EFFECT OF LIMING ACID SOILS ON PHYSICO-CHEMICAL CHARACTERISTICS OF THE SOILS AND COFFEE SEEDLING VIGOR IN MBOZI DISTRICT, TANZANIA

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A DISSERTATION SUBMITED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN SOIL SCIENCE AND LAND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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EXTENDED ABSTRACT

Soil acidity is one of the most important soil factors affecting crop growth and ultimately yield and profitability of coffee in Mbozi District Tanzania. Soils tend to be naturally acidic in areas where rainfall is sufficient to cause substantial leaching of basic ions such as calcium and magnesium, which are replaced by hydrogen ions. Most soils in Mbozi District are acidic due to high rainfall and/or the use of soil acidifying fertilizers over a long period of time. Low soil pH causes aluminium and manganese toxicities while calcium, phosphorus and magnesium become deficient. In order to counteract the situation, liming is inevitable. This study was conducted on Ultisols of Mbimba sub-station, located in Mlowo Ward, Mbozi District, Songwe Region Tanzania. The study area is located within latitudes $9^0$05’35.97”S and $9^0$05’13.10”E and longitudes $32^0$57’14.51”E and $32^0$57’22.32”E. The area experiences mean annual rainfall ranging between 1 000 and 1 500 mm with a monomodal distribution pattern. The study aimed at increasing soil productivity for coffee through the use of agricultural lime and ultimately improve livelihoods of the coffee farmers in Mbozi District. Different levels of dolomite lime at 0 $kgha^{-1}$, 1 000 $kgha^{-1}$, 2 000 $kgha^{-1}$ and 2 500 $kgha^{-1}$ were used whereby NPK (22.6.12 +3S) at 150 $kgha^{-1}$ was used at basal application rate. The field layout was set in a randomized complete block design with three replications. The results indicated that lime at 1 000 $kgha^{-1}$ and 2 000 $kgha^{-1}$ increased soil pH between 0.22 and 0.97 units and the increase of P was significant at $P<0.001$. Lime applied at a rate of 2 000 $kgha^{-1}$ increased available P concentration by 5.73 - 7.28 $mgkg^{-1}$ while exchangeable Potassium concentration increased by 0.14 - 6.01$mgkg^{-1}$ in all 3 levels of lime and K increase was significant at $P = 0.05$. Soil Ca and Mg increased between 0.19 and 6.82 cmol(+)kg^{-1} and

0.54 - 1.98 cmol(+)kg^{-1} respectively after application of dolomitic lime. Plant height increased between 60.4 and 67.1 cm, branches between 29-31, internodes between 23 and 27, canopy width between 74.7 and 79.5cm and stem girth between 8.2 and 9cm. A very strong positive correlation was found between lime and Mg (R^2 = 0.8643), moderate positive correlation between lime and N (R^2 = 0.4453), between lime and P (R^2 = 0.7064), between lime and K (R^2 = 0.4043), between lime and Ca (R^2 = 0.5288) while weak correlation between lime and Na (R^2 = 0.2007. Correlation value of < 0.4 is considered as weak, 0.4 - 0.8 moderate correlation and 0.8> as very strong correlation. Thus, the study recommends the use of 2 000 $kgha^{-1}$ of $CaMg(CO_3)_2$ lime to be used by Mbimba Mbozi farmers in coffee farms.

DECLARATION

I, Dismas Pangalas Mfaume, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

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ANOVA	Analysis of Variance
Ca	Calcium
CEC	Cation Exchange Capacity
Cu	Copper
ESP	Exchangeable Sodium Percent
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
ISBN	International Standard Book Number
ISRN	Improvement Science Research Network
K	Potassium
kg	Kilogram
mg	Milligram
Mn	Manganese
N	Nitrogen
Na	Sodium
NRCS	Natural Resources Conservation Service
OM	Organic Matter
P	Phosphorus
TaCRI	Tanzania Coffee Research Institute
TCB	Tanzania Coffee Board
TEB	Total Exchangeable Bases
TMA	Tanzania Meteorological Agency
TN	Total Nitrogen
USDA	United States Department of Agriculture –

WRB	World Reference Base
Zn	Zinc

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Acid soils occupy approximately 60 percent of the land area of the earth. Such soils develop under humid climatic conditions from non-carbonaceous soil forming rocks in all thermal belts of the earth (Somner, 2009). Soil acidification is partly a consequence of the depletion of calcium and magnesium. This occurs through leaching of Ca^{2+} and Mg^{2+} by infiltrating water and uptake by crops and lead to high concentrations of H^{+} and Al^{3+} ions, which are an indicator of acidity. Acid soils manifest a number of limitations in agriculture, especially in the production of good quality and biologically valuable food. Drops soil pH below 5, Al is solubilized into toxic forms like $(Al\ (H_2O)_6)^{3+}$ which is now presenting in 40% of the arable lands in the world (Gupta *et al.*, 2013). Soil acidity serves to increase the presence of trivalent aluminum Al^{3+} in the soil solution and soil exchange complex (Lidon and Barreiro, 2002; Kochian *et al.*, 2005). High Al^{3+} concentrations in the soil solution limits plant nutrients uptake (P, Ca, Mg, B, Zn and Mo), root elongation and seedling growth (Hutchinson *et al.,* 1986; Bruce *et al.*, 1988). At soil pH $\leq$ 5.5, Al-toxicity is a major stress factor for plant growth (Poschenrieder *et al*., 2008; Merino-Gergichevich *et al*., 2010). Soil acidity limits the fertility of soils by limiting nutrients availability to the plant (Nebojsa *et al.,* 2015). In general, many soils contain adequate amounts of the essential plant nutrients for plant growth and development. Low soil pH limits plant accessibility to nutrients. However, conflicting reports show that prior liming of highly weathered acid soils can result in an increase, a decrease or no change in the availability of nutrients (Amarasiri and Olsen, 1973). For example, in acid soils, Ca and Mg contents increase and adsorption of phosphate by amphoteric soil surfaces generally decrease slowly as the pH is raised from 4 to 7; but in soils initially high in exchangeable Al^{3+}, liming results in the formation of new, highly active, phosphate adsorbing surfaces as the

Al^{3+} ions precipitate as insoluble polymeric hydroxy-Al cation species (Hynes and Knowles, 1984).

Another constraint that hinders coffee productivity is limited or none use of organic mulch in the area. The challenge to crop breeders is to develop crop varieties adaptable to low soil pH (Ryan and Delhaize, 2010). Similarly, liming is recommended for acidic soils so as to adjust pH to levels needed by the crop. Cordingley (2010), in his work on smallholder coffee farms in four coffee zones of Tanzania (Southern, Eastern, Western, North and Lake zone), noted that 80% of the surveyed districts had minimum pH of less than 5.5, and 20% less than 5.0. Under acidic conditions some of the vital nutrients such as P, Ca and Mg are made unavailable in the soil solution for plant uptake due to the abundance of elements such as Al and Mn (Cyamweshi *et al.,* 2014). In order to counteract the effect of soil acidity on crop growth, liming is an important practice to be applied to soils in order to restore Ca and Mg availability for plants and adjust soil acidity (Carvalho and Van Raij, 1997; Nduwumuremyi *et al.*, 2013). Naidu *et al.* (1990) observed the beneficial effect of liming in reduced micronutrient toxicity while increasing the availability of Ca, P, Mo and Mg in the soil. Thus, lime application in such soils is one of the key measures that can preserve or increase soil productivity (Mao *et al.*, 2008). Lime requirement is an issue relevant today and in future because of the soil re-acidification due to increase in biomass production, increased temperature and/or increased rainfall (Loide, 2004). However quantitative evidence on the effect of soil acidity on yield is not well known especially for perennial crops. Proper combination of agriculture lime and NPK fertilizer will most likely give high yields of coffee plants (Sebastian *et al.*, 2012). This research aimed at quantifying the effect of $CaMg\ (CO_3)_2$ on coffee vigor and increase coffee productivity through liming and improve livelihoods of the coffee farmers of in Mbimba sub-station in Mbozi District.

1.1 Problem Statement and Justification

Mbozi District is the major producer of Arabica coffee in Tanzania, alternating with Mbinga District in Ruvuma Region (TCB, 2012). In Mbozi District, coffee production has been low due to the increase in mortality rate of coffee seedlings as a result of limited access of nutrients attributed to low soil pH. Average production of coffee parchment ranges from 250 – 450 g per tree while production potential of Arabica coffee is 3.5-5 kg per tree. Optimum soil pH for coffee ranges between 5.6 and 6.6 (Kimaro *et al.*, 2001). Cordingley (2010), in his work on smallholder coffee farms in four coffee zones of Tanzania (Southern, Eastern, Western, North and Lake zone), noted that 80% of the surveyed districts had minimum pH of less than 5.5, and 20% less than 5.0. This indicates that the soils are strongly acidic. Low soil pH increases Al solubility and concentration in the soil solution there by reducing root proliferation and function. This decreases the ability of plants to extract water and nutrients from the soil and hence negative effect on crop growth and productivity (Obiri-Nyarko, 2011). Coffee production in 2012 was 5 224 tonnes, in 2013 it was 15,370 tonnes, in 2014 it was 9 351 tonnes and in 2015 production was 7 665 tonnes. This is a systematic drop in yield over a period of 3years. Annual mean rainfall ranged between 1131.4-1314.1mm and annual mean temperature ranged between 20.9 - 21.96 ^{0}C (TCB, 2012). Thus, yield is limited in Mbozi soils due to increasing unavailability of N, P, Ca, Mg and increasing Al toxicity due to acidification. In order to counteract the effect of soil acidity on crop growth and production, liming is an inevitable practice.

1.2 Objective

1.2.1 Overall objective

To increase coffee productivity through agriculture liming and improve livelihoods of the coffee farmers in Mbozi District.

1.2.2 Specific objectives

i. To carry out pedological characterization and fertility assessment of Mbimba substation in Mbozi District area, under coffee production.

ii. To determine and recommend the optimal lime rate of the Mbimba Mbozi District soils for coffee production.

iii. To evaluate/assess the effect of $CaMg(CO_3)_2$ lime on the growth (vigor) of coffee seedling.

REFERENCES

Amarasiri, S. L. and Olsen, S. R. (1973). Liming as Related to Solubility of P and Plant Growth in an Acid Tropical Soil 1. *Soil Science Society America Journal* 37(5): 716-721.

Bruce, R. C., Warrel, L. A., Edwards, D. G. and Bell, L. C. (1988). Effects of aluminum and calcium in the soil solution of acid soils on root elongation of glycine max cv Forrest. *Australia Journal of Agriculture Research* 39: 319-338.

Carvalho, M. C. S. and Van Raij, B. (1997). Calcium sulphate, phosphogypsum and calcium carbonate in the amelioration of acid subsoils for root growth. *Plant and Soil* 192(1): 37-48.

Cordingley, J. (2010). *Soil fertility survey of Tanzania's smallholder coffee sector for developing lime and fertilizer recommendations.* Report to Tanzania Coffee Board. Crop nutrition laboratory services, Nairobi, Kenya. 60pp.

Cyamweshi, R. A., Nabahungu, N. L., Mukashema, A., Ruganzu, V., Gatarayiha, M. C., Nduwumuremyi, A. and Mbonigaba, J. J. (2014). Enhancing nutrient availability and coffee yield on acid soils of the central plateau of Southern Rwanda. *Global Journal of Agricultural Research* 2(2): 44-55.

Gupta, N., Gaurav, S. S. and Kumar, A. (2013). Molecular basis of aluminium toxicity in plants: a review. *American Journal of Plant Sciences* 4(12): 21-29.

Hutchinson, T. C., Bosic, L. and Munoz-Vega, G. (1986). Responses of five species of conifersseedlings toaluminum stress. *Water, Air and Soil Pollution* 31: 294-299.

Hynes, R. K. and Knowles, R. (1984). Production of nitrous oxide by Nitrosomonas europaea: effects of acetylene, pH, and oxygen. *Canadian Journal of Microbiology* 30(11): 1397-1404.

Kimaro, D. N., Msanya, M. B., Kimbi, G. G., Kileo, E. P. and Mbogoni, J. D. J. (2001). Land resource inventory and suitability assessment for the major use types in Morogoro Urban District Tanzania. *Soil and Land Resources of Morogoro Rural and Urban District*, Volume Department of Soil Science, Sokoine University of Agriculture, Morogoro Tanzania. *ISBN* 2001: 605: 29-36.

Kochian, L. V. Pineros, M. A. and Hoekenga, O. A. (2005). The physiology, genetics and molecular biology of plant aluminum resistance and toxicity. *Plant and Soil* 274(1-2): 175-195.

Lidon, F. C. and Barreiro, M. G. (2002). An overview into aluminum toxicity in maize. *Bulg Journal of Plant Physiology* 28(3-4): 96-112.

Loide, V. (2004). About the effect of the contents and ratios of soil's available Potassium, Calcium and Magnesium of the limed acid soils. *Agronomy Research* 2004 (1): 71-82.

Mao, J., Olk, D. C., Fang, X, H. Z. and Schmidt-Rohr, K. (2008). Influence of animal manure application on the chemical structures of soil organic matter as investigated by advanced solid-state NMR and FT-IR spectroscopy. *Geoderma* 146: 353-362.

Merino, G. C. Alberdi, M. Ivanov, A. G. and Reyes, D. M. (2010). Al3+ - Ca2+ interaction in plants growing in acid soils: Al-phytototoxicity response to calcareous amendments. *Journal of Soil Science and Plant Nutrition* 10: 217-243.

Naidu, R., Syers, J. K., Tillman, R. W. and Kirkman, J. H. (1990). Effect of liming and added phosphate on charge characteristics of acid soils. *European Journal of Soil Science* 41(1): 157-164.

Nduwumuremyi, A., Ruganzu, V., Mugwe, J. N. and Cyamweshi, R. A. (2013). Effects of unburned lime on soil pH and base cations in acidic soil. *ISRN, Improvement Science Research Network Soil Science* 2013: 3-5.

Nebojsa, G., Miroljub, A., Slavisa, G. and Jasmina, K. (2015). The effect of liming on the acidity level of Dystric cambisol and the content of available forms of some microelements. International *Journal of Agronomy and Agricultural Research* 7(4): 36-43.

Obiri-Nyarko, F. (2011). Ameliorating soil acidity in Ghana: a concise review of approaches. *ARPN Journal of Science and Technology* 2: 142-154.

Poschenrieder, C., Gunsé, B., Corrales, I. and Barceló, J. (2008). A glance into aluminum toxicity and resistance in plants. *Science of Total Environment* 400: 356 – 368.

Ryan, P. R. and Delhaize, E. (2010). The convergent evolution of aluminium resistance in plants exploits a convenient currency. *Functional Plant Biology* 37: 275-284.

Sebastian, C., Thomas, D., Natalia, U., Lucia. V. and Mark, C. (2012). Analysis of management and site factors to improve the sustainability of smallholder coffee production in Tarrazú, Costa Rica. *Agriculture Ecosystems and Environment* 155: 172-181.

Somner, M. E. (2009). Soil acidification. *Land Use, Land Cover and Soil Sciences-Volume VII Soils and Soil Sciences* 2: 187-199.

Tanzania Coffee Board (TCB) (2012). *Coffee Industry Development Strategy Annual Report*. Government Printer, Tanzania. 16pp.

CHAPTER TWO

2.0 PEDOLOGICAL CHARACTERIZATION AND FERTILITY ASSESSMENT OF THE MBIMBA SUBSTATION SOILS, UNDER COFFEE PRODUCTION IN MBOZI DISTRICT, TANZANIA

ABSTRACT

Pedological characterization was carried out on soils of Mbimba Mbozi, Tanzania. A representative soil profile (TaCRI-P1) was identified, excavated and described using FAO (2006) Guidelines. Four disturbed soil samples and three undisturbed core samples were taken from the soil profile horizons for physico-chemical laboratory analysis. The pedon developed under udic moisture and thermic temperature regimes was very deep (> 150 cm), well drained and had brown to black topsoil. Soil texture ranged from clay loam to clay. Soil pH was rated as very strong acid to medium (4.73 - 5.98) for all horizons. Organic carbon was low to medium and N was very low to low; CEC was medium to high and exchangeable bases ranged from low to high. Bulk densities were high (2.24 - 2.44 g/cc) for topsoil and low (0.33 - 0.91) for subsoil colour over dark brown to dark reddish subsoil colour. Soil moisture retention properties indicated that surface horizon (0 - 5 cm) retained more water followed by intermediate (45 - 50 cm) horizon and the subsoil (95 - 100 cm) respectively. According to USDA Soil Taxonomy and World Reference Base for Soil Resources, the pedon at Mbimba was classified as *Typic Palehumults* and as *Haplic Alisols,* respectively. These taxa reflected properties that may guide on the use and management of soils at Mbimba. The upper two horizons of pedon before lime application had total nitrogen level ranging between 0.04 - 0.17%, Phosphorus 2.91 - 4.59 $mgkg^{-1}$, Potassium 2.36 - 1%, Calcium 2.36 - 2.35 $cmol(+)kg^{-1}$ and Magnesium 0.71 - 1.93 $cmol(+)kg^{-1}$ which were rated as low to medium. Thus, application of inorganic (N, P, K -

rich), Ca+Mg and organic fertilizers is recommended to increase nutrient availability. Use of CaMg $(CO_3)_2$ as soil amendment should also be taken into consideration to raise soil pH and enhance balanced nutrient availability for coffee growth.

Key words: Soil characterization, soil morphology; physical characteristics; soil classification

2.1 Introduction

Characterization of soil properties is fundamental to all soil studies (Buol *et al.*, 2011). Complete soil characterization for classification purposes requires that all horizons of a standard soil profile (to a depth of 180 cm) be analysed. Results from such an analysis provide information that can give a clear understanding of the origin of such soils, morphology, classification and spatial distribution of soils in an area (Msanya *et al*., 2003; Kebeney *et al.*, 2014). Climatic and other ecological characteristics as well as socioeconomic factors are also important elements in land management (Providence *et* al., 2016). Plant nutrients in soils originate from parent materials from which soils were formed through the weathering of rocks and minerals (Agricultural Research Council, 2009). Soil variability is the result of natural processes and management practices (Robert, 1993). Natural variability results from complex geological and pedological processes. Soil properties and related site characteristics are important for one to be able to advise both current and future potential land users on how to use the land in the best possible way (Msanya *et al.*, 2003). Assessment of the potentials and limitations of soils for different land uses provides the basis for formulating appropriate management strategies which target specific management problems to improve crop production and soil and water conservation strategies (Muya *et al.*, 2011; Msanya *et al.*, 2003). According to Jenny cited by Munishi (2010), soil forming factors namely climate, parent material, biota, relief and time influence the morphological, physical, chemical and biological characteristics of soils. Chemical weathering of silicate rocks plays a major role in geochemical cycles, particularly in the cycle of CO_2**.** Carbon dioxide is removed from the atmosphere by rock weathering process and is converted to bicarbonate in streams and eventually in oceans. Soil characterization provides better understanding of soil genesis (Buol *et al.*, 2011). According to Lufega and Msanya (2017), for effective planning for different land uses, pedological characterization provides information related to potentials and constraints of the land. The intensification of agriculture on land requires a thorough knowledge of the soil as a resource and attributes of the land, its potential and constraints for appropriate soil and water management systems (Msanya *et al.*, 2003). In addition, environmental characteristics (e.g. climate) and socio-economic factors are also important elements in pedological characterization to provide data and knowledge on soil properties related to the site characteristics (slope, soil color, vegetation) (Lufega and Msanya, 2017). Also, the knowledge of site characterized soil's physical and chemical properties together with other ecological conditions will aid in determining the correct type and amounts of fertilizer to be applied for optimum crop nourishment and production (Msanya *et al.*, 2003). To carry out specific soil characterization before crop establishment is important, as crop production is a function of soil properties. Soil characterization provides the basic information necessary to create functional soil classification schemes and to assess soil fertility in order to unravel some unique soil problems in an ecosystem (Tenga *et al.*, 2018).

2.2 Materials and Methods

2.2.1 Description of study sites

The study was conducted in Mbozi District, Songwe Region Tanzania. The study area is located within latitudes $9^0$05'35.97"S and $9^0$05'13.10"S and longitudes $32^0$57'14.51"E and $32^0$57'22.32"E. The field trial was carried out at Mbimba substation located in Mlowo

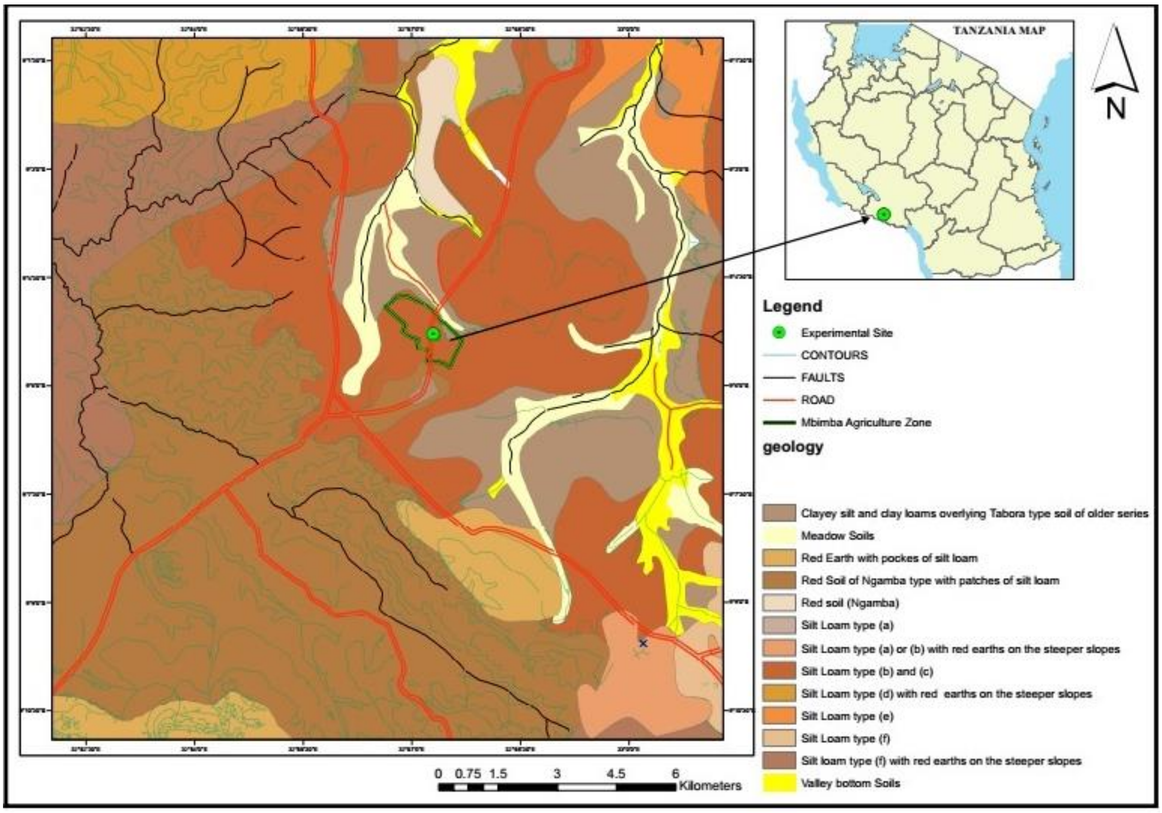

Figure 2.1: Location of the studied soil profile depicted on the generalized soil map of Mbimba, Mbozi District, Tanzania (Source: TZ Government Printer)

Ward, Mbimba Village, and 2 km from the headquarters of Mbozi District and Songwe Region along Mbeya - Zambia highway. Figure 2.1. shows the location of the studied representative soil profile depicted on the generalized soil map of Mbimba, Mbozi District, Tanzania, which is based on textural differentiation. The average altitude of the study area is 1 400 m.a.s.l. The rain season starts between November and December and lasts until May. Mean annual soil temperature at a depth of 50 cm ranges between 20.9 and 22.5^0 C. Soil temperature trends appear to decrease from 2010 to 2017 may be due to increase in soil moisture as a function increase of rainfall. The study area experiences monomodal rainfall pattern with mean annual rainfall ranging between 1 000 and 1 500 mm (Fig. 2.2 and Fig. 2.3).

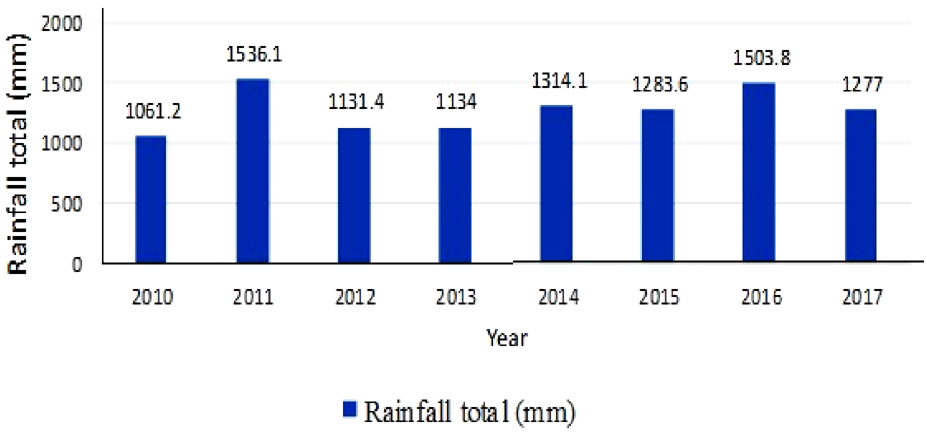

Figure 2.2: Mean annual rainfall in Mbozi District (2010 - 2017) Source: Mbimba TMA Office

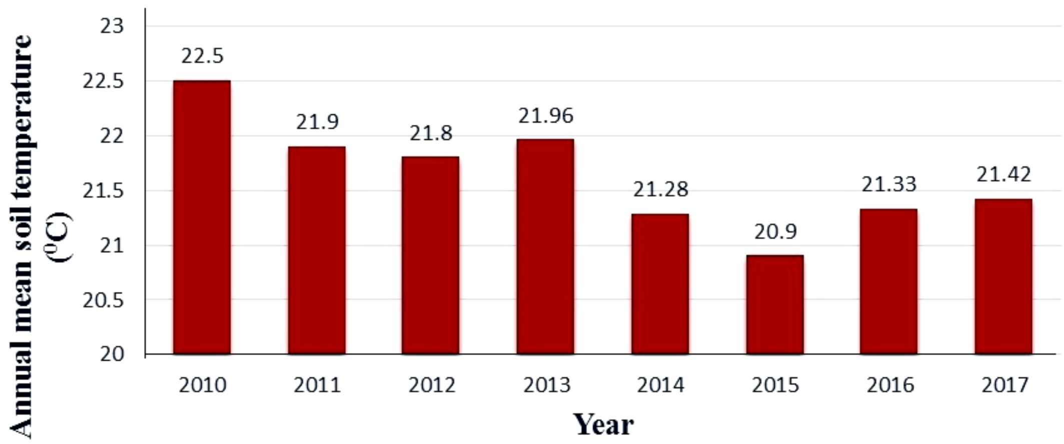

Figure 2.3: Annual soil temperature (20 cm depth) in Mbozi District, Tanzania (2010-2017) Source: Mbimba Agrometeorological Station

2.2.2 Field work

Reconnaissance survey in the study area was carried out based on transect walks, auger observations and soil descriptions to establish the soil settings at the study site on the basis of landforms and other physiographic attributes (FAO, 2006). Data and information based on landform, soil morphological characteristics, elevation, slope gradient, vegetation and land use/crops were collected from different observation sites that represented the major landforms. The informations were collected and presented in field description forms designed according to the FAO Guidelines for Soil Description (FAO, 2006). Based on the information gathered during the survey, a single profile for classification of the soil at the study area was established and excavated. Soil horizons were identified, demarcated, described and sampled according to FAO Guidelines for Soil Profile Description (FAO, 2006). Geo-referencing of the representative profile was done using global positioning system (GPS) Model Garmin ***etrex*** 20. Disturbed soil samples were taken from respective genetic horizons of representative profile for laboratory determination of physical and chemical properties. Three undisturbed samples were also taken from the profile for the determination of bulk density and soil moisture characteristics.

2.2.3 Laboratory methods

Undisturbed samples were used for determination of bulk density and moisture retention characteristics. Bulk density was determined by the core method (Blake and Hartge, 1986). Pressure plate membrane apparatus (National Soil Service, 1990) was used to determined soil moisture retention characteristics. Disturbed soil samples were air-dried, ground and passed through a 2-mm sieve for physical and chemical soil properties. Particle size distribution was determined by hydrometer method (Day, 1965) after dispersing soil with sodium hexametaphosphate and textural classes determined using the USDA textural triangle (USDA, 1965). Soil pH was measured potentiometrically in water and 1M KCl at a ratio of 1:2:5 soil-water and soil-KCl suspensions (Thomas, 2009). Organic carbon was determined by the Walkley and Black wet oxidation method (Nelson and Sommers, 1982) and the organic carbon was converted to organic matter by multiplying by a factor of 1.724 (Duursma and Dawson, 1981). Total nitrogen was determined by the micro-Kjeldahl digestion – distillation method (Moberg, 2001). Available P was extracted by the Bray and Kurtz 1 method (Moberg, 2001). Cation exchange capacity (CEC soil) was determined by the 1M ammonium acetate saturation method (pH 7.0) (Moberg, 2001). Cation exchange capacity of clay (CEC clay) was calculated using the formula outlined by Baize (1993) as follows: [CEC clay = ({CEC soil – (% OM * 2)}/ % clay) * 100]. Magnesium and $Ca2^{+}$ in the ammonium acetate filtrates were quantified by Atomic Absorption Spectrophotometer while Na^{+} and K^{+} were quantified by the flame photometer, respectively. Total exchangeable base (TEB) was calculated arithmetically as sum of the four exchangeable bases (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) for a given soil sample. Formulas used for the calculation of sodium adsorption ratio, exchangeable sodium percent and base saturation were as given by Landon (1991). Soil extractable Cu, Zn, Fe and Mn were extracted by the DTPA method (Lindsay and Norvell, 1978). The electrical conductivity was determined in 1:2:5 soil:water suspensions, electrometrically (potentiometrically) using an electric conductivity meter (Rhoades, 1996). Soil samples for total elemental analysis were prepared through sorting, grinding to powdery form and sieving the powder sample through a sieve of 75 micro millimeters. The powdery samples were exposed to XRF spectrometry for determination of minerals composition in the samples. Total elemental composition was determined by using PAN analytical XRF spectrometry (Mobius *et al.,* 2010).

2.2.4 Classification of soils

Using field and laboratory data, the soil at the study area was classified to family level of USDA Soil Taxonomy (Soil Survey Staff, 2014) and to tier-2 of FAO World Reference Base for Soil Resources (IUSS Working Group WRB, 2015).

2.2.5 Soil fertility evaluation

Soil fertility characterization was carried out for the purpose of establishing the fertility status of the soil at the study site before application of dolomitic lime. By using an auger, soil was sampled at the depth of 0 - 30 cm, gathered, mixed thoroughly to constitute composite sample for the fertility evaluation. The samples were taken to SUA soil laboratory for analysis. In the laboratory the soil sample was air dried, ground to break soil aggregates and sieved through 2 mm sieve for comprehensive laboratory analysis, for soil fertility evaluation. The parameters analysed for soil fertility evaluation were; particle size distribution which was determined by the hydrometer method (Gee and Bauder, 1986), soil pH was determined electrometrically in 1:2:5 soil: 0.01M $CaCl_2$ suspensions (Thomas, 2009), organic carbon by the wet oxidation method (Nelson and Sommers, 2009) and total nitrogen by the micro-Kjeldahl digestion – distillation method (Bremner, 2009). Available phosphorus was determined using filtrates extracted by Bray and Kurtz-1 method and determined by spectrophotometer at 884 nm wavelength following colour developed by molybdenum blue method (Bray and Kurtz, 1945). Cation exchange capacity (CEC) was determined by the neutral buffered 1M ammonium acetate saturation method (Somners and Miller, 2009). Calcium and Magnesium in the ammonium acetate filtrates were quantified by Atomic Absorption Spectrophotometer while K^+ and Na^+ were quantified by flame photometer. Plant available Cu, Zn, Fe and Mn were extracted by the DTPA method (Lindsay and Norvell, 1978). The electrical conductivity was determined in 1:2:5 soil:water suspensions, electrometrically (potentiometrically) using an electric conductivity meter (Rhoades, 1996). The undisturbed soil samples were used to determine bulk density and the soil moisture characteristics. The bulk density was determined by the core method (Blake and Hartge, 1986). Soil moisture retention characteristics were determined using sand kaolin box for low suction values and pressure apparatus for higher suction values (NSS, 1990).

2.3 Results and Discussion

2.3.1 Morphological characteristics of the studied soil profile

Some important morphological properties of the soil profile at Mbimba TaCRI substation are presented in Table 2.1. The soil was very deep (>150 cm), well drained, with gray to very dark gray colour. The soil structure of the topsoil was moderate, medium subangular blocky, while the consistence was very friable when moist, and sticky and plastic when wet. The three bottom horizons (28 - 190+ cm) were very clearly different from the topsoil (0 – 18 cm). The soil structures of these horizons were moderate to strong medium subangular blocky, while the consistence was very friable when moist, and very sticky and very plastic when wet. Roots were distributed throughout the profile but highly dense at in topsoil and decreasing with with increasing depth. Soil horizon boundaries were quite distinct, ranging mostly from clear to abrupt with either smooth or wavy horizon topography. Few distinct clay cutans, and common distinct clay cutans were observed respectively in the third and fourth horizons affirming the processes of clay eluviation and illuvation as typical pedogenic processes in the studied soil.

Table 2.1: Key morphological characteristics of the studied soil profile TaCRI-P1

Horizon	Depth (cm)	Texture	Moist Color[1]	Consistence[2]	Structure[3]	Other key pedogenic features[4]	Horizon boundary[5]
Ap	0 - 18	Clay	db(5YR3/2)	vfr, s&p	m,m,sbk	-	cs
Ah	18 - 28/35	Clay	bl(5YR2.5/1)	vfr, s&p	m-s,sbk	-	cw
Bt1	28/35 - 82/99	Clay	drb(7.5YR3/4)	vfr, vs&vp	m-s,sbk	fdcc	cw
Bt2	82/99 - 190+	Clay	sb(7.5YR3/4)	sha, fr, s&p	m-s,m,sbk	cdcc	-

[1]Soil color: db=dark brown, bl=black, drb=dark reddish brown, sb=strong brown
[2]Consistence: fr=friable, vfr= very friable, s&p=sticky and plastic, vs &vp= very sticky and very plastic, sha = slightly hard
[3]Structure: m,m,sbk=moderate medium subangular blocky, m-s,sbk=moderate to strongsubangular blocky
[4]Other pedogenic features: fdcc=few distinct clay cutans, cdcc=common distinct clay cutans
[5]Horizon boundary: cs=clear smooth, cw=clear wavy

2.3.2 Soil physical characteristics

Soil physical properties of the horizon soil samples are presented in Table 2.2.

2.3.2.1 Soil particle size distribution and silt/clay ratios

Tables 2.2 indicate soil particle size distribution and silt/clay ratios. Particle size distribution of the four horizons Ap, Ah, Bt1 and Bt2 all show clay texture dominance and clay content increased down the profile. The results are similar to those indicated by Kebeney *et al*. (2015) for soils of Busia County, Western Kenya. This supports the fact that the soil has developed largely under similar soil forming factors and have attained comparable degree of pedogenesis (USDA, 1975). Silt/clay ratios of the subsoil are lower compared to those of the upper two horizons indicating higher degree of weathering in the subsoil. On the basis of textural class, soils of Mbimba substation indicate good water and nutrient holding capacity that is important for coffee growing. Similarly, Akpan-Idiok and Ogbaji (2013) indicated that clayey texture is associated with high water retention capacity and high nutrient retention. In Bangladesh and Western Kenya, some researchers observed consistent clay increase with depth as an indication of clay migration (Khan *et al*., 2012). Texture is the most stable physical property which influences other soil properties like soil structure, consistence, soil moisture regime and infiltration rate, runoff rate, erodibility, workability, permeability, root penetrability and fertility of the soil (Landon, 1991). Textural data of the studied pedons are presented in Table 2.2.

Table 2.2: Selected physical properties of the studied pedon TaCRI-P1 in Mbimba Substation, Mbozi, Tanzania

Horizon	Depth (cm)	Sand	Clay	Silt	Textural class	Silt/clay ratio	BD Mg m^{-3}	Porosity (%)	PR (MPa)	#PAW (mm)
			%							
Ap	0 - 18	30.2	47.1	22.6	C	0.48	0.97	63.4	1.01	14.4
Ah	18 - 28/35	30.2	48.1	21.6	C	0.45	nd	nd	0.79	nd
Bt1	28/35 - 82/99	22.2	60.1	17.6	C	0.29	1.15	56.6	0.84	30.72
Bt2	82/99 - 190+	26.2	54.1	19.6	C	0.36	0.95	64.2	2.21	54.60

C = clay #PAW = Plant available water nd = not determined PR = Penetration resistance

Note:

1. Porosity=(1-(Bulk density/Particle density) x 100) assuming particle density 2.65g/cm^3
2. PAW(mm)=10 [Moisture at Field Capacity (FC) in m^3/m^3 - Moisture at Permanent Wilting Point (PWP) in m^3/m^3 x horizon depth in cm]
3. PR (kg/cm^2) based on penetrometer model: DIK-5551 Japanese (Daiki Rika Kogyo Co. LTD. = (100 x penetrometer reading(r)/0.7952(40- r)^2 where r is in mm
4. PR (MPa)=PR(kg/cm^2) x 0.0981

2.3.2.2 Bulk density and porosity

Bulk density (BD) is an important parameter for the description of soil quality and ecosystem function. The upper two horizons of Mbozi soils have BD value of 0.97g cm^{-3} while subsoil BD values of Mbimba ranged from 0.95 - 1.15 gcm^{-3}. Critical levels of BD for clays are 1.0 to 1.60 gcm^{-3} and for sands is 1.20 to 1.80 gm^{-3} with potential root restriction occurring at ≥ 1.40 gcm^{-3} for clay; and ≥1.60 gcm^{-3} for sands (Hagan *et al.*, 2010). Mbaga *et al.* (2017) indicated that BD critical range for clay soils is from 1.46 to 1.63 gcm^{-3} and potential root restriction occurs at values ≥ 1.4 g cm^{-3} for clays. Similarly, Mbaga *et al.* (2017) pointed out that BD of 1.46 to 1.63 gcm^{-3} for silts and clays, may impose many stresses such as mechanical resistance, poor aeration and changes in hydrological system in soil. Mbimba soils have low BD values according to London (1991) who stipulated that cultivated soils have bulk density ranging from 0.9 to 1.4 gcm^{-3} which would the growth of coffee plants. The Mbimba soils bulk density values similar to those reported by Kebeney *et al.* (2015) for soils of Western Kenya. Low bulk density values may be attributed to presence of organic matter and/or the presence of allophane which contribute to formation of porous soil structure (Yatno and Zauyah, 2008; Brady and Weil, 2008). Bulk density affects infiltration, rooting depth, available water capacity, soil porosity, plant nutrient availability and soil microbial activity which influence key soil processes and productivity (USDA-NRCS (2016). Low bulk density facilitates water infiltration, high soil microbial activity and easy plant root penetration for nutrients and water extraction. Cass (1999) indicated that, top soils that are loose facilitate root growth and easy tillage. The relatively higher bulk density in the mid horizon of studied soil profile may be due to lower organic carbon and organic matter content (Dalal and Mayer, 1986). According to De Geus (1973), as quoted by Landon (1991), bulk density of 1.46 to 1.63 for silts and clays may cause hindrance to root penetration. Blake and Hartge (1986) pointed out that, bulk density is influenced by the amounts of organic matter in the soil. The bulk density determines the magnitude of particle to particle contacts and how they influence the total porosity and available soil moisture (Landon, 1991). Total porosity (% vol/vol) of the studied soils show that topsoil has porosity of 63.4 while subsoils have porosity ranging between 56.6 to 64.2%. Landon (1991) pointed out that, total porosity of the soils usually lies between 30 and 70% and may be used as a very general indication of degree of compaction in the same way as bulk density is used. The Ap horizon indicate higher porosity value than Bt1 horizon (Table 2.2). This may be due to high organic matter on Ap horizon than Bt1 horizon.

2.3.2.3 Penetration resistance

Table 2.2 presents the penetration resistance values of the studied pedon. Topsoil penetration resistance values of the studied pedons ranged from 0.79-1.01MPa while those of subsoils ranged from 0.84-2.21MPa. This indicates low soil compaction in topsoil which may be attributed to presence of organic matter. According to Busscher *et al*. (2000) and Kebeney *et al*. (2015), penetration resistance of <2.94MPa, implies less possibility of soil compaction in the profile horizon and hence this is not likely to impair plant growth and development.

2.3.2.4 Soil moisture retention characteristics

Soil water retention curves of the studied profile are presented in Figure 2.4, showing amounts of water retained by the soil at various suction pressures for three sections of the studied soil profile i.e. surface horizon (0 - 5 cm), intermediate horizon (45 - 50 cm) and subsurface horizon (95 - 100 cm). Surface horizon retained less water than other horizons under all suction pressures. The trend of moisture retained at various suction pressures was as follows: surface soil < intermediate < subsurface soil. This is in line with the fact that clay content increased with depth (Table 2.2). Similar trend was observed for other soils in Tanzania by Massawe *et al.* (2017). When clay content increases, ability of soil to retain water increases at any particular matric potential and the more gradual is the slope of the curves (Blake and Hartge 1986; Hillel, 2007). Moreover, the results correspond to Landon (1991) and Hillel (2007) that clay soils, generally show slow and regular decrease in water content with increased suction pressure. According to Haghnazari *et al.* (2015), soil particle size distribution, organic matter and soil type influence the variation of available moisture content in the soil. Plant available water (PAW) in the studied soil profile appears to increase with increasing depth (Table 2.2). This is attributed to increase of clay content down the profile.

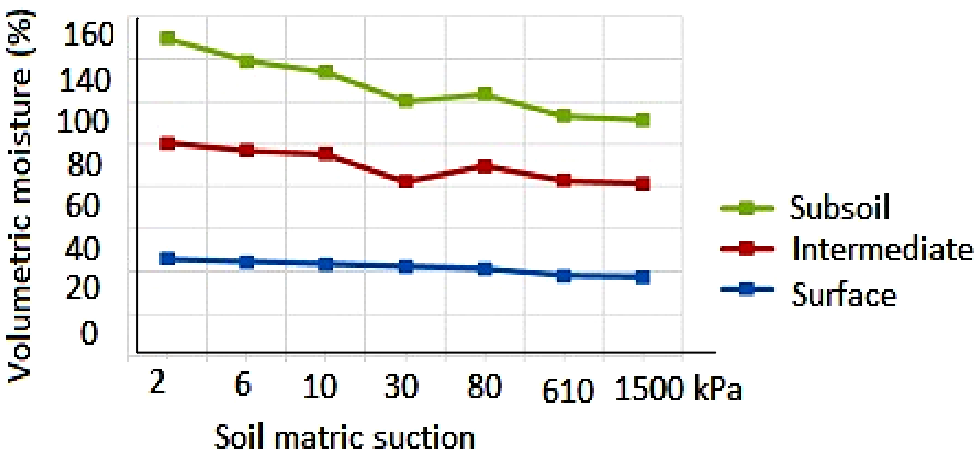

Figure 2.4: Soil moisture characteristics curve of the studied soil in Mbozi District, Tanzania

2.3.3 Chemical properties

2.3.3.1 Soil reaction (pH)

Soil pH is an important chemical property because of its influence on nutrient availability (Dejarme-Calalang and Colinet, 2014). According to Kimaro *et al.* (2001), coffee plants thrive well in soils of pH 5.6 to 6.6. Furthermore, Baize (1993) pointed out that most plants thrive well in soils with pH 6.5 - 7.5. From this point of view, the studied soils with pH (water) values ranging from 5.8 to about 6.0 (Table 2.3) may present some limitations to crop production. According to Gilkes and Hughes (1994), low pH may adversely affect availability of various plant nutrients such as phosphorus and basic cations like Ca and Mg. According to Msanya (2012), the pH values observed in the studied soil profile have been rated as medium acid. Such values are likely going to trigger nutrient imbalances, toxicity and nutrient unavailability. Low pH in horizons could be attributed to the relatively high leaching of Na, Ca, and Mg ions which is due to high rainfall and nutrient mining/uptake by plants. According to Bremner and Mulvaney (1982) low soil pH values have potential to cause toxicity problems and deficiency of some essential plant nutrients as well as affect soil microbial activities due to high concentration of H^+ and Al^{3+}. Soil pH <5.5 could also cause dissolution of aluminum and iron minerals which precipitates with phosphorus effectively causing its fixation.

2.3.3.2 Available phosphorus

The results in Table 2.3 indicate that available phosphorus decreased down the pedon. According to Tisdale *et al*. (1993), phosphorus is highly affected by pH. Phosphorus availability decreases as soils become acidic. In the Table 2.3, P concentration ranges between 0.11 and 4.59 $mgkg^{-1}$. The upper two layers of the pedon have phosphorus content ranging between 2.91 and 4.59 $mgkg^{-1}$. According to Landon (1991), available P (Bray-Kurtz 1) at <7 $mgkg^{-1}$ is considered as low phosphorus. Furthermore, concentration of P < 3 and 3 - 6.5 ppm is considered as acutely deficient and deficient respectively.

Table 2.3: Soil reaction and selected macronutrients

Horizon	Depth (cm)	pH 1:2:5		OC	OM	TN	C/N	Avail P mg/kg
		H_2O	KCl		%			Bray and Kurtz 1
Ap	0 - 18	5.82	4.86	2.44	4.21	0.17	14	4.59
Ah	18 - 28/35	5.79	4.84	2.04	3.51	0.15	14	2.91
Bt1	28/35 - 82/99	5.96	4.99	0.91	1.57	0.07	13	0.43
Bt2	82/99 - 190+	5.98	5.03	0.33	0.57	0.04	8	0.11

According to Hodges (2014), an available P level of 15 mg/kg is generally considered as the critical level below which P deficiency symptoms are likely to occur in many crops. Trends of available P in the studied soil decreases with increasing profile depth. The possible cause can be due to decrease in organic matter content with depth because soil organic matter plays a key role in P availability due to its ability to coat aluminium and iron oxides, which reduces P sorption (Debicka *et al.*, 2015). Similarly, low soil pH observed may provoke the reaction of P iron (Fe) and aluminium (Al) thereby producing insoluble Fe and Al phosphates that are not readily available for plant uptake (Hodges, 2014) as shown in the equation below:

$Al^{3+} + H_2PO_4^- + H_2O \longrightarrow Al(OH)P_2PO_4 + H^+$. The presence of chemically active oxides/hydroxide can also fix P as follows: $Al(OH)_3 + H_2PO_4^- \longrightarrow$ Al(OH)H2PO4 + OH- and $Fe(OH)_2 + H_2PO_4^- \longrightarrow Fe(OH)H_2PO_4^- + OH^-$

2.3.3.4 Organic carbon, organ matter, total nitrogen and carbon/nitrogen ratio

The two-subsoil horizons have very low to low organic carbon content ranging from 0.33 - 0.91. According to Msanya *et al.* (1996), organic carbon less than 0.6 is considered as very low and 0.60 - 1.25 as low. The OM content in the studied pedon ranged from low to medium (0.6 - 4.2%) and decreased down the profile (Table 2.3). OM level in the soil is strongly correlated with the soil's CEC, and is a source of many plant nutrients, particularly nitrogen (Brandy and Weil, 2008). Soil organic matter enhances soil water retention because of its hydrophilic nature and its positive influence on soil structure (Lal, 2004). Total nitrogen level as shown in Table 2.3 ranges between 0.04 and 0.17%. Total nitrogen levels of less than 0.2% and organic carbon values below 0.6% are considered low for agricultural activities (Landon, 1991). According to Msanya *et al.* (2003), low N content in the soil requires N fertilizer application for optimal plant growth. The low soil pH also may be the cause for low nitrogen content as low pH affects microbial activity in the soil and the consequence is low organic matter breakdown (Landon, 1991). C/N ratios in the studied soil ranged from 8 - 14 and there was a general trend of narrowing of the ratios with increasing depth. According to Msanya *et al.* (2001), the C/N ratios in the upper 100 cm were rated to be of moderate to good quality whereas those in the deeper subsoil were rated to be of poor quality, although Msanya *et al*. (2001) indicated that, C:N ratio of 10:1 indicates good quality organic material, they cautioned that C:N ratio might not be a good indicator of soil fertility, and thus encouraged use of individual C and N values instead.

2.3.3.5 Exchangeable Ca, Mg, Na, K and CEC

The results on exchangeable cations of the studied soil profile are given in Table 2.4. Exchangeable cations were rated as very low to high for Calcium, while Magnesium was rated as medium and the Potassium rated as medium to very high. Exchangeable cations levels were variable within thestudied pedon with a general tendency for Mg and K to increase down the profile. Tenga *et al.* (2018) made similar observations and pointed out that exchangeable cations increase down the profile for highly leached soils. Amount of exchangeable sodium in Mbimba soils varied from 0.03 to 0.19 cmol(+)kg^{-1} (Table 2.4). According to Kimaro *at al*. (2001), sodium concentration levels <0.1 and 0.10 - 0.30 cmol(+)kg^{-1} are considered as very low and low respectively. Thus, the upper horizon (Ap) had very low sodium while the (Ah) horizon had low sodium concentration which increases down the profile indicating leaching of Na. According to Kimaro *et al.* (2001), soils with ESP <3 is considered as non-sodic and soils with ESP 6 - 10 considered as slightly sodic. Thus, the soils of Mbimba Mbozi are considered as not salt-affected. Potassium level ranged between 0.05 and 1 indicating low potassium concentration while the optimal concentration for optimal arabica growth is 1.5 - 2.5% (Clowes, 2001). Furthermore, in all horizons, concentration of cations increased down the profile which may be due to leaching of these cations. Levels of exchangeable cations have direct implications on the cation exchange capacity (CEC), soil pH and finally plant nutrient imbalances, unavailability and nutrient induced deficiencies. For example, Mg acts as a phosphorus carrier in plants and therefore, P uptake is influenced by exchangeable Mg (Lufega and Msanya, 2017). Cation Exchange Capacity (CEC) in the studied soil profile was rated as medium to high (24 - 27 cmol(+)kg). High CEC is due to clay content in the pedon (Metson, 1961). The FAO (1979a) quotes values of 8 - 10 cmol(+)kg^{-1} of soil as indicative for minimum value in the top 30 cm of the soil for satisfactory crop production, provided other factors remain favourable. According to Landon (1991), any value <4 cmol(+)kg^{-1} soil (measured at the pH of the soil) indicates a degree of infertility normally not suitable for crop production. In the Table 2.4, percent base saturation (BS) varied from 19.62 to 30.54 cmolkg^{-1} and decreased with depth. According to Landon (1991), BS% <20 is considered as low, between 20 and 60% medium and > 60% high. Generally, the soil of Mbimba Mbozi was rated to be of low fertility. Edem and Ndaeyo (2009) pointed out that availability of nutrients for uptake by plants depends not only upon absolute levels of nutrients but also on the nutrient ratios. Ca/Mg ratios in the studied soil profile ranged between 0.04 and 3.3 for all horizons while Ca/Mg ratios of 2 to 4 are considered as favourable for most crop plants to grow (Lufega and Msanya, 2017; Msanya *et al.*, 2001). The upper two horizons (Ap and Ah) had Ca/Mg ratio between 2.6 - 3.3 implying optimal conditions.

Table 2.4: Exchangeable bases and nutrient ratios in the studied soil profile TaCRI-P1

Site	Horizon	Exchangeable bases cmol(+)/kg						BS%	Ca/Mg
		Ca	Mg	K	Na	CEC	TEB		
Mbimba TaCRI	Ap	4.59	1.41	1.3	0.03	24	7.33	30.54	3.3
	Ah	4.02	1.57	0.05	0.05	25	7.21	28.84	2.6
	Bt1	1.95	1.63	1.86	0.1	27	5.54	20.51	1.2
	Bt2	0.07	1.91	3.13	0.19	27	5.3	19.62	0.04

CEC=Cation exchange capacity, TEB =Total exchangeable bases, BS=Base saturation.

2.3.3.6 Micronutrient concentration in the studied soil

Table 2.5 presents results on the analysed micronutrients Cu, Mn, Fe and Zn. The results indicate the concentrations of the micronutrients as follows: Cu (0.04 - 6.80 mgkg^{-1}), Zn (1.07 - 5.93 mgkg^{-1}), Mn (21.08 - 193.03 mgkg^{-1}) and Fe (68.22 - 101.28 mgkg^{-1}). According to Landon (1991), concentration of micronutrients of Cu (2 - 250 mgkg^{-1}), Zn (1 - 900 mgkg^{-1}), Mn (20 – 10 000 mgkg^{-1}) and Fe (50 - 150 mgkg^{-1}) are considered as optimal ranges. Thus the results imply Cu to be deficient while Mn, Fe, and Zn are sufficient. The levels of micronutrients decreased with depth (Table 2.5). Similarly, Landon (1991) pointed out that availability of micronutrients decreases with increase in soil pH. Results in Table 2.3 indicate that the pH of surface horizon of the study area is very acidic and the pH decrease slightly as you move down the profile. Massawe *et al.* (2017) pointed out that, Cu and Mn are more available at pH of 5 to 6.5 and decrease when pH is below 5 or above 6.5.

Table 2.5: Micronutrient contents of the studied soil profile TaCRI-P1 in Mbimba Mbozi, Tanzania

Horizon	Depth (cm)	Micronutrient content mgkg^{-1}			
		Cu	Zn	Mn	Fe
Ah	10 - 18	6.80	5.93	193.03	101.28
Ap	18 - 28/35	2.63	3.13	82.85	97.82
Bt1	28/35 - 82/99	0.26	1.40	45.28	72.45
Bt2	82/99 - 190+	0.04	1.07	21.08	68.22

2.3.3.7 Total elemental composition of the studied soil Mbimba Mbozi, Tanzania

Results on total elemental composition of the studied soil are given in Table 2.6a. Silica (SiO_2) is the most abundant oxide ranging from 38.70 - 45.90%. The high values of SiO_2 indicate the existence of amorphous silica (Lufega and Msanya, 2017). Concentration of Al_2O_3 (20.01 - 23.08%) and Fe_2O_3 (19.60 - 32.20%) are available in abundance compared to other oxides. The possible reason is the high presence of gibbsite and hematite in the soil (Kileo, 2000). Trends of other oxides i.e TiO_2 and RuO_2 indicate that their abundance increases down the profile while MnO and K_2O decrease down the profile. According to Kileo (2000), soils in Mbeya have high concentration of TiO_2 similar to what is shown in the Table 2.5. According to Drever (1994), terrestrial plants and their associated microbiota, directly affect silicate mineral weathering in several ways: by generation of chelating ligands, by modifying pH through production of CO_2 or organic acids, and by altering the physical properties of a soil.

Table 2.6a: Total chemical composition of the studied soil pedon TaCRI-P1 at Mbimba Mbozi District, Tanzania[1]

Depth (cm)	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	F_2O_3	ZrO_2	RuO_2	Sr	W	Zn	Cu	Ni	S	Bi	Pb	Cr	V
					%								mgkg[1]							
0 - 18	22.02	45.9	0.87	3.46	1.1	2.88	1.07	19.6	0.97	0.8	34	207	155	298	56	1079	100	44	187	158
18 - 28/35	22.05	45.2	0.87	3.53	1.15	2.88	1.08	20.2	1.01	0.9	35	192	125	126	72	900	99	41	199	133
28/35 - 82/99	20.01	38.7	0.99	3.49	0.91	3.19	1.18	26.4	1.53	1.3	30	171	111	98	86	831	101	49	186	157
82/99 - 190+	23.08	43.3	0	3.29	0.68	3.04	1.05	23.1	1.15	0	26	208	96	81	56	627	103	38	192	144

Table 2.6a [1] **Note:** Recovery of reference standard during analysis of soil

Element Spike	Al_2O_3	SiO_2	P_2O_5	K_2O	Cao	TiO_2	MnO	Fe_2O_3	ZrO_2	RuO_2
					%					
Actual value	21.03	45.92	0.87	3.26	1.15	2.86	0.97	19.6	80.99	0.89
Measured value	20	40.88	0.75	3.20	1.14	2.48	0.97	19.01	79.00	0.80
Recovery %	95	89	86	98	99	87	100	97	98	90

Spike=In house reference sample. Most recoveries are close to actual value which is an indication that the analytical procedures were accurate and thus, validated the data presented in this study. For that case the analytical data obtained were presented without any adjustment

The results on total elemental composition of Mbimba Mbozi soil as determined by total XRF are shown in Table 2.6a. Observed data shows that K_2O, MnO and Bi do not show significant variations in their concentration across the profile which implies there were no losses or gains through leaching or anthropogenic activities. Concentrations of S, Cu, Zn, CaO and SiO_2 apparently decreased down the soil profile. Higher concentrations of these elements in top soils may be contributed by application of fertilizers, fungicides or pesticides. Similarly, the upper three layers of the profile showed higher concentration of P_2O_5 and RuO than the subsoil. Concentration of Fe_2O_3 and TiO_2 increased down the profile which is likely due to leaching of some iron oxides and titanium oxides. The concentrations of Al_2O_3, ZrO_2, Sr, W, Ni, Pb and V showed inconsistent distribution within the profile.

Table 2.6b: Concentration of potential toxic elements and their maximum limit.

Element	Maximum limit in agriculture soils	References
Zn	300 mg kg^{-1}	Commission of the European Communities (1986)
Pb	300 mg kg^{-1}	Li *et al.* (2006)
Cr	600 mg kg^{-1}	Pasquini (2006)
Ni	75 mg kg^{-1}	Commission of the European Communities (1986)
Cu	140 mg kg^{-1}	Commission of the European Communities (1986)

Concentration of potentially toxic elements in the studied soil profile are indicated in Table 2.6a. Concentration of Pb (41 – 49 mg kg^{-1}), Cr (186 – 199 mg kg^{-1}) and Zn (96 – 155 mg kg^{-1}) found in the studied soil were found within the normal levels that are commonly reported in many soils around the world. According to Commission of the European Communities (1986), Zn concentration of 300 mg kg^{-1}, Ni concentration of 75 mg kg^{-1} and Cu concentration of 140 $mgkg^{-1}$ are considered as maximum limit in the agriculture soils while (Li *et al.*, 2006) considered Pb concentration of 300 mg kg^{-1} as maximum limit and Pasquini (2006) 600 mg kg^{-1} is maximum limit for Cr in agriculture soils (Table 2.6b). The soil profile also had Cu concentration of 298 mg kg^{-1} and Ni concentration of 86 mg kg^{-1} which are above the maximum limit in agriculture soil. The high concentration of these elements may have been contributed by application of pesticides and fungicides in the coffee farm.

2.3.3.8 Classification of the studied soil at Mbimba, Mbozi, Tanzania

Tables 2.7 and 2.8 present the results on the classification of the representative soil profile of the study area using respectively the USDA Soil Taxonomy (to family level) and World Reference Base (WRB) for Soil Resources schemes (to tier 2). Diagnostic horizons and other features were identified in both systems and were then used to classify the soils using the taxonomic keys of the systems. According to USDA Soil Taxonomy ***umbric epipedon*** and ***argillic subsurface horizon*** were the diagnostic horizons of the soil. These horizons translated respectively into ***umbric horizon*** and ***argic horizon*** in the WRB system. The soil classified as ***Gently undulating, very deep, clayey, medium acid, udic, isohyperthermic, Typic Palehumults*** in the USDA Soil Taxonomy and as ***Haplic Alisols (Clayic, Cutanic, Hyperdystric, Humic, Profondic)*** in the WRB for Soil Resources.

2.4 Conclusions

- The representative soil of the study area under coffee production in Mbimba Mbozi District was classified as Ultisol (USDA Soil Taxonomy) and Lixisol (WRB).
- The soil is highly weathered, typically very deep, fine textured with moderate to strong subangular blocky structure. Generally, the soil has good physical properties.
- The pH of the soil is acidic due to the high rainfall of the study area

Table 2.7: Summary of diagnostic features of the studied pedon TaCRI-P1 at Mbimba Substation, Mbozi, and classification according to USDA Soil Taxonomy (Soil Survey Staff, 2014)

Diagnostic horizon(s)	**Other diagnostic features**	**Order**	**Suborder**	**Greatgroup**	**Subgroup**	**Family**
Umbric epipedon; argillic horizon	Gently undulating (slope 5%), very deep, clayey, medium acid, udic SMR, isohyperthermic STR, presence of clay cutans	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently undulating, very deep, clayey, medium acid, udic, isohyperthermic, Typic Palehumults*

Table 2.8: Summary of diagnostic horizons and features of the studied soils and classification according to World Reference Base for Soil Resources [IUSS Working Group WRB (2015)]

Diagnostic horizon(s)	**Other diagnostic features/materials**	**Reference Soil Group (Tier 1)**	**Principal Qualifiers**	**Supplementary qualifiers**	**Tier 2 Soil name**
Umbric horizon; Argic horizon	Gently undulating (slope 5%), very deep, clayey, presence of clay cutans (cutanic), high organic matter content	Alisols	Haplic	Clayic, Cutanic, Hyperdystric, Humic, Profondic	*Haplic Alisols (Clayic, Cutanic, Hyperdystric, Humic, Profondic)*

- The soil's essential nutrients N, P K, Ca and Mg are deficient ranging from very low to low.
- Micronutrient levels of Cu are low particularly in the subsoil, whereas Zn, Mn and Fe levels are adequate.

2.5 Recommendations

- Nitrogen, Phosphorus, Potassium, Calcium and Magnesium that were found to be deficient in the studied area need to be supplemented in form of fertilizers so as to improve arabica coffee growth and productivity in Mbimba Mbozi.
- Soils of Mbimba Mbozi need application of lime in order to raise soil pH from medium acid to better levels that will favor arabica coffee growth.

REFERENCES

Agricultural Research Council (2009). Republic of South Africa. Department of Education, Soil science course material. *Agroecosystems* 53: 83-92.

Akpan-Idiok, A. U. and Ogbaji, P. O. (2013). Characterization and Classification of Onwu River Floodplain Soils in Cross River State, Nigeria. *International Journal of Agricultural Research* 8: 107-122.

Baize, D. (1993). *Soil Science Analysis. A Guide to Correct Use*. John Wiley and Sons Ltd. West Sussex. 192pp.

Blake, G. R. and Hartge, K. H. (1986). Bulk Density. In: *Methods of Soil Analysis, Part 1,* 2nd Edn. Agronomy Monograph No. 9. (Ed.: Klute, A.). American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin. pp 364-376.

Brady, N. C. and Weil, R. R. (2008). *The Nature and Properties of Soils*. 13th Edn. Pearson Education, Inc. 965pp.

Bray, R. H. and Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science* 59: 39-45.

Bremner, J. M. (2009). Nitrogen-total. In: *Methods of Soil Analysis Part 3: Chemical Methods: SSSA Book series no. 5.* (*Edited by Sparks D.L.*), Soil Science of America Inc. 5th Edition. pp. 1085-1121.

Buol, S. W., Southard, R. J., Graham, R. C. and McDaniel, P. A. (2011). *Soil genesis and classification*. John Wiley and Sons. [https://www.tib.eu/en/search/id/.../Soil-Genesis-and-Classification-6th-edition] site visited on 10/09/2017.

Busscher, W. J., Frederick, J. R. and Bauer, P. J. (2000). Timing effects of deep tillage on penetration resistance and wheat and soybean yield. *Soil Sci. Soc. Am. J.* 64: 999 - 1003.

Cass, A. (1999). *Interpretation of Some Soil Physical Indicators for Assessing Soil Physical Fertility. In: Soil Analysis: An Interpretation Manual.* 2nd edition, (Edited by Peverill, K. I., Sparrow, L. A. and D. J. Reuter, D. J.). CSIRO Publishing, Melbourne. pp. 95–102.

Dalal, R. and Meyer, R. J. (1986). Long term trend in fertility of soils under continuous cultivation and cereal cropping in Queensland II. Total organic carbon and its rate of loss from soil profile. *Australian Journal of Soil Research* 24: 301-309.

Day, P. R. (1965). Particle fractionation and particle size analysis. In: Black C.A, Evans D. D., White, J. L., Ensminger, L. E. and Clark, F. E. (Eds.), Methods of soil analysis: Physical and mineralogical methods, American Society of Agronomy, Madison, Wisconsin. 545-566pp.

De Geus, J. G. (1973). Fertilizer guide for the tropics and subtropics. *Fertilizer Guide for the Tropics and Subtropics.*, (Ed. 2). Cornell University. Centre d'etude de l'azote, 774 pp.

Debicka, M., Kocowicza, A., Webera, J. and Jamroza, E. (2015). Organic matter effects on phosphorus sorption in sandy soils. *Arch. Agron. Soil Sci.* 62: 840-855.

Dejarme-Calalang, G. M. and Colinet, G. (2014). A review of soils and crops in the Bukidnon Highlands of Northern Mindanao, the Philippines. *Biotechnology Agronomy Society and Environment* 18(4): 544–557.

Drever, J. I. (1994). The effect of land plants on weathering rates of silicate minerals. *Geochimica et Cosmochimica Acta* 58(10): 2325-2332.

Duursma, R. Dawson. (1981). Organic sea surface films, Marine Organic Chemistry EK Hunter, K. A and Liss, P. S. pp259–298.

Edem, S. O. and Ndaeyo, N. U. (2009). Fertility status and management implications of wetland soils for sustainable crop production in Akwa Ibom State, Nigeria. *Environmental Development Sustainability* 11: 393-406.

FAO, Food and Agriculture Organization of the United Nations (2006). *Guidelines for Soil Description.* 4th Edn. Food and Agriculture Organization of the United Nations, Rome. 110pp.

Gee, G. W. and Bauder J. W. (1986). Particle-size analysis 1. *Methods of soil analysis: Part 1—Physical and mineralogical methods*, (methodsofsoilan1), pp383-411.

Gilkes, R. J. and Hughes, J. C. (1994). Sodium fluoride pH of south-western Australian soils as an indicator of P sorption. *Australian Journal of Soil Research* 32: 755-766.

Hagan, D., Dobb, C., Timilsina, N., Escobedo, F., Toor, G. and Andreu, M. (2010). Anthropogenic effects on the physical and chemical properties of subtropical urban soils. *Soil Use and Management* 28: 78-88.

Haghnazari, F., Shahgholi, H. and Feizi, M. (2015). Factor affecting the infiltration of soil: review. *International Journal of Agronomy and Agricultural Research* (*IJAAR*), vol. 6, no. 5, pp. 21-35.

Hillel, D. (2007). *Soil in the Environment*: *Crucible of Terrestrial Life.* 1st Edn. Academic Press/Elsevier, Amsterdam. ISBN: 9780123485366. 320p.

Hodges, S. C. (2014). Soil Fertility Basics. Soil Science Extension North Carolina State University. 2007; [athttp//.plantstress. com/Articles/min_deficiency_i/soil_fertility.pdf] site visited on 7th May; 2018.

IUSS Working Group WRB (2015). World Reference Base for Soil Resources 2014, Update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Reports No. 106. FAO, Rome.

Karuma, A. N., Gachene, C. K. K., Msanya, B. M., Mtakwa, P. W., Amuri, N., Gicheru, P. T. (2014). Soil morphology, physico-chemical properties and classification of typical soils of Mwala District, Kenya. *International Journal of Plant and Soil Sci*ence 4(2): 156-170.

Kebeney, S. J., Msanya, B. M., Ng'etich, W. K., Semoka, J. M. R. and Serrem, C. K. (2015). Pedological characterization of some typical soils of Busia County, Western Kenya: Soil Morphology, Physico-chemical Properties, Classification and Fertility trends. *International Journal of Plant and Soil Science* 4: 29-44.

Kebeney, S. J., Msanya, B. M., Ng'etich, W. K., Semoka, J. M. R. and Serrem, C. K. (2014). Pedological Characterization of Some Typical Soils of Busia County, Western Kenya. Soil Morphology, Physico-chemical Properties, Classification and Fertility Trends. *International Journal of Plant and Soil Science* 4(1): 30-44.

Khan, Z. H., Hussain, M. S. and Ottner, F. (2012). Morphogenesis of Three Surface-Water Gley Soils from the Meghna Floodplain of Bangladesh. *Dhaka University Journal of Biological Science* 21(2): 17-27.

Kileo, E. P. (2000). Land suitability assessment of the Wami plains in Morogoro, Tanzania with respect to the production of the main food crops and extensive grazing. Thesis, for Award degree of MSc. at Sokoine University of Agriculture, Morogoro, Tanzania. 152pp.

Klute, A. (1986). Water retention. In: *Methods of Soil Analysis, Physical and Mineralogical Methods.* Part 1, 2nd Edition. Edited by Klute A. Agronomy Monograph No. 9. 1986: 635-662.

Lal, R. and Shukla, M. K. (2004). *Principles of Soil Physics.* Marcel Dekker, Inc. New York. Basel. 716pp.

Landon, J. R. (1991). *Booker Tropical Soil Manual.* A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific and Technical Publishers, Essex. 474pp.

Liang, J. and Karamanos, R. E. (1993). DTPA-extractable Fe, Mn, Cu and Zn. *Soil Sampling and Methods of Analysis*. pp. 87-90.

Lindsay, W. L. and Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper 1. *Soil science society of America Journal* 42(3): 421-428.

Lufenga, S. M. and Msanya, B. M. (2017). Pedological characterization and soil classification of selected soil units of Morogoro District, Tanzania. *International Journal of Plant and Soil Science* 16(1): 1-12.

Massawe, I. H., Msanya, B. M. and Rwehumbiza, F. B. (2017). Pedological characterization and fertility evaluation of paddy soils of Mvumi village, Kilosa District, Tanzania. *Int. J. Curr. Res. Biosci. Plant Biology* 4(4): 49-60.

Mbaga, H. R., Msanya, B. M. and Mrema, J. P. (2017). Pedological characterization of typical soil of Dakawa Irrigation Scheme, Mvomero District, Morogoro Region, Tanzania.

Metson, A. J. (1961). *Methods of Chemical Analysis for Soil Survey Samples*. New Zealand Department of Scientific and Industrial Research. 102pp.

Moberg, J. P. (2001). *Soil and Plant Analysis Manual*. (Revised Edition). The Royal Veterinary and Agricultural University, Chemistry Department, Copenhagen, Denmark. 133pp.

Mobius, J., Lahajnar, N. and Emeis, K. C. (2010). Diagenetic control of nitrogen isotope ratios in Holocene sapropels and recent sediments from the Eastern Mediterranean Sea. *Biogeosciences* 7: 3901 – 3914.

Msanya, B. M., Kimaro, D. N., Kimbi, G. G., Kileo, E. P. and Mbogoni, J. D. J. (2001). Land resource inventory and suitability assessment for the major use types in Morogoro urban district, Tanzania. Soil and Land Resources of Morogoro Rural and Urban Districts, Volume Department of Soil Science, Sokoine University of Agriculture, Morogoro Tanzania. ISBN. 2001; 605:29.

Msanya, B. M. (2012). Guide to general rating of some chemical and physical soil properties. Sokoine University of Agriculture, Faculty of Agriculture, Department of Soil Science, Morogoro, Tanzania. 3pp.

Msanya, B. M., Kimaro, D. N., Kileo, E. P., Kimbi, G. G., Munisi, A. I. M., 2001. Land Resources Inventory and Suitability Assessment for the Production of the Major Crops in the Eastern Part of Morogoro Rural District, Tanzania. Soils and Land Resources of Morogoro Rural and Urban Districts, Vol. 3. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania. 69pp.

Msanya, B. M., Kaaya, A. K., Araki, S., Otsuka, H. and Nyadzi, G. I. (2003). Pedological characteristics, general fertility and classification of some benchmark soils of Morogoro District, Tanzania. Science and Engineering Series. *African Journal of Science and Technology* 4(2): 101-112.

Msanya, B. M., Wickama, J. M., Kimaro, D. N., Magoggo, J. P. and Meliyo, J. L. (1996). Investigation of the environmental attributes for agricultural development in Kitanda village, Mbinga District, Tanzania. Technical Report No 5. Department of soil science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania and Ministry of Agriculture, National Soil service, Agricultural Research Institute, Mlingano, Tanga, Tanzania. pp38.

Munishi, J. A. (2010). Pedological characterisation of soils and assessment of their agricultural potential in selected districts of Mbeya Region, Tanzania. Dissertation for Award of MSc. Degree at Sokoine University of Agriculture, Morogoro, Tanzania. pp. 135.

Muya, E. M., Obanyi, S., Ngutu, M., Sijali, I. V., Okoti, M., Maingi, P. M. and Bulle, H. (2011). The physical and chemical characteristics of soils of Northern Kenya Aridlands: Opportunity for sustainable agricultural production. *Journal of Soil Science and Environmental Management* 2(1): 1– 8.

National Soil Service (NSS), 1990. Laboratory Procedures for Routine Analysis. Agricultural Research Institute, Mlingano, Tanga, Tanzania. 212p.

Nelson, D. W. and Sommers, L. E. (2009). Total carbon, organic carbon, and organic matter. In: *Methods of Soil Analysis Part 3: Chemical Methods: SSSA Book series no. 5.* (*Edited by Sparks D.L.*), Soil Science of America Inc. 5th Edition. 961-1010 pp.

Providence, U., Msanya, B. M., Mtakwa, P. W., Uwingabire, S. and Sirikare, S. (2016). Pedological Characterization of Soils Developed from Volcanic Parent Materials of Northern Province of Rwanda. *Agriculture, Forestry and Fisheries* 5(6): 225-236.

Rhoades, J. D. (1996). Salinity: Electrical conductivity and total dissolved solids. In: *Methods of Soil Analysis, Part 3: Chemical Methods* (Ed.: Sparks, R. L.). Soil Science Society of America, Madison. pp. 417-435.

Robert, P. (1993). Characterization of soil conditions at the field level for soil specific management. *Geoderma* 60(1-4): 57-72.

Soil Survey Staff (2014). *Keys to Soil Taxonomy*. 12th Edn. United States Department of Agriculture, Natural Resources Conservation Service. [https://www.nrcs. usda.gov/wps/PA_NRCSConsumption/download?cid...ext=pdf] site visited on 9th May; 2018.

Soil Survey Staff USA. (1975). *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*. US Government Printing Office. 754pp.

Somner, M. E. and Miller, W. P. (2009). Cation exchange capacity. In: *Methods of soil analysis. Part 3, Chemical Methods* (Ed.: Sparks, R.L.). Soil Science Society of America, Madison. pp.475-490.

Tenga, J. J., Msanya, B. M., Semoka, J. M., Semu, E. and Mwango, S. B. (2018). Pedological Characterization and Classification of Some Typical Soils in Three Agro-Ecological Settings of South-Eastern Tanzania. *International Journal of Scientific and Engineering Research* 9(2): 692-702.

Thomas, G. W. (2009). Soil pH and soil acidity. In: *Methods of Soil Analysis Part 3—Chemical Methods: SSSA Book series no. 5. (Edited by Sparks D.L.),* Soil Science of America Inc. 5th Edition. pp. 475-490.

Tisdale, S. L., Nelson, W. L. and Beaton, J. D. (1993). *Soil Fertility and Fertilizers*. 6th Edn. Prentice Hall, Upper Saddle, New Jersey. pp. 305-319.

USDA, United States Department of Agriculture -NRCS, Natural Resources Conservation Service (2016). Soil bulk density/moisture/aeration. Soil quality kit-Education for educators. [climatesmartfarming.org/wp-content/uploads/2016/.../Cornell-Farmework-Manual.pdf] site visited on 12/10/2017.

USDA, United States Department of Agriculture (1965). Textural triangle. United States Department of Agriculture. *Soil Science Society of America Proceedings* 32: 62-63.

Yatno, E. and Zauyah, S. (2008). Properties and management implications of soils formed from volcanic materials in Lembang area, West Java. *Indonesian Journal of Agricultural Science* 9(2): 44-54.

CHAPTER THREE

3.0 DETERMINATION OF OPTIMAL LIME RATE FOR MBIMBA ACIDIC SOILS UNDER ARABICA COFFEE (*Coffea arabica* L.) IN MBOZI DISTRICT, TANZANIA

ABSTRACT

Soil acidity is among the major constraints to coffee productivity in Mbimba, Mbozi District, Tanzania. An experiment was conducted in 2017 - 2018 to evaluate dolomitic lime + NPK (22.6.12+3S) fertilizer effect on vegetative growth of arabica coffee grown on acid soils of Mbozi District. The experiment was set in a randomized complete block design with lime $CaMg(CO_3)_2$ applied under different application levels of 0 $kgha^{-1}$, 1000 $kgha^{-1}$, 2000 $kgha^{-1}$ and 2500 $kgha^{-1}$. Results showed that lime increased soil pH by 0.22 - 0.97 units in the limed plots while control plot had the same pH. Phosphorus concentration varied between 0.52 and 17.57 $mgkg^{-1}$ before application of lime and at lime rate of 2000 $mgkg^{-1}$ P concentration increased from 0.52 to 23.3 $mgkg^{-1}$ while Potassium concentration significantly (P = 0.5) varied from 1.01 - 2.10 $cmol(+)kg^{-1}$ before application of lime and increased from 1.15 - 8.11 $cmol(+)kg^{-1}$ after application of lime in all 3 levels of lime. Soil Ca and Mg varied significantly (P = 0.05) from 2.36 - 5.67 $cmol(+)kg^{-1}$ before application of lime and increased from 2.94 - 15.82 $cmol(+)kg^{-1}$ after application of dolomitic lime. There was a very strong positive correlation between lime and Na (R^2 = 0.94), moderate positive correlation between lime rate and Ca (R^2 = 0.74), Mg (R^2 = 0.85) and weak correlation between lime rate and N (R^2 = 0.38) and P (R^2 = 0.20). Application of lime at 2000 $kgha^{-1}$ in coffee field is recommended to improve nutrient availability and coffee yield on acid soils of Mbimba, Mbozi District, Tanzania.

Keywords: Acid soils, Arabica coffee, dolomite lime

3.1 Introduction

Most of the reactions that control the availability of nutrients in soils are dependent upon physico-chemical processes which occur at the soil solution-particle interface (Bolt, 1979). The ion exchange, dissolution, precipitation, oxidation-reduction, adsorption and complexation processes are the ones controlling nutrient availability to the plant. The combined interaction of these processes influences the amount and speciation of nutrient ions in the soil solution and thus their availability for plant growth (Balistrieri, 1994). However, these processes are also influenced by the pH of the soil medium. According to Kimaro *et al.* (2001), optimum soil pH for arabica coffee ranges between 5.6 and 6.6. In order to counteract the effect of soil acidity on crop growth, liming is a traditional practice often applied to soils to restore Ca and Mg availability for plants and adjust soil acidity (Carvalho and Van Raij, 1997; Cyamweshi *et al*., 2013). Naidu *et al.* (1990) observed the beneficial effect of liming in reducing micronutrient toxicity while increasing the availability of Ca, P, Mo and Mg in the soil. In Mbozi District, there has been low coffee production due to increase in mortality rate of coffee seedlings as a result of limited access of nutrients due to low soil pH and Al toxicity as well as low production of coffee parchment which ranges from 250 - 450g per tree while the production potential of Arabica coffee is 3.5 – 5 kg per tree. Low soil pH in Mbozi District also accelerates the increase in infestation of coffee *Fusarium stilboides.* According to Rutherford and Phiri (2006), coffee bark disease which is caused by *Fusarium stilboides,* tends to be more prevalent where trees are grown in acidic soils and soils with low or imbalanced nutrients. Such conditions should be avoided by adjusting soil pH and nutrient content. Cordingley (2010), in his work on smallholder coffee farms in Mbozi District, Tanzania noted that 80% of the surveyed districts had minimum pH of less than 5.5, and 20% less than 5.0. According to Cordingley (2010), adding Mg and Ca in acid soils could improve soil fertility and plant nutrition. Moreover, coffee plants deficient in Ca and Mg might have their development reduced up to 50%, in relation to plants cultivated in limed soils with low acidity and normal Ca and Mg levels. Correction of soil acidity makes coffee plants more tolerant to drought and avoids the cation competition effect of K, which is supplied in high doses due to its importance in grain filling (Andrade, 2001). Uchida and Hue (2000) said "low soil pH causes aluminium and manganese toxicities while calcium, phosphorus, magnesium and molybdenum become deficient". According to Omogbohu and Akinkunmi (2007), lime is the major means of ameliorating soil acidy because it has very strong acid neutralizing capacity, which can effectively remove existing acidity. Application of lime at an appropriate rate promotes- several chemical and biological changes in the soils, which are beneficial or helpful in improving crop yields on acid soils. Adequate liming eliminates soil acidity and toxicity of Al, Mn, and H; improves soil structure, aerationand availabilities of Ca, P, Mo, and Mg. Lime raises pH and N_2 fixation; and reduces availabilities of Mn, Zn, Cu, and Fe and leaching loss of cations (Fageria and Baligar, 2008). Liming without fertilizer application results in soil fertility decline that might lead to serious problems in coffee production (Onwonga *et al*., 2013). -Lime application increases CEC of the soil as reported by Achalu *et al*. (2012) and increases the concentration of Ca^{2+} and thereby increase the soil pH due to the replacement of H^+ and Al^{3+} from the soil solution by Ca and or Mg on the exchange complex.

3.2 Materials and Methods

3.2.1 Description of study sites

The study was conducted in Mbozi District, Songwe Region, Tanzania. The study area is located within latitudes $9^0$05'35.97"S and $9^0$05'13.10"E and longitudes $32^0$57'14.51"E and $32^0$57'22.32"E. The field trial was carried out at Mbimba substation found in Mlowo ward, Mbimba Village that is located at 1km from the headquarters of Mbozi District and Songwe Region along Mbeya - Zambia highway. The average altitude is 1400 m.a.s.l. and the rain season starts between November and December and lasts until around May. Climate data for the last 8 years were obtained from Mbimba TMA station. Soil temperature at a depth of 0 – 50 cm ranges between 19 and 22^0C. The study area experiences monomodal rainfall pattern with mean annual rainfall ranging between 1 000 and 1 500 mm.

3.2.2 Experimental materials

Liming material used was Dolomite [$CaMg(CO_3)_2$] with particle size of 60% wire mesh sieve with 95 - 108% neutralizing values. Fertilizer used contained N (22%), P (6%), K (12%) and Sulphur (5%) known as Yara Java 22:6:12+S with application rate of 60 g per tree. Plant material used was TaCRI 1F coffee variety released in the year 2013 from Tanzania Coffee Research Institute (TaCRI). The arabica variety is recommended to be grown in Southern highlands of Tanzania and have a yield potential of 6t ha^{-1} of coffee parchment.

3.2.3 Soil sampling

Soil sampling was done for the purpose of determining the status of physico-chemical properties of the soil before application of lime. By using an auger, 12 randomly selected points from the area covering 0.25 ha, soil were sampled at a depth of 0 - 30 cm and thoroughly mixed to constitute a composite sample. Twelve soil samples were taken to SUA Soil Science laboratory for analysis.

3.2.4 Plant material sampling

The most frequently taken plant parts in space and time are the leaves, either deciduous or evergreen (Ernst, 1995). Leaf samples were taken at the third pair of leaves from the tip of an actively growing branch. The leaf samples were harvested during the morning and in each of the four experimental plants, two healthy plants were selected and leaves were taken and made into composite according to the -experiment layout. The composite sample taken was of 400 g fresh weight. According to Reisenauer (1978) plant material sampling needs to consider the nature of the crop, season and economic consideration. Twelve plant material samples were taken to SUA laboratory for chemical nutrients' determination.

3.2.5 Laboratory analysis

In the laboratory the soil samples were air dried, ground to break soil aggregates and sieved through 2 mm sieve for laboratory analysis. Soil pH was determined electrometrically in 1:2:5 soil:1 M Potassium chloride suspensions (Thomas, 2009). Organic carbon was analysed by the wet oxidation method (Nelson and Sommers, 1982) and total nitrogen by the micro-Kjeldahl digestion - distillation method (Bremner, 2009). Available P was determined according to Bray and Kurtz 1 method (Bray and Kurtz, 1945). Cation exchange capacity (CEC) was determined by the neutral buffered 1 M ammonium acetate saturation method (Somners and Miller, 2009). Plant leaves harvested in the site were used to determine Ca^{++}, Mg^{++}, K^{+} and Na^{+} in the ammonium acetate filtrates and quantified by atomic absorption spectrophotometer and flame photometer. Plant extractable Cu, Zn, Fe and Mn were extracted by the DTPA method (Liang and Karamanos, 1993). Lime sample for total elemental composition were prepared and the powder samples were exposed to XRF spectrometry machine for determination of the total elemental composition of the samples using PAN analytical XRF spectrometer (Mobius *et al.,* 2010).

3.2.6 Experimental design and treatments

The experimental design used was randomized complete block design with three replications (Table 3.1). The maximum possible application rate of lime per hectare was given the value X and the other rates were derived to figures rounded up to nearest decimal point through the following equations:

T1 =No lime (control)

T2 = 0.5X

T3 = 0.75X and

T4 = X

Application rate of lime per hectare (X) was calculated by using Adams and Evans Single Buffer Method (1962) whereby 10 ml of Adams- Evans buffer solution was added to each soil sample whose previously pH was determined in water. The contents were stirred and allowed to settle for 15 minutes. The Adams -Evans pH was determined and then compared with Adams - Evans standard. The value of X determined by this procedure was 2 500 kgha^{-1}. The treatments were calculated as T1 = 0 lime, T2 = 1 000 kgha^{-1}, T3 = 2 000 kgha^{-1}and T4 = 2 500 kgha^{-1}. The treatments were assigned to the experimental plots of 2m x 2m by size in an area of 0.25 ha.

Table 3.1: Treatments and description

Block	Plot	Lime rate (kgha^{-1})
1	1	0
	2	1000
	3	2000
	4	2500
2	5	2500
	6	2000
	7	0
	8	1000
3	9	0
	10	2000
	11	1000
	12	2500

3.2.7 Experimental procedures carried out

In the experimental plots, soil was opened to a depth of 10 cm deep and application of dolomitic lime at different rates was done according to layout of the plots then mixed thoroughly to allow thorough incorporation of the lime into the soil. The procedure of lime application was done prior to rain season. In the early rain season, N.P.K fertilizer with a composition of 22:6:12 +3S was applied as a blanket rate application to all plots at 150 $kgha^{-1}$ fertilizer. Data on plant height, canopy and girth were collected by tape measure and caliper respectively while number of branches and internodes by physical counting.

3.2.8 Data processing and analysis

Data obtained in the field were pooled in the process of analysis using analysis of variance (ANOVA) with GenStat version 13.1. Significant treatment means were separated using Duncan Multiple Range Test. Moreover, linear correlations between soil nutrient availability and coffee yield were also performed using the same GenStat 13.1.

3.3 Results and Discussion

Soil pH

Results of soil chemical analysis are presented in Table 3.2. The results indicate that the pH before application of lime ranged between 4.25 and 5.72 and soil pH for plots treated with different levels of lime ranged between 5.23 and 6.66 with pH increment ranging between 0.22 and 0.97 units. Highest pH value of 6.66 was recorded in the plot that received 2 500 $kgha^{-1}$, followed by 2 000 $kgha^{-1}$ and 1 000 $kgha^{-1}$ of lime. Kimaro *et al.* (2001), indicated that coffee grows well at soil pH that lies between 5.6 and 6.6. Similarly, Msanya *et al.* (2001), indicated that soil with pH ranging between 5.6 and 6.6 is highly suitable for growing rainfed arabica coffee. Results in Table 3.4 indicate that lime levels 2500 $kgha^{-1}$, 2 000 $kgha^{-1}$ and 1 000 $kgha^{-1}$ showed significant difference against the control plot at ($P<0.001$). Furthermore, the three different levels of lime did not differ significantly at ($P<0.05$) during the study time (Table 3.4). Limed plots showed a decrease in soil acidity after application of $CaMg(CO_3)_2$. This may be due to the effect of application of lime to the acidic soils. According to Fageria *et al.* (2002), liming materials that contain basic cations and basic anions (CO_3^{-2}) are able to pull H^+ from exchange sites to form $H_2O + CO_2$. The dolomite lime reaction in soil is illustrated as follows:

$CaMg(CO_3)_2 + 4H^+ \rightarrow Ca^{2+} + Mg^{2+} + 2CO_2 + 2H_2O$.

This reaction neutralizes H^+ and releases Ca^{2+} and Mg^{2+}, resulting in an increase in soil pH and pH dependent CEC (Meda *et al.*, 2002). Moreover, liming effect on soil pH under coffee trees might have been enhanced by favorable clay soil texture that was recorded in Mbimba, Mbozi, Tanzania.

3.4 Chemical Nutrient Availability under Arabica Coffee

3.4.1 Total Nitrogen

The percentage total nitrogen in the soil varied from 0.08 to 0.22 % before application of lime (Table 3.2) while nitrogen concentration after application of lime ranged between 0.15 and 22%. According to Sagi *et al.* (1991) and Silberbush and Lips (1991), surface layers (A-horizon/plow-depth zone) of cultivated soils have nitrogen between 0.08 and 0.4%. Kimaro *et al.* (2001) indicated that total nitrogen of less than 0.10% is considered as very low, 0.10 - 0.20% low, 0.21 - 0.5% medium, and greater than 0.50% considered as high (Table 3.5). Thus, these values (0.15 - 22%) are rated as low to medium (Table 3.5). The total nitrogen levels in different soils that received different lime rates of application are not significantly different ($p=0.05$). The low nitrogen content in the coffee plantation soils may be because of depletion due to uptake by plants. Poor microbial activity may have contributed to low soil N content.

Table 3.2: Selected chemical data before application of lime

S/N Block	Plot	pH (H_2O)	N (%)	P Bray (mg/kg)	Mg	K	Ca	Na	CEC
						cmolkg^{-1}			
1	1	4.88	0.20	14.44	0.71	1.01	2.36	0.04	27.20
	2	4.93	0.21	15.17	0.82	1.16	3.10	0.05	30.40
	3	4.25	0.08	0.99	1.71	1.85	3.98	0.08	29.20
	4	4.85	0.21	17.57	0.74	1.06	3.02	0.05	27.60
2	5	5.52	0.19	10.18	1.23	1.41	4.35	0.05	28.20
	6	5.12	0.20	14.64	0.83	1.11	3.54	0.05	26.20
	7	5.46	0.16	6.52	1.17	1.41	4.35	0.05	28.80
	8	5.47	0.20	10.51	1.33	1.55	4.27	0.06	29.00
3	9	5.67	0.15	1.86	0.97	1.46	4.35	0.06	31.20
	10	5.74	0.16	1.05	0.84	1.31	4.64	0.05	32.00
	11	5.58	0.22	0.52	1.24	1.46	5.08	0.06	34.00
	12	5.52	0.11	13.68	1.93	2.10	5.67	0.10	31.20

Table 3.3: Main effects of lime on soil chemical properties

S/No Block	Lime rate kgha^{-1}	pH (H_2O)	TN -(%)	P (Bray) (mg/kg)	Mg	K	Ca	Na	CEC
							cmolkg^{-1}		
	0	4.87	0.17	15.9	0.89	1.51	2.94	0.17	28.2
1	1000	5.68	0.15	11.7	1.28	1.15	3.29	0.32	26.8
	2000	5.89	0.18	21.2	1.59	2.51	4.90	0.18	31
	2500	5.23	0.17	7.8	1.85	2.93	5.73	0.17	29.6
		5.31	0.16	10.3	1.60	2.74	5.34	0.14	26.6
	2500								
2	2000	5.37	0.18	12.7	1.49	3.54	6.91	0.18	25
	0	6.43	0.22	22.1	1.88	3.34	6.50	0.20	26.2
	1000	6.19	0.16	8.3	1.62	7.78	15.19	0.19	26.8
	0	5.52	0.18	12.8	1.37	2.74	5.34	0.2	27
3	2000	6.34	0.19	9.5	3.91	8.11	15.82	0.22	23
	1000	5.98	0.20	23.3	1.63	3.24	6.32	0.18	31
	2500	6.66	0.19	10.9	2.02	6.41	12.49	0.21	27.2

Table 3.4: Effects of lime on soil chemical properties means separated by Duncan Multiple Range Test

Parameter	pH (H_2O)	TN %	P Bray and Kurtz I (Bray)	K	Ca	Mg	Na	CEC
					cmol(+)kg^{-1}			
Control	5.113^{a}	0.1900^{a}	13.00^{c}	2.530^{a}	4.70^{a}	1.333^{a}	0.182^{a}	25.60^{a}
1000 kgha^{-1} Lime	5.680^{b}	0.1700^{a}	11.30^{b}	3.723^{a}	7.448^{ab}	1.492^{ab}	0.190^{a}	40.60^{b}
2000 kgha^{-1} Lime	5.757^{b}	0.1833a	22.20^{d}	4.720^{a}	7.731^{ab}	1.813^{b}	0.1925^{a}	27.41^{a}
2500 kgha^{-1} Lime	6.133^{b}	0.1733a	9.00^{a}	4.027^{a}	9.108^{b}	2.322^{c}	0.3875^{a}	24.20^{a}
F pr.	<0.001	0.609	0.493	0.722	0.035	<.001	0.209	0.010

Mean values followed by the same letter are not significant different. Mean separation was performed by Duncan Multiple Range Test

3.4.2 Phosphorus

The results in Table 3.3 show that P concentration ranged between 7.8 and 23.3 mgkg^{-1} after application of lime while a range of 0.52 to 17.57 mgkg^{-1} was observed in coffee field before lime application (Table 3.2). Plots that received lime, showed the trend of available P to decrease as lime rate increases up to 2 500 kgha^{-1}. This is in line with findings from Fageria and Baligar (2008), Deressa (2013), Athanase (2013) and Melese *et al*. (2015) that over liming reduces availability of P in the soil because of high rate of calcium fixing the soluble phosphorus. Similarly, at high pH (> 6.5), soluble P precipitates as calcium phosphate (Bolan, 2003). According to Kimaro *et al.* (2001), available phosphorus in the soil that ranges between 7 and 20 mgkg^{-1} is considered as medium and above 20 as high (Table 3.5). Landon (1991) indicated that in soils with phosphorus concentration of <15 mgkg^{-1}, crops do not respond to P fertilizer application while crop response is likely at phosphorus concentration of 15 - 50 mgkg^{-1} provided the soils are acidic. The levels of available P were significantly different at (P = 0.05) at all levels of lime as shown in Table 3.4. High mean value was obtained with lime rate of 2 000 kgha^{-1} followed by 0 kgha^{-1}, 1 000 kgha^{-1} and 2500 kgha^{-1}. This indicates that application of 2 500 kgha^{-1} of lime in clay soils of Mbozi, Tanzania reduces availability of phosphorus to the plant. This could be due to P precipitation as Ca phosphate (Bolan, 2003).

3.4.4 Exchangeable bases

3.4.4.1 Potassium

Exchangeable K concentrations before application of lime ranged between 1.01 and 2.10 cmol(+) kg^{-1} (Table 3.2) while K concentration of 1.15 - 8 cmol(+)kg^{-1} was recorded after application of lime as shown in Table 3.3. Kimaro *et al.* (2001) indicated that K concentration between 0.20 and 0.40 is rated as very low to low. After application of lime, concentration of K is rated as high to very high (Table 3.5). This is in line with Fageria and Baligar (2008) that liming acid soils increases soil pH and improves soil K and enhances retention of K^+ and thereby decreasing K^+ leaching. Liming increases K^+ retention in soils by replacing Al^{3+} on the exchange sites with Ca^{2+}, allowing K^+ to compete better for exchange sites and increasing the effective cation exchange capacity. Table 3.4 indicates that there was no significant difference among different levels of lime at (P = 0.05).

3.4.4.2 Calcium

Calcium concentration before application of lime is shown in Table 3.2 and for the limed field it is presented in Table 3.3. For calcium concentration prior to liming ranged between 2.36 and 5.67 $cmolkg^{-1}$ which is considered as low (Kimaro *et al.*, 2001). Application of lime increased concentration of Ca from 3.29 - 15.82 $cmolkg^{-1}$. Kimaro *et al.* (2001) classified calcium concentration ranging between 5.1 and 20 $cmolkg^{-1}$ as medium to high. Different levels of lime have shown significant differences in Ca concentration (Table 3.4) with exception of lime rate of 1 000 $kgha^{-1}$ and 2 000 $kgha^{-1}$ that did not differ significantly at (P = 0.05). This may be due to good number Ca ions in the soil still not reacted and increase in exchangeable calcium in the soil may have been activated by application of dolomite lime.

3.4.4.3 Sodium

Exchangeable sodium after application of lime ranged between 0.14 - 0.32 $cmolkg^{-1}$ which is considered as low (table 3.5). Exchangeable sodium before application of lime ranged between 0.04 - 0.10 $cmolkg^{-1}$ which was very low. According to Van Wambeke (1991); Brady and Weil (2008), sodium value ranging between 0.15 and 0.28 $kgha^{-1}$ is considered as low. Statistically, analysed sodium (Table 3.4) did not differ significantly in all levels of lime applied though high mean value was recorded in the plot that received 2500 $kgha^{-1}$ of lime material. This may be because of addition of Ca^+ by lime that causes reduction of sodium ions.

3.4.4.4 Magnesium

Exchangeable magnesium recorded before application of lime was 0.71 - 1.93 cmol(+) kg^{-1}. According to Kimaro *et al.* (2001 and Landon (1991), this concentration is rated as low to medium. Field plots that received lime showed concentration of magnesium between 1.28 - 3.91 cmol(+)kg^{-1}. Msanya *et al.* (1996) indicated that the range between 1.10 and 3.91 cmol(+)kg^{-1} is medium to high. Statistical analysis showed that there were significant differences among all levels of lime (Table 3.4). Higher mean values were noted in the plots that received 2 500 $kgha^{-1}$ of lime, followed by 2 000 $kgha^{-1}$, 1 000 $kgha^{-1}$ and 0 $kgha^{-1}$ respectively. Potassium and magnesium ratio of 4:1 was determined. Loide (2004) pointed out that a K: Mg of 3:1 or a little wider is favourable for plant growth. The increase of magnesium concentration could be associated with application of $CaMg(CO_3)_2$ lime.

3.4.5 Cation exchange capacity

The effect of lime on CEC was recorded as 26.2 - 75 cmol(+)kg^{-1} (Table 3.3) while the range of 26.20 - 34.0 $cmolkg^{-1}$ was recorded before application of lime (Table3.2). Kimaro *et al*. (2001), indicated that CEC value ranging between 25 and 40 cmol(+)kg^{-1} is considered as high (Table 3.5). The benefit of lime in enhancing CEC was also reported by Achalu *et al*. (2012) who indicated that liming of acidic soil has positive effect on CEC. Plots that received 1 000 $kgha^{-1}$ differed significantly at (P = 0.05) against the rest of the plots that received 0 $kgha^{-1}$, 2 000 $kgha^{-1}$ and 2 500 $kgha^{-1}$ respectively that did not differ significantly (Table 3.4). High mean value of CEC was recorded in the plots that received 1 000 $kgha^{-1}$ of lime and low CEC recorded in the plots that received 2 500 $kgha^{-1}$ of lime (Table 3.4). This may be due to over liming those results in Ca fixation and lower CEC.

Table 3.5: Ratings of soil chemical properties

Parameter	Very low	Low	Medium	High	Very high
TN%	<0.10	0.10-0.20	0.21-0.50	>0.50	6.06
P (Bray-Kurtz 1		<7	7-20	>20	
K (Clayey soil)	<0.20	0.20-0.40	0.41-1.20	1.21-2.00	>2.00
Ca	<2.00	2.0-5.0	5.1-10	10.1-20.0	>20.0
Mg	<0.3	0.3-1.0	1.1-3.0	3.1-6.0	>6.0
Na	<0.1	0.1-0.3	0.31-0.70	0.71-2.00	>2.00

Source: Landon (1991)

Table 3.6: Initial plant micro nutrients

		Micronutrient levels ($mgkg^{-1}$)			
Block	**Plot**	**Cu**	**Zn**	**Fe**	**Mn**
1	1	153.85	81.04	4290.07	2354.06
	2	123.35	69.39	3315.05	2716.85
	3	164.01	79.74	3680.68	2584.93
	4	123.35	70.68	13918.34	4860.65
2	5	160.62	99.16	12212.07	2584.93
	6	86.07	57.73	4411.94	3112.63
	7	133.51	82.33	7458.87	2255.11
	8	245.34	103.04	15015.23	4662.76
3	9	99.63	75.86	5143.21	4135.06
	10	143.68	108.22	14771.48	2782.82
	11	170.79	93.98	9165.14	2387.04
	12	150.46	97.86	14405.85	2914.74

Table 3.7: Concentration of micronutrients after application of lime

Lime rate	Micronutrient levels (mg/kg)			
($kgha^{-1}$)	**Cu**	**Zn**	**Fe**	**Mn**
0	94.47	48.47	2014.46	1427.33
1000	88.50	46.10	1828.11	1144.61
2000	102.43	48.47	2476.30	1409.21
2500	96.46	55.59	3156.90	1452.70

3.4.6 Micronutrient concentration

Initial plant concentration before lime application of Cu was (86.07 - 245.34 $mgkg^{-1}$), Zn (57.73 - 108.22 $mgkg^{-1}$), Fe (3315.05 - 15015.23 $mgkg^{-1}$) and Mn (2354 - 4860.65 $mgkg^{-1}$). According to Landon (1991) classification, the concentration of Cu and Zn are in medium range but concentration of Fe and Mn are in excess or toxic. Application of lime has led to concentration of Cu (88.50 - 102.43 $mgkg^{-1}$), Zn (46.10 - 55.59 $mgkg^{-1}$), Fe (1828.11 - 3156.90 $mgkg^{-1}$) and Mn (1144.61 - 1452.70 $mgkg^{-1}$. The results show a decreasing trend of micronutrient concentration with increasing soil pH. Similarly, Landon (1991) pointed out that availability of micronutrients decreases with increase of soil pH. Highest mean values were obtained in lime levels of 2000 $kgha^{-1}$ and 2500 $kgha^{-1}$ for Cu and Zn while high mean values for Mn and Fe were obtained in the control plot. Different lime levels have significant different effect at ($P<0.001$) on concentration of Cu, Zn and Mn while Fe was significantly affected by the different levels of lime at P = 0.021 (Table 3.8).

Table 3.8: Effect of lime on plant micronutrients

Parameter	Cu	Zn	Mn	Fe
0 $kgha^{-1}$ Lime	5.861^{ab}	1.809^{b}	92.75^{b}	163.5^{b}
1000 $kgha^{-1}$ Lime	5.495^{a}	1.493^{a}	78.35^{a}	115.8^{a}
2000 $kgha^{-1}$ Lime	6.898^{c}	2.057^{c}	88.14^{b}	137^{ab}
2500 $kgha^{-1}$ Lime	6.228^{b}	1.930^{bc}	73.48^{a}	137^{ab}
F pr.	<.001	<.001	<.001	0.021

Mean values followed by the same letter are not significant different. Mean separation was performed by Duncan Multiple Range Test

The results show that there was a direct influence of dolomite lime ($CaMg(CO_3)_2$) + NPK (23:6:12+3S) on soil chemical properties on coffee plantation (Figure 3.1). A very strong positive correlation was found with Mg (R^2 = 0.8643), moderate positive correlation on N (R^2 = 0.4453), P (R^2 = 0.7064), K (R^2 = 0.4043) and Ca (R^2 = 0.5288) while a weak correlation found with Na (R^2 = 0.2007). Correlation value of <0.4 is considered as weak, 0.4 - 0.8 as moderate correlation and >0.8 as very strong correlation (Bolin, 2014).

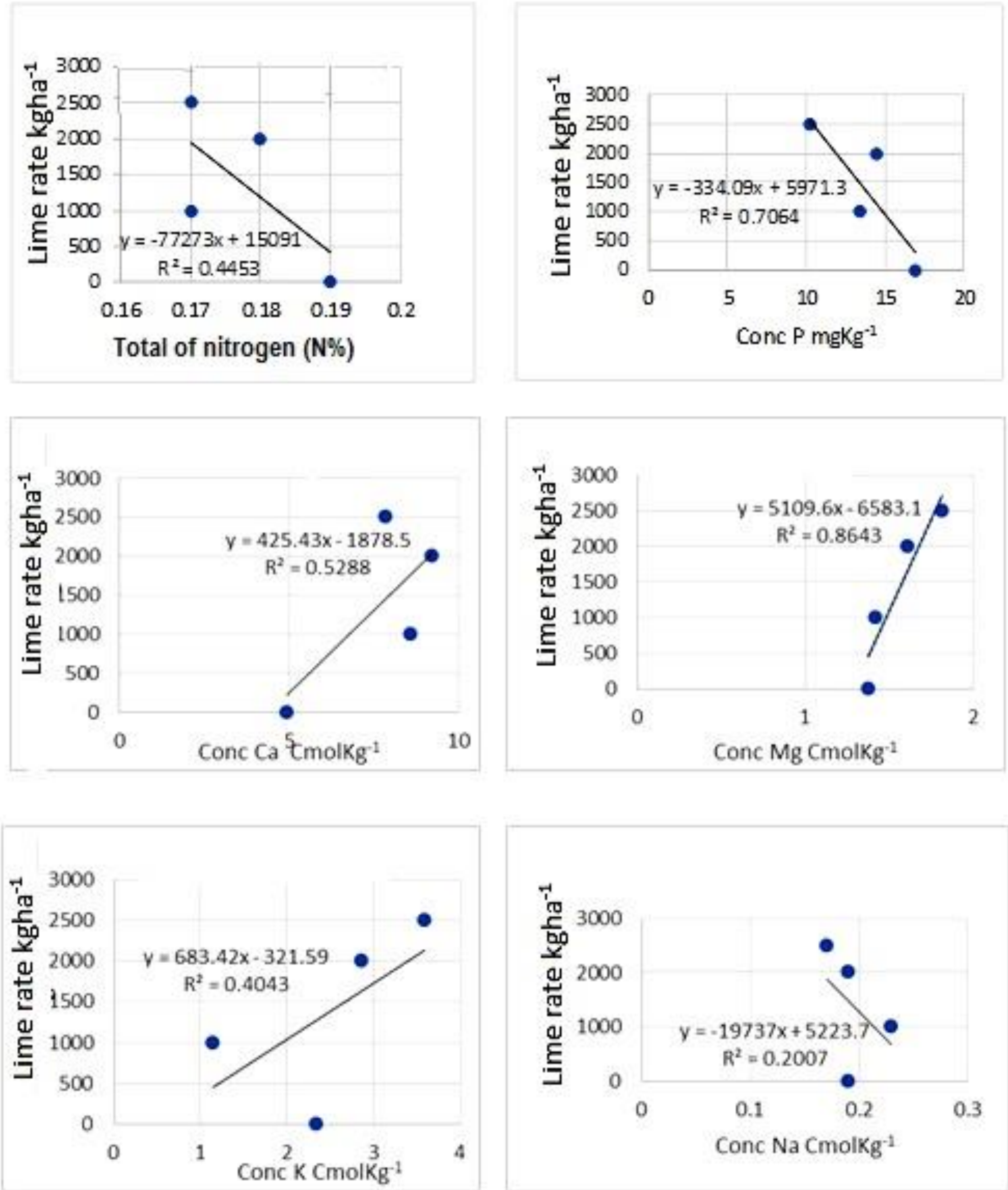

Figure 3.1: Regression correlation between lime rate + fertilizer and concentration increase of N, P, K, Ca, Mg and Na

3.5 Conclusions and Recommendations

The following conclusions can be drawn for soils under arabica coffee cultivation in Mbimba Mbozi plantations in Southern Highlands of Tanzania: -

- The pH in water of the soil is classified as very strongly acidic to strong acidic ranging from 4.82 - 5.8.

- Nitrogen and phosphorus were deficient to high ranging from 0.08 - 0.22% and 7 - 23mgkg^{-1} respectively.
- Liming with $CaMg(CO_3)_2$ has proved effective in reducing soil acidity by increasing soil pH by 0.22 - 0.97 units at lime level of 2000 kgha^{-1}.
- The study recommends application of N & P rich fertilizers like NPK (22.6.12+3S).
- Application of 2000 kgha^{-1} of $CaMg(CO_3)_2$ is recommended to raise soil pH from strong acidity to slight acidity (pH of 6.6) that is optimal for coffee production.

REFERENCES

Achalu, C., Heluf, G., Kibebew, K. and Abi, T. (2012). Status of selected physicochemical properties of soils under different land use systems of Western Oromia, Ethiopia. *Journal of Biodiversity and Environmental Sciences* 2(3): 57-71.

Adams, F. and Evans, C. E. (1962). A Rapid Method for Measuring Lime Requirement of Red-Yellow Podzolic Soils 1. *Soil Science Society of America Journal* 26(4): 355-357.

Andrade, C. D. (2001). Liming and fertilizing of coffee. *Viçosa: Learn Easy*. 130pp.

Athanase, N. (2013). Soil acidification and lime quality: sources of soil acidity, its effects on plant nutrients, efficiency of lime and liming requirements. *Agricultural Advances* 2(9): 259-269.

Balistrieri, L. S., Murray, J. W. and Paul, B. (1994). The geochemical cycling of trace elements in a biogenic meromictic lake. *Geochimica et Cosmochimica Acta* 58(19): 3993-4008.

Bolan, N. S. and Hedley, M. J. (2003). Role of carbon, nitrogen and sulfur cycles in soil acidification. In: *Handbook of soil acidity, Marcel Dekker, New York*. pp. 29-56.

Bolin, J. H. (2014). Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach. New York, NY: The Guilford Press. *Journal of Educational Measurement* 51(3): 335-337.

Brady, N. C. and Weil, R. R. (2008). *The Nