONCLUSIONS

The OC content of the studied soils varied widely among and within the studied pedons. Generally the OC contents of surface horizons were higher than those in the subsurface horizons. Except for pedons 1 and 2 (Uyole 1 and 2) the OC levels in the surface A horizons can be rated as high to very high, with values ranging between 4.4 to 10.2. On the basis of OC and N contents and C:N ratio, the inherent fertility of most of the studied soils can be rated as moderate. When comparing Japanese and Tanzanian volcanic ash soils (on the basis of OC versus C:N ratios), the distribution pattern and values for these attributes are quite similar although the absolute values of OC are much higher for Japanese soils than for Tanzanian soils.

On the basis of Kumada *et al.* (1987) classification method for characterization of humic acids, most of the studied soils contain A type humic acids (representing stable forms of humic acids), particularly in the surface A, buried A, AB and BA horizons. Other types of humic acids observed in the soils were B and P (mostly in the subsoils). Rp type humic acids which normally represent early stages in the humification process were not detected in the studied soils.

On the basis of UV-VIS spectroscopy of the studied soils, the Tanzanian Andosols compare very well with Japanese Andosols.

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# Pedological and Soil Fertility Characteristics of *Striga* Infested Soils Under Maize in Chunya and Iringa Districts of Tanzania

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## Abstract

Maize yields in both Iringa and Chunya districts have been reported to be low due to infestation with *Striga*. A study was therefore conducted to characterize *Striga* infested soils and assess their fertility status under maize production in 6 villages of Chunya and Iringa districts. The soils of Iringa were classified as Cambisols and those of Chunya as Arenosols. The results further showed that, the majority of the soils were of sand to loamy sand texture. Such soils are well drained with low water holding capacity, conditions that favour *Striga* germination. The fertility status was established through physical and chemical analyses of the soils. One hundred and four composite soil samples were collected from the two districts. Laboratory analysis showed that most of the soils were acidic with pH ranging from 4.13 to 7.74 and low to medium cation exchange capacity (CEC). Organic carbon was low with a range of 0.01 to 0.07% while total N values were also low ranging from 0.028 to 0.86%. Phosphorus was low with few samples indicating medium values. Exchangeable bases were generally low with most soils having saturation values of < 50%. Overall, the soils are of low fertility status. The low fertility status and the sandy texture are possibly the cause of high *Striga* infestation and low maize yields in the two districts. The soils are of low productivity requiring improvement of their organic matter content and application of inorganic fertilizers if improved maize yields are to be realized. It is further recommended that tillage practices that improve the soil physical conditions be adopted, not only for greater maize yields but also as one of the strategies to control the *Striga* weed.

**Key words:** fertility, maize, soil, *striga*

## Introduction

Maize is the most important food crop grown and consumed in Tanzania. World wide according to Baltazary (2003) maize ranks second among the cereals produced with an average yield of 4 tons ha<sup>-1</sup> and it is the major food crop for many nations. In Tanzania maize is the major food crop and its production contributes 67% of all the cereal crops cultivated (Baltazary, 2003). Although maize is a major food crop in Tanzania, yield per unit area is still low with an average of 1200 kgha<sup>-1</sup> as opposed to the national potential average yield of 4000 – 8000 kg ha<sup>-1</sup>. The main problems of maize production in Tanzania include low fertility status, environmental factors and crop pests. Among the major crop pests *Striga* (witch weed), is widely distributed in the country. Poor crop husbandry practices of also contribute to low maize yields. Maize plant grows and develops well in soils with high contents of N, P and K, under acidic soil condition (Housenbuiller, 1985).

*Striga* is an obligate root parasitic weed that belongs to the *Scrophulariaceae* family. It requires host substrate for seeds to germinate. Attachment to the roots of the host is facilitated by haustoria for drawing water and nutrients (Parker and Riches, 1993). The success of *Striga* as a weed is due to the small size of its seeds, which are easily carried and spread by winds, high number of seeds per plant and lots of time of seed viability of up to 20 years (Parker and Riches, 1993). *Striga* reduces photosynthesis in the field (Mohamed, 2004) through inhibition of nutrients uptake. In doing so *Striga* infestation causes reduction in yield that can vary between 10% to 100% depending on the intensity of infestation (Parker and Riches, 1993). *Striga* are

found predominantly and wide spread in areas where both fertility and rainfall are low (Kim, 1991). The infestation of *Striga* varies between zones, resulting in difference in the variation in crop losses among zones. These variations are as influenced by differences in water availability and soil fertility status (Kwacha, 2001).

The weed is widely spread in farms where maize is grown in Tanzania particularly in Iringa and Mbeya regions. The intensity of infestation varies from one farm to another and from one area to another. Damage caused by *Striga* is more severe in maize than other cereal crops. Other cereal crops that are parasitized by *Striga* weeds include sorghum and millet. These are less common in the Southern Highlands of Tanzania i.e. Iringa and Mbeya regions. According to Kwacha (2001) among cereals, maize is a poor competitor with weeds and therefore more affected by *Striga*.

A study was therefore carried out to characterize the maize growing soils of Iringa and Chunya Districts in terms of physical, chemical and fertility status in order to recommend a package of judicious management options for improved maize yield and control of *Striga*.

## **Materials and Methods**

### ***Soil morphology***

*One representative soil profile was made in the dominant soil of each of the six villages. The soil profiles were excavated to a depth of 200 cm except where soil depth was limited by bedrock or strongly cemented material. These profiles were described according to the standard guidelines for soil profile description (FAO, 1990) to provide data on soil morphology. Bulk soil samples were then taken from each soil horizon for physical and chemical analyses.*

### **Soil fertility evaluation**

Composite soil samples were obtained from 103 farms belonging to contact farmers from three villages in each of the two districts. Sampling was carried out to a depth of 0-20cm. The collected composite samples were air dried, ground to pass through a 2mm sieve and stored in polythene bags ready for laboratory soil analyses.

### **Soil chemical analysis**

Soil pH was measured in both soil/water and 1M KCl suspension using Glass-pH meter (Sparks, 1996). Total nitrogen was determined by the macro-Kjeldahl method (Sparks, 1996). Organic carbon was determined by the Walkley-Black method (Sparks, 1996). Cation exchange capacity was determined by neutral ammonium acetate (Buffered at pH 7.0) saturation method (Sparks, 1996). The exchangeable bases ( $K^+$ ,  $Ca^+$ ,  $Mg^+$ , and  $Na^+$ ) were extracted by ammonium acetate solution and then quantified by Atomic Absorption Spectrophotometer for  $Ca^+$  and  $Mg^+$ , while a flame photometer was used for  $K^+$  and  $Na^+$  (Sparks, 1996). Soil available phosphorus was determined by the Bray-1-Method for soil samples with pH below 7.0 (Bray and Kurtz, 1945) and Olsen method for soil samples with pH above 7.0. Particle size distribution was determined using the Bouyoucous hydrometer method (Klute, 1994). Cation exchange capacity of clay was estimated using the relationship proposed by Baize (1993) as follows:

$$CEC_{clay} = \frac{\{CEC_{soil} - (\%OM \times 2)\}}{\%clay} \times 100 \quad \text{where, OM is organic matter.}$$

## ***Soil classification***

Using both the morphological data collected in the field and laboratory data, the soils of the study areas were classified using the two most common soil classification systems used in Tanzania, i.e. USDA Soil Taxonomy and the FAO World Reference Base (WRB). The soils were classified to subgroup level of the USDA Soil Taxonomy (Soil Survey Staff, 1998) and to level-2 of the FAO World Reference Base (FAO/ISRIC/ISS, 1998).

## **Results and Discussion**

### **Soil physical and morphological characterization**

It was apparent that all the studied soil profiles have developed from parent materials that are coarse textured colluvial deposits from the surrounding granitic rock hills (Table 1). The surface horizons are coarse textured with textural classes ranging from sandy loam to sand. The sand fraction of these soils is mainly quartz. Generally, the sub surface horizons of the profiles in Iringa District have slightly higher clay content than those of Chunya District. This implies that although all the soils of the study areas are not well developed, the soils of Chunya District are less developed than those of Iringa District. This is further supported by stronger colour development in the subsoils of Iringa District compared to those of Chunya District (Table 1). The profiles are characterized by slight weathering of parent materials. The soils of Iringa District show evidence of horizon differentiation in terms of structure development and subsurface horizons with reddish yellow or yellowish red colours (Table 1).

The soil profiles of *Striga*-infested soils of Iringa and Chunya Districts are characterized by slight weathering of the parent material and absence of illuviated clays. The soil profiles of the selected *Striga* infested villages of Chunya District are characterized by an ochric diagnostic horizon only whereas those of Iringa District are characterized by an ochric diagnostic horizon and a cambic subsurface diagnostic horizon which is normally regarded as a minimum B-horizon.

### **Chemical properties of profile samples**

The levels of soil organic matter in Chunya District are low with organic C contents in the surface horizons ranging from 0.21% in Lupa village to 0.65% in Upendo village (Table 2). The levels of soil organic matter contents in Iringa District are also low with organic C contents in the surface horizons ranging from 0.43% in Mfyome village to 1.26% in Mangalali village. The CEC is generally low in the soils of Iringa District with values ranging from 4.6 to 12.6  $\text{cmol}(+)\text{kg}^{-1}$  whereas it is very low in Chunya District where values range from 4.0 to 7.2  $\text{cmol}(+)\text{kg}^{-1}$ . This is mainly due to the sandy nature of these profiles. The base saturation (BS) is low in both Iringa and Chunya districts with values  $< 50\%$ , and the pH values of most horizons being  $< 7.0$ . The BS of most of the horizons comprising the soil profiles in Chunya district are very low with values ranging from 2.3 to 46.5  $\text{cmol}(+)\text{kg}^{-1}$  whereas the BS values for soil profiles in Iringa district are generally slightly higher than those of Chunya District with values ranging from 15.8 to 50.9  $\text{cmol}(+)\text{kg}^{-1}$ .

Table 1: Some physical and morphological properties of the studied soil profiles

Profile/ Horizon	Depth (cm)	Munsell soil colour (Munsell Color, 1994)		Particle size distribution			
		Dry	Moist	Clay (%)	Silt (%)	Sand (%)	Textur- al class
<b>1. Mangalali village, Iringa District</b>							
Ap	0 – 18	Brown (10YR 5/3)	Very dark gray (10YR 3/1)	14	22	64	SL
Bw	8 – 23	Light brownish gray (10YR 6/2)	Dark grayish brown (10YR 4/2)	21	12	66	SCL
Bg	23 – 50	Pale brown (10YR 6/3)	Brown (10YR 5/3)	38	8	54	SC
Bcg	50 – 90+	Light brownish gray (10YR 6/2)	Grayish brown (10YR 5/2)	50	7	43	C
<b>2. Kiwera village, Iringa District</b>							
Ap	0 – 12	Light brown (7.5YR 6/3)	Brown (7.5YR 4/3)	9	6	85	S
BA	12 – 30	Yellowish red (5YR 5/6)	Reddish brown (5YR 4/4)	12	4	84	LS
Bw	30 – 112	Light reddish brown 2.5YR 6/3)	Reddish brown (2.5YR 5/3)	24	6	70	SCL
Bcir	112 – 180+	Pale red (2.5YR 6/2)	Weak red (2.5YR 5/2)	45	3	52	SC
<b>3. Mfyome village, Iringa District</b>							
Ap	0 – 12	Light yellowish brown 10YR 6/4)	Dark yellowish brown (10YR 4/4)	8	2	90	S
BA	12 – 36	Strong brown (7.5YR 5/6)	Strong brown (7.5YR 4/6)	9	11	80	LS
Bw	36 – 178	Reddish yellow (5YR 6/6)	Yellowish red (5YR 5/6)	21	6	73	SCL
Bcir	178 - 182+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
<b>4. Mamba village, Chunya District</b>							
Ap	0 - 23	Grayish brown (10YR 5/2)	Very dark grayish brown (10YR 3/2)	7	7	86	LS
AB	23 - 48	Light yellowish brown (10YR 6/4)	Dark yellowish brown 10YR 4/4)	9	7	84	LS
BA	48 - 95	Brownish yellow (10YR 6/6)	Dark yellowish brown (10YR 4/4)	12	6	82	LS
Bw	95 – 200+	Brownish yellow (10YR 6/8)	Yellowish brown (10YR 5/8)	17	4	79	SL
<b>5. Upendo village, Chunya District</b>							
Ap	0 - 9	Grayish brown (10YR 5/2)	Very dark grayish brown (10YR 3/2)	7	7	86	LS
AB	9 - 21	Pale brown (10YR 6/3)	Brown (10YR 4/3)	5	9	86	LS
BA	21 - 50	Very pale brown (10YR 7/4)	Yellowish brown (10YR 5/4)	7	9	84	LS
Bw	50 - 132	Yellow (10YR 7/6)	Yellowish brown 10YR 5/6)	7	9	84	LS
Bcir-mn	132 – 170+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
<b>6. Lupa village, Chunya District</b>							
Ap	0 - 16	Light brownish gray (10YR 6/2)	Dark grayish brown (10YR 4/2)	2	9	89	S
BA	16 - 43	Light gray (10YR 7/2)	Grayish brown (10YR 5/2)	2	9	89	S
Bw	43 - 120	Very pale brown (10YR 8/2)	Light gray (10YR 7/2)	7	4	89	S
Bcir-mn	120 – 174+	Very pale brown (10YR 8/2)	Light gray (10YR 7/2)	2	9	89	S

Table 2: Selected chemical properties of the studied soil profiles

Horizon	Depth (cm)	pH		ECe (dS/m)	Org. C (%)	OM (%)	Total N (%)	Avail. P mg/kg	CEC-soil (cmol(+)/kg)	CEC-clay (cmol(+)/kg)	Exchangeable bases (cmol(+)/kg)					BS %
		H <sub>2</sub> O	KCl								Bray1	Ca <sup>2+</sup>	Mg <sup>2+</sup>	K <sup>+</sup>	Na <sup>+</sup>	
<b>1. Mangalali village, Iringa District</b>																
Ap	0 – 18	6.81	5.30	0.05	1.26	2.2	0.09	5.35	12.6	55.1	3.76	1.45	0.26	0.17	5.64	44.8
Bw	8 – 23	6.22	4.49	0.03	0.85	1.5	0.06	4.59	8.6	25.3	2.52	0.99	0.15	0.25	3.91	45.5
Bg	23 – 50	6.17	4.44	0.03	0.32	0.6	0.05	0.86	10.0	23.0	3.00	1.72	0.18	0.45	5.35	53.5
Bcg	50 – 90+	6.13	3.95	0.03	0.37	0.6	0.04	0.75	12.8	22.7	2.38	1.88	0.17	0.87	5.30	41.4
<b>2. Kiwere village, Iringa District</b>																
Ap	0 – 12	6.32	5.12	0.03	0.50	0.9	0.04	4.71	9.6	85.1	0.82	0.41	0.14	0.13	1.50	15.6
BA	12 – 30	5.95	4.31	0.01	0.21	0.4	0.02	1.28	4.6	31.5	1.06	0.81	0.11	0.05	2.03	44.1
Bw	30 – 112	6.16	4.23	0.01	0.14	0.2	0.02	1.44	10.0	39.4	0.34	0.87	0.24	0.13	1.58	15.8
Bcir	112 – 180+	5.63	4.14	0.02	0.14	0.2	0.02	0.27	10.8	22.8	1.24	2.79	0.52	0.27	4.82	44.6
<b>3. Mfyome village, Iringa District</b>																
Ap	0 – 12	6.13	4.72	0.02	0.43	0.7	0.04	8.88	8.6	86.7	2.18	0.76	0.11	0.20	3.25	37.8
BA	12 – 36	5.00	4.16	0.04	0.21	0.4	0.04	9.26	6.8	66.5	0.31	0.10	0.15	0.17	0.73	10.7
Bw	36 – 178	7.46	5.61	0.07	0.17	0.3	0.02	7.90	5.8	24.5	0.01	2.52	0.17	0.25	2.95	50.9
Bcir	178 – 182+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
<b>4. Mamba village, Chunya District</b>																
Ap	0 – 23	6.82	5.57	0.02	0.43	0.7	0.03	15.56	6.0	61.9	1.02	0.37	0.11	0.04	1.54	25.7
AB	23 – 48	6.82	4.67	0.01	0.19	0.3	0.02	3.16	4.6	42.9	1.49	0.50	0.09	0.06	2.14	46.5
BA	48 – 95	6.24	4.40	0.03	0.17	0.3	0.02	2.56	4.6	32.8	0.61	0.55	0.08	0.05	1.29	28.0
Bw	95 – 200+	5.90	4.78	0.03	0.14	0.2	0.02	1.87	5.2	27.4	0.11	0.90	0.12	0.03	1.16	22.3
<b>5. Upendo village, Chunya District</b>																
Ap	0 – 9	6.72	5.69	0.03	0.65	1.1	0.04	10.54	7.2	66.8	1.99	0.37	0.09	0.02	2.47	34.3
AB	9 – 21	6.81	5.44	0.02	0.32	0.6	0.02	3.53	7.2	119.2	1.34	0.36	0.07	0.03	1.80	25.0
BA	21 – 50	6.73	5.49	0.01	0.17	0.3	0.02	1.28	7.4	96.3	0.59	0.42	0.08	0.04	1.13	15.3
Bw	50 – 132	6.00	4.36	0.01	0.09	0.2	0.01	0.86	5.8	77.9	0.15	0.25	0.12	0.03	0.55	9.5
Bcir-mn	132 – 170+	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
<b>6. Lupa village, Chunya District</b>																
Ap	0 – 16	6.16	4.67	0.03	0.21	0.36	0.02	11.34	6.0	259.3	0.37	0.13	0.04	0.02	0.56	9.3
BA	16 – 43	5.40	4.16	0.01	0.21	0.36	0.02	2.19	6.6	289.3	0.09	0.03	0.02	0.01	0.15	2.3
								0.43								
Bw	43 – 120	6.81	4.87	0.01	0.06	0.10	0.07		4.0	53.8	0.20	0.13	0.03	0.01	0.37	9.3
Bcir-mn	120 – 174+	7.24	5.12	0.02	0.06	0.10	0.02	1.76	5.2	248.4	0.31	0.23	0.03	0.06	0.63	12.1

### Classification of the studied soil profiles

Based on the morphological, physical and chemical characteristics presented in Table 1 and 2 and the identified diagnostic horizons and other diagnostic properties, the studied soil profiles were classified using the two soil classification systems commonly used in Tanzania: The soil profiles in Kiwera and Mfyome villages in Iringa District were classified as Chromic Cambisols in the FAO-World Reference Base because they are in a transitional stage of development from young to mature soils as shown by significant development of red colours in their subsurface horizons. These profiles were also classified as Dystric Haplustept in the US Soil Taxonomy system. The soil profile in Mangalali village, Iringa District was classified as Vertic Cambisol in the FAO-World Reference Base because it exhibit some vertic properties. It was also classified as Typic Dystrustept in the US Soil Taxonomy system. The soil profiles in Upendo and Lupa villages in Chunya District were classified as Hyperdystric Arenosols (FAO-WRB) and that of Mamba village in the same district as Orthidystic Arenosol (FAO-WRB) because of their coarse texture and very low base saturation. All these soil profiles were also classified as Ustic Quartzipsamments in the US Soil Taxonomy system. Details of the six profiles are provided in tables 1 and 2.

### Physical properties of the soils

The results show that 39.6% of all the soils had a sand texture, 51.5% a loamy sand texture and only a few samples indicated sandy clay loam and sandy loam textures. Sand is the dominant fraction in the soils a condition that promotes free drainage and low water holding capacity of the soils (Parker and Riches, 1993). Such textures also exhibit low cation exchange capacity and hence low in nutrient reserves. Sand and sand loamy soils loose nutrients through leaching resulting in very low nitrogen content. Low soil moisture promotes the development of *Striga* in maize fields. Such soils are well drained with low water holding capacity, according to Parker and Riches (1993). This is another soil condition that promotes *Striga* infestation and leads to poor maize growth and yield as reported by Kilima et al. 2007. According to Ngugi (1982) maize performs well in soil texture ranging from loamy to silt loamy. Some organic manure addition can help to improve the soil structure, followed by increased moisture and nutrient retention hence increased maize production.

Table 3: Some representative physical properties of the soils

District	Village	Particle size distribution (%)			Textural class
		Sand	silt	clay	
Iringa	Mangalali	91	5	4	S
	Akiwera	93	5	2	S
	Mfyome	89	4	7	S
Chunya	Mamba	86	7	7	LS
	Upendo	86	7	7	LS
	Lupa	89	9	2	S

## **Chemical properties of the soils**

### **Soil pH**

The soil pH of the soils range from 5.73 to 7.33 indicating a variation from strongly acidic to about slightly alkaline (Table 4) as rated by London, (1991). Seventy three percent of the soil samples were rated as strongly acidic to very slightly alkaline. Maize performs well in soils with pH range from 5.0 to 8.0. Based on pH, the soils of the two villages are suitable for maize production. Normally low soil pH favours low soil organic matter decomposition, promotes P fixation, increased solubility of the bases and hence greater leaching capacity, low CEC and increased concentration of micronutrients and aluminium. These are conditions that are associated with low soil fertility status and hence greater potential to *Striga* infestation.

### **Organic Carbon**

Total organic carbon ranged from 0.02% to 0.50% and these were rated as low according to the classification by London (1991). Low OC results into poor soil structure, low cation exchange capacity, low water holding capacity and low retention of mineral elements. Such soils are not fertile and are of low productivity. Organic carbon content is often taken as a measure of the quality of organic matter in soils, which in turn is taken as a crude measure of soil fertility status (Moukam and Ngakanou, 1997). Due to low soil fertility status, *Striga* infestation will be dominant in such areas (Kwacha, 2001).

### **Total Nitrogen**

Total soil nitrogen varies from low (0.03%) to medium levels (0.43%). Soil N is crucial in both maize production and *Striga* control. Low levels normally favour *Striga* infestation. The soils of Chunya have more soil N than the Iringa soils (table 4)

### **Cation Exchange Capacity**

The CEC ranged from 5.00 to 17.10 Cmol(+)Kg<sup>-1</sup> of soil, which was rated as very low to medium according to London (1991) method of classification of soils. Forty three percent of the soil samples were rated as medium in CEC, 56% of the soils were rated as low and 3% of them rated as very low. The CEC gives an idea of the potential fertility status of the soils and the capacity of the soils to retain nutrients against leaching (Amur, 2003). Based on CEC results the soils of Mfyome, Mamba, Lupa and Upendo are not suitable for maize production, unless some amendments are added to such soils. This is the reason as to why the soils are infested by *Striga* weeds.

### **Available Phosphorus**

The available phosphorus determined by Bray-1-method ranged from 3.03 to 28.97 mgPkg<sup>-1</sup> soil and were rated as very low to medium. The available P determined by Olsen method ranged as low to medium (London, 1991). Sixty eight of the soil samples contained medium Bray-1-Phosphorus, 18% were of low P content, and 14% of the soil samples were rated as containing high available P values. For Olsen P, 75% of the soil samples were rated as medium and 25% of them as low. Based on London (1991) criterion, it is known that Olsen P values greater than 8 mg/Kg of soil are considered as adequate for maize production. Thus half of the soil samples from

which available Phosphorus were determined by Olsen were found to be suitable for maize production and half of them showed inadequate P levels, and hence a need for P- fertilizers. Based on Uriyo, *et al* (1977) criterion, Bray-1 P values of 25 mg/Kg of soils and above are adequate for maize production. Thus, 54% of the soil samples from which available P were determined by Bray-1-method are suitable for maize production and 46% of the soils are not suitable for maize production, and thus need to be fertilized with P- fertilizers. However phosphorus has rarely shown any marked effect on *Striga* infestation (Parker and Riches, 1993).

Table 4: Some chemical properties of the surface soils of Iringa and Chunya Districts

S/ No	Village	pH	OC	TN	Avail P mg/kg	CEC Cmol/ kg	Exchangeable bases Cmol/kg				% BS
							Ca	Mg	K	Na	
	<b>Iringa district soils</b>										
1	Mangalali A	6.55	0.20	0.04	7.79	17.1	1.77	1.17	0.12	0.65	21.7
2	Mangalali B	6.99	0.44	0.04	22.4	13.9	1.75	0.88	0.13	0.56	23.9
3	Lukwambe A	6.99	0.50	0.03	11.09	14.1	1.94	0.99	0.05	0.70	26.1
4	LukwambeB	7.13	0.49	0.05	14.38	13.4	3.22	1.06	0.17	0.61	37.8
5	Kitowo	5.73	0.31	0.03	28.97	12.1	1.27	0.73	0.09	0.52	9.8
6	Chapakazi – Kiwere	6.06	0.33	0.03	15.83	15.1	1.43	0.91	0.10	0.59	20.1
7	Makondo - Kiwere	5.96	0.45	0.04	27.11	14.9	1.74	0.09	0.13	0.55	16.8
8	Mwaya – Kiwere	6.25	0.42	0.03	49.31	14.6	1.77	0.86	0.10	0.60	22.8
9	Maramba A – Mfyome	6.55	0.03	0.39	6.02	7.20	0.59	0.29	0.13	0.17	16.4
10	Maramba B–Mfyome	5.94	0.02	0.48	4.40	5.00	1.03	0.49	0.10	0.12	34.8
11	Mhefu – Mfyome	6.00	0.03	0.35	5.54	6.40	1.72	0.87	0.09	0.23	45.5
12	Matembo – Mfyome	6.45	0.05	0.04	4.06	7.30	1.61	0.64	0.16	0.08	34.1
13	Msosa – Mfyome	7.25	0.04	0.43	10.30	6.20	1.73	0.54	0.14	0.12	40.8
	<b>Chunya district soils</b>										
14	Mamba A	7.33	0.04	0.29	3.03	7.30	2.40	0.43	0.08	0.13	41.6
15	Mamba B	6.88	0.03	0.29	7.36	6.70	1.04	0.41	0.07	0.12	24.5
16	Mamba C	6.81	0.02	0.10	6.28	5.90	0.66	0.20	0.09	0.08	17.5
17	Mamba D	6.99	0.03	0.23	4.16	6.60	0.99	0.36	0.08	0.14	23.8
18	Mamba E	6.74	0.03	0.76	13.02	7.80	1.05	0.45	0.09	0.10	21.7
19	Mamba F	6.81	0.03	0.36	3.74	9.30	0.78	0.29	0.06	0.11	13.3
20	Mamba G	6.86	0.04	0.42	13.53	9.00	2.52	0.77	0.08	0.16	39.2
21	Ifuma – Lupa	6.30	0.03	0.34	16.08	9.13	0.70	0.36	0.13	0.09	14.0
22	Ngonilima – Lupa	6.96	0.04	0.31	9.70	6.63	1.24	0.38	0.10	0.06	26.8
23	Kagera – Lupa	6.67	0.03	0.42	15.07	8.30	0.84	0.32	0.15	0.08	16.7
24	Lupa - Lupa	6.52	0.02	0.20	11.88	7.20	1.10	0.29	0.07	0.31	24.6
25	Kitete – Upendo	7.08	0.04	0.41	8.8	7.87	3.13	0.40	0.14	0.07	47.5
26	Maendeleo – Upendo	6.98	0.03	0.38	4.51	6.73	1.91	0.36	0.08	0.09	36.3
27	Mihame – Upendo	6.84	0.03	0.41	7.57	8.33	2.32	0.89	0.07	0.13	40.9

#### Exchangeable Cations and Base Saturation

The proportion of CEC accounted for by exchangeable bases (Ca, Mg, K and Na) is frequently used as indicator of soil fertility (London, 1991). The average soil base saturation ranged from 9.8% to 47.5% (Table 4). This is considered as very low to

low. According to London (1991) criterion of classification, the % Base Saturation (BS) is used as an index of soil fertility evaluation. The BS>50% indicates that the soils are fertile while BS<50% indicates infertile soils. Overall, the soils of the two Districts are of low soil fertility status, and this has contributed to low maize yield and high *Striga* infestation.

### **Conclusions and Recommendation**

- The soils of Iringa and Chunya districts were found to be dominated by sand with a very low clay fraction. Such soils are also well drained with low water holding capacity, conditions that may promote *Striga* infestation.
- The soils were also found to have low levels of most nutrients especially N, P, Ca, Mg, K and organic carbon. Thus they are soils of low soil fertility status another factor that favours *Striga* infestation and low maize yields.
- It is proposed that the soils can still be productive if the soil organic resource base is built up through use of green manure, crop residues and the BNF technology
- Adoption of tillage practices that preserve soil moisture will be important in the control of *Striga*, especially in Iringa district.
- Application of inorganic fertilizers especially N and P will increase maize yield and farmers income

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# **THE INFLUENCE OF SOIL INTRINSIC PROPERTIES ON SOIL EROSION: THE CASE OF NORTHERN SLOPES OF THE ULUGURU MOUNTAINS, MOROGORO, TANZANIA.**

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## **ABSTRACT**

Soil erosion and resulting land degradation have been identified as serious problems since the 1920s in Tanzania. Soil erosion in Tanzania is mainly water induced and results from rainwater runoff on fragile lands such as steep slopes, overgrazed lands and other degraded lands due to various factors like deforestation and over-cultivation. This paper discusses a study carried out to assess the contribution of soil properties to soil erosion in the Northern slopes of the Uluguru Mountains. Two geomorphic units along mountain ridges and foothills on slopes ranging from 30 to 70% were studied for various soil physical characteristics including clay ratio, dispersion ratio, particle size analysis, bulk density, infiltration rate, gravel content, aggregate stability and soil loss due to erosion. Results from the study revealed that on one hand high soil organic matter, dry stable aggregates (>2 mm), bulk density and infiltration rate reduce significantly ( $P < 0.05$ ) rill and interrill erosion. On the other hand, clay ratio, silt, very fine sand and gravel content increase soil erosion. The study argues that the application of organic material would improve soil physical properties and hence reduce soil erosion. Appropriate farming practices such as terracing, contour farming strip farming among others which stabilise soil aggregates are also recommended to minimise soil erosion.

## **1.0 INTRODUCTION**

Soil erosion is the detachment and subsequent transport of soil particles from the soil mass to some other place by agents of erosion (Ellison, 1947). In farmlands, the soil particles thus carried away are from the top fertile soil, which is the feeding zone of most crop plants. This leads to reduced agricultural production and hence has adverse economic implications particularly in countries like Tanzania whose economy relies extremely on agriculture.

In Tanzania, soil erosion prevails almost everywhere but its effects are more pronounced in the humid mountain areas (Rapp *et al.*, 1973). The catchment areas which have undergone severe soil erosion in Tanzania include the Usambaras (Watson, 1973), Kilimanjaro (Mitchel, 1965), Meru (Anderson, 1962), Uluguru (Temple, 1973) and parts of Southern highlands (Pereira and Hosegoods, 1962). However, soil erosion is equally rampant in the semi arid areas with low relief in Central Tanzania. In this zone, the erosion prone areas include the sparsely populated but over stocked Dodoma region (Stapples, 1933; Rensburg 1955), Singida region (Christianson, 1973) and parts of Tabora, Arusha and Shinyanga regions (Rounce *et al.*, 1942). Besides high rainfall, the contributing factors are overgrazing (overstocking), high density of settlement and /or cultivation on steep lands and indiscriminate deforestation and wild fires.

In the mountainous areas of Tanzania, Uluguru area being one of them, soil erosion is singled out as a major problem hampering agriculture development. Previous studies in the northern slopes of the Uluguru Mountains, mainly concentrated on soil erosion estimation (Rapp *et al.*, 1972). Information on the contribution of soil intrinsic characteristics on soil erosion in the area has not been enough documented so far. Availability of such information can contribute to formulation of intervention programmes aiming at reducing soil erosion in the northern slopes of the Uluguru Mountains.

Water induced soil erosion, which is the most dominant form of soil erosion in Tanzania, is influenced by a number of factors of which the major ones are climate (rainfall erosivity), soil properties (soil erodibility), landform (slope length/steepness) and management (crop/land management) (Greenland and Lal, 1977).

The erodibility of the soil refers to its vulnerability or susceptibility to erosion. It is the reciprocal of soil resistance to erosion. Although soil resistance depends in part on topographic position, slope steepness and the intensity of disturbance created by man, the properties of the soil are the most determinants (Morgan, 1986). Erodibility is the inherent property of a given soil which makes some soils more susceptible to erosion than others even when all other factors influencing erosion remain constant (De Vleeschauwer *et al.*, 1978). Factors that affect soil erodibility may fall into 3 broad categories including (1) Physical factors of the soil, such as the physical composition of the soil, (2) Topographic features, such as the slope of the land, and (3) The management of the land, such as farming practices. Soil erodibility can be assessed from measurable soil properties (Wischmeier and Mannering, 1969) or computed from the Universal Soil Loss Equation (USLE) of Wischmeier and Smith (1960) through the use of standard erosion plots.

Middleton (1930) was one of the first researchers to recognize that a readily dispersed soil can also be easily detached and carried away. This, together with other later studies led to the grouping of all properties that affect dispersion as indicators of the soil vulnerability to detachment and transport and therefore to soil erosion. Such properties include dispersion ratio (Middleton, 1930), clay ratio (Bouyoucos, 1935), aggregate stability (Gerdel, 1937; Peele *et al.*, 1938), organic matter (Alexander and Middleton, 1952) and soil textural properties (Wischmeier and Mannering, 1969). According to these studies, low values of organic matter, aggregate stability, sand and clay indicate that the soil is readily erodible, while low values of dispersion ratio, clay ratio and silt means that the soil is less vulnerable to erosion.

The main objective of the study discussed in this paper was to assess the contribution of intrinsic soil physical properties to soil erosion in the northern slopes of the Uluguru Mountain, Morogoro, Tanzania. Specific objectives included (1) to determine soil physical properties which influence soil erodibility on the Uluguru Mountains; (2) to estimate soil erodibility indices which have influence on soil erosion and (3) to establish relationship between soil loss through rill and interrill erosion and the erodibility indices in the study area.

## 2.0 MATERIALS AND METHODS

### 2.1 The study area

The study area is located on the northern slopes of the Uluguru Mountains between 37°59' and 37° 41' E and 6°54' and 6°51' S. The climate of the area belongs to the tropical savannah of the low latitude environment. The mean annual rainfall varies with altitude, from 1000 mm at 600 m above sea level (a.s.l) to 2,300mm at 1,500 m a.s.l. Annual rainfall are distributed into two relatively distinct periods; the long rains season (Masika) which lasts from March to May and short rains (Vuli) which commonly extends from October to December. Mean annual temperatures vary from 25° C at 600 m a.s.l. to 19° C at 1,500m a.s.l.

The study area consisted of two geomorphic units, the mountain ridges, and mountain foothills. On the mountain ridges, two sites were selected for study while on the mountain foothill, four sites were studied. The selection of the sites was based on both the slope gradient and soil type.

In accordance with The World Soils Reference Base, the soils of the selected sites on the mountain ridges were *Epidystri-Endoskeletal Cambisol* and *Hapli-Leptic Phaeozen* which occurred on slope gradient ranges of 60-70% and 50-60% respectively. These sites are referred to as site 1 and 2 in the rest of the text. The soil types and slope gradient (in brackets) of the sites on the mountain foothills were: *Episkeleti-Hyperferralic Cambisol* (60-70%), *Chromi-Endoleptic Cambisol* (50-60%), *Chromi-Profondic Acrisol* (40-50%) and *Hapli-Chromic Lixisols* (30-40%) (Kimaro *et al.*, 1999). These sites are referred to as 3, 4, 5 and 6 respectively in the rest of the text.

Common land use in the studied areas consisted of settlements on both geomorphic units and agriculture with the production of vegetables, beans, maize, and bananas on the mountain ridges. On the mountain foothills in addition to those crops less vegetables, pigeon pea and cassava are also cultivated.

### 2.2. Data collection and analysis

#### 2.2.1 Determination of dry aggregate stability

Determination of dry aggregate stability was done following the procedure outlined by Kemper and Rosenau, (1986). Undisturbed soil samples were collected from the topsoil (0-30cm) by using a spade. Three (3) samples were taken from each site. The samples were further dried at room temperature for two weeks. After drying, a sample of 200g was taken and put on the top sieve in a nest of 4.0, 2.0 and 1.0mm sieves and shaken for 20 minutes at speed of 50 rpm. This operation was repeated 3 times each time using 200g of dry soil sample. The Stable Dry sieved Aggregates (SDA) in each size group were expressed as a percent of the total weight of the sample on air-dry basis.

### **2.2.2 Gravel Content**

The dry stable aggregates in each of the sieves were thoroughly washed with water to remove all the soil. The remaining gravels (i.e. diameter > 2.00mm) were oven dried and weighed. Their weights were expressed as percentage of the original total weight of the sample.

### **2.2.3 Particle size analysis of soil sample**

The particle size analysis was determined by the hydrometer method following procedure by Day (1965). Two approaches were used. One in which pure water was used as a dispersion medium and a 5% hexametaphosphate solution. The particle size separates were determined as the conventional clay (<0.002mm), silt (0.002-0.05mm) and sand (0.05-2.00mm). Additionally, various sand fractions were obtained through sieving as follows: Coarse sand (1.00-2.00mm), Medium sand (0.50-1.00mm), Fine sand (0.10-0.05mm) and Very fine sand (0.05-0.10mm).

### **2.2.4 Infiltration rate measurements**

Infiltration measurements were taken using the modified Tension Infiltrometer, UNCEL (University of Newcastle Environmental Laboratory) type.

### **2.2.5. Bulk density**

The bulk density of the surface soils was measured with a spring soil-sampler (5.7 cm in diameter and 5cm in height) following the procedure outlined by Blake (1965). Triplicate samples of the soils were collected at the periphery of each measuring point. The length (L), diameter (2r), and the mass of oven-dried undisturbed cores were measured and bulk density ( $P_b$ ) was calculated from the ratio of the mass (m) to volume of soil core as:  $P_b = m / (\pi r^2 L)$

### **2.2.6 Organic carbon determination**

Organic carbon in soil was determined by the wet combustion method as described in Walkley - Black (1934) Method. Measurements were done in duplicates.

### **2.2.7 Dispersion ratio**

Dispersion ratio (DR) was determined in accordance with the procedure after Middleton (1930). It is calculated as % (silt + clay) in an untreated soil sample mechanically shaken for 16 hours to % (silt + clay) of an equal amount of treated test sample ( $H_2O_2$  - dithionite - calgon) which is also shaken for 16 hours.

$$DR = [\%(\text{clay} + \text{silt}) \text{ in untreated sample}] / [\%(\text{Clay} + \text{silt}) \text{ in treated sample}]$$

### **2.2.8 Clay ratio**

Clay ratio (CR) was determined in accordance with the procedure after Bouyoucos (1935). It is calculated as the ratio of % sand to % (silt + clay). Clay ratio is given as:

$$CR = [\% \text{ sand (0.05 to 2.00 mm)}] / [\% (\text{Silt} + \text{clay}) \text{ 0.002 to 0.05 mm}]$$

### 2.2.9 Percent silt and percent very fine sand

This index was determined following the procedure by El-Swaify and Dangler (1976). It is calculated as % (Silt + very fine sand) where silt includes fractions between 0.002 to 0.05 mm and very fine sand include those between 0.05 to 0.10mm.

### 2.2.10 Percent dry sieved aggregate and gravel content

This index was calculated as a weight of stable aggregate that remain in the 4mm sieve (during dry sieving) expressed as % of original dry sample weight. The gravel content was calculated as the weight of gravel exceeding 2.5mm expressed as % of weight of the test sample (Yoder, 1944).

## 3.0 RESULTS AND DISCUSSION

### 3.1 Erodibility indices

Table 1 shows a summary of values for the various erodibility indices as computed for the six studied sites from the two geomorphic units.

Table 1: Erodibility indices in the northern slopes of the Uluguru Mountain, Morogoro, Tanzania.

Erodibility indices	Geomorphic units						
	Mountain ridges			Mountain foothills			
	Site 1*	Site 2	Site 3	Site 4	Site 5	Site 6	
Dispersion ratio	0.7	0.5	0.8	0.7	0.9	0.7	
Clay ratio	2.3	4.4	1.7	1.3	0.7	0.6	
Silt & very fine sand (%)	14.5	19.5	16.2	17.8	12.1	10.9	
Organic matter (%)	2.1	1.2	2.8	2.8	1.4	3.3	
Bulk density (g/cm <sup>3</sup> )	1.1	1.2	1.2	1.3	1.2	1.2	
Steady state infiltration rate at different tensions	5 cm	2.0	2.0	2.0	2.1	2.0	2.5
	7 cm	1.0	1.1	0.8	0.9	0.5	1.3
	10 cm	0.6	0.6	0.4	0.4	0.2	0.7
Dry aggregates (%)	> 4 mm	57.2	48.4	58.6	52.3	72.9	74.2
	> 2mm	69.1	57.8	71.2	66.8	93.8	83.8
Gravel content (%)	2.9	5.2	11.8	1.7	5.1	0.2	

\*Key: Soil type for: - Site 1: Haplic - Leptic Phaeozem  
 - Site 2: Epidystri - Endoskeletal Cambisol  
 - Site 3: Episkeleti - Hyperferralic-Cambisol  
 - Site 4: Chromi - Endoskeletal - Cambisol  
 - Site 5: Haplic - Chromic Lixisol  
 - Site 6: Chromi - Profondic Acrisol

The dispersion ratio did not vary much from sites to sites as it ranged from 0.5 to 0.9 (Table 1). On the contrary the clay ratio variation was a bit high being particularly lower on the mountain foothills and higher on the mountain ridges (Table 1). According to Bouyoucos (1935) who found that clay ratio is highly correlated with soil erodibility, this implies that, soils in the mountain ridges are more susceptible to erosion than those in the mountain foothills. This is also confirmed below through measurement carried to

estimate soil losses due to rill and interrill erosion whereby soil losses were relatively low on Sites 5 and 6 which have the lowest clay ratio values.

Silt and very fine sand percentages were lowest in the mountain foothills (Site 6) and highest on the mountain ridge (Site 2) (Table 1). Soil texture is one of the most important parameter that determines soil erodibility. Large soil particles are resistant to transport because of the greater force required to entrain them while fine particles are resistant to detachment because of their cohesiveness (Morgan, 1986). Hence, soils with higher silt content are more erodible. According to Richter and Negandank (1977), soils with 40-60% silt content are the most erodible.

Organic matter content was highest in the mountain foothills (Site 6) and lowest on the mountain ridge (Site 2) (Table 1). Organic matter has a significant impact on several soil properties. Decomposition products of organic matter bind soil particles together to form granular structures, which facilitate water movements (Uriyo *et al.*, 1979) and thus have influence on water induced soil erosion. Coarse organic matter in the surface soil reduces the impact of the falling raindrops. It also checks surface runoff of water and to some extent, wind erosion.

Soil bulk density did not show much variation from both geomorphic units as it ranged only from 1.1 to 1.3 g/cm<sup>3</sup> (Table 1). Soil bulk density has an influence on soil hydraulic conductivity, soil porosity, and characteristics of soil moisture retention among other soil properties, which have influence on soil erosion. Generally, soils of low bulk density have more favorable physical conditions than those of high volumes (Uriyo *et al.*, 1979).

The lowest infiltration rate was found at Site 5 at a tension of 10 cm while the highest rate was recorded at Site 6 at a tension of 5cm (Table 1). Infiltration rates also have influence on soil erodibility. If the rainfall intensity exceeds the infiltration capacity, the infiltration will equal the infiltration capacity and the excess rainfall will form surface run off. If rainfall intensity is less than or equal to the infiltration capacity of the soil, no surface run off will occur (Horton, 1945). However, as a mechanism for generating run off this comparison for rainfall intensity and infiltration capacity does not always hold. Morgan (1977) in studies on sandy soil of infiltration capacity of greater than 40 mm/ha in Bedfordshire (UK) showed that runoff occurs with rainfall of intensities less than 40 mm/hour. The important factor controlling run off production on these soils is not infiltration capacity but a limiting moisture content which, when exceeded, results in a reduction of pore water pressure at the soil surface to zero, allowing pounding of water to take place (Morgan, 1986). This explains why sands, which have low levels of capillary storage produce run off very quickly even though rainfall intensity has not yet exceeded their infiltration capacity.

In general, there were higher percentages of dry aggregates > 2 mm on in the mountain foothills than along mountain ridges (Table 1). The resistance of the soil particles to water erosion is linked with the degree of aggregation of soil particles and the stability of the aggregates (Hudson, 1971). Stability of aggregates is a function of whether the cohesive force between particles withstands the applied disruption force (Kemper and Rosenau, 1986). Generally, however, aggregate stability depends on the type of clay mineral present. Illites and smectites form aggregates more readily but the open lattice structure of these minerals and the great extent of swelling and shrinkage,

which occurs on wetting and drying, render aggregates of soils with these clays less stable than those ones formed by kaolinite (Morgan, 1986).

### 3.2 Soil loss due to rill and interrill erosion

Maximum annual soil losses due to rill and interrill erosion were recorded in the mountain ridges (372.7 t/ha/year) while minimum losses were found on the mountain foothills (40.2 t/ha/year) (Table 2).

Table 2: Mean soil loss due to rill and interrill erosion in the northern slopes of the Uluguru Mountain, Morogoro, Tanzania.

Geomorphic Unit	Site number	Rill erosion (t/ha/yr)	Interrill erosion (t/ha/yr)	Total Rill and Interrill erosion (t/ha/yr)
Mountain ridges	1	257.9	114.8	372.7
	2	161.1	61.3	222.4
Mountain foothills	3	235.1	98.3	333.4
	4	111.1	44.3	155.4
	5	91.3	41.1	132.4
	6	28.0	12.2	40.2

Source: Kimaro *et al.*, (1999)

### 3.3 Correlation between soil properties and erodibility indices

Correlation and regression equation of various soil properties with soil erosion were computed and are summarized in Table 3. Soil properties that have negative correlation with rill and interrill soil erosions include organic matter content, dry stable aggregates, bulk density, infiltration rate at tension rate of 5cm and 7cm and dispersion ratio (Table 3). These results are in agreement with findings from other studies elsewhere in the world such as Middleton (1930), Gerdel, (1937), Peele *et al.* (1938), Mc Calla (1945), Horton (1945), Anderson (1951) and Morgan (1986).

Table 3: Simple correlation coefficient (r), coefficient of determination ( $r^2$ ) and regression equations of various soil properties (erodibility indices) with soil loss through rill ( $SL_R$ ) and interrill ( $SL_I$ ) erosions.

Independent variable	Dependent variable (soil loss by)	Regression equation	r	$r^2$
% Organic Carbon	Rill erosion	$SL_R = -66.759\% \text{ O.C} + 21.74$	-0.418	0.175
	Interrill erosion	$SL_I = -16.129\% \text{ O.C} + 82.97$	-0.203	0.04
% Silt & % very fine sand	Rill erosion	$SL_R = 10.145\% \text{ S} + \% \text{ VFS} - 22.94$	0.434	0.188
	Interrill erosion	$SL_I = 4.155\% \text{ S} + \% \text{ VFS} - 0.95$	0.357	0.127
Clay ratio	Rill erosion	$SL_R = 30.2 \text{ CR} + 78.3$	0.571	0.326
	Interrill erosion	$SL_I = 8.918 \text{ CR} + 46.51$	0.339	0.115
% Gravel content	Rill erosion	$SL_R = 3.887\% \text{ G.C} + 113.32$	0.206	0.042
	Interrill erosion	$SL_I = 5.193\% \text{ G.C} + 38.72$	0.552	0.305
% Dry stable aggregates > 4.0mm	Rill erosion	$SL_R = -4.444\% \text{ DSA} > 4\text{mm} + 400.03$	-0.616	0.379
	Interrill erosion	$SL_I = -1.81\% \text{ DSA} > 4\text{mm} + 171.7$	-0.504	0.254
% Dry stable aggregates > 2 mm	Rill erosion	$SL_R = -3.326\% \text{ DSA} > 2\text{mm} + 376.05$	-0.558	0.311
	Interrill erosion	$SL_I = -1.347\% \text{ DSA} > 2\text{mm} + 161.36$	-0.454	0.206
Bulk density	Rill erosion	$SL_R = -734.001 \text{ BD} + 101.155$	-0.603	0.364
	Interrill erosion	$SL_I = -352.5 \text{ BD} + 485$	-0.582	0.339
Infiltration rate (at Tension = 5cm)	Rill erosion	$SL_R = -265.182 \text{ IR}_5 + 685.78$	-0.657	0.432
	Interrill erosion	$SL_I = 143.349 \text{ IR}_5 + 362.03$	-0.714	0.510
Infiltration rate (at Tension = 7cm)	Rill erosion	$SL_R = -13.03 \text{ IR}_7 + 142.89$	-0.043	0.002
	Interrill erosion	$SL_I = 25.856 \text{ IR}_7 + 86.1$	-0.170	0.029
Infiltration rate (at Tension = 10cm)	Rill erosion	$SL_R = 51.929 \text{ IR}_{10} + 105.3$	0.129	0.017
	Interrill erosion	$SL_I = 6.29 \text{ IR}_{10} + 65.08$	-0.031	0.001
Dispersion ratio	Rill erosion	$SL_R = 249.816 \text{ DR} + 306.04$	-0.376	0.141
	Interrill erosion	$SL_I = 49.878 \text{ DR} + 97$	-0.151	0.123

A number of the studied soil properties seem to promote both rill and interrill erosion. These include the silt, very fine sand and gravel content of the soil and clay ratio. These parameters are positively correlated with both rill and interrill soil erosion in the studied soils. According to Wischmeier and Mannering (1969) and El-Swaify and Dangler (1976) the content of silt and very fine sand enhances soil erosion. However, Roose (1977) and Aina *et al.* (1981) reported that gravels protect soil surface against erosion, thus there is need for more study to investigate this aspect.

#### 4.0. CONCLUSION AND RECOMMENDATIONS

##### 4.1. Conclusion

Soils on mountain ridges had relatively higher clay ratio values, silt and very fine sand percentages and organic matter content compared to those at the foothills. On the other hand, there were higher percent of dry stable aggregates >2.0mm on the mountain foothills than along mountain ridges. Bulk density, dispersion, infiltration rate, and gravel content did not show clear trend among the two geomorphic units and soil types. Meanwhile, the soil loss through rill and interrill erosion was relatively low on sites 5 and 6 suggesting that Lixisols and Acrisols are relatively resistant to erosion compared to Phaeozems and Cambisols.

The regression and correlation analyses revealed that there was negative correlation between soil losses due to rill and interrill soil erosion and organic matter content, dry stable aggregates, bulk density, infiltration rate at tension rate of 5cm and 7cm and dispersion ratio. Nevertheless, clay ratio, percent silt and very fine sand and percent gravel content were positively correlated with soil losses due to rill and interrill soil erosion.

#### 4.2 Recommendations

Considering the annual soil losses due to rill and interrill erosion, the need to control soil erosion by controlling soil properties cannot be overemphasized in the study area. The following recommendations are further pertinent:

- There is need to improve soil physical properties so as to reduce soil losses due to soil erosion. This can be achieved by adopting practices such as application of organic material on the soil, which would increase soil organic matter content to improve soil aggregation and soil infiltration capacity.
- The studied area, being situated on steep slopes, farming practices to check speed of water run off should be introduced and promoted among farmers. Such practices may include planting cover crops, use of soil bunds, use of terraces, growing vetiver grasses, contour farming, polyvarietal cultivation, and strip farming among others.

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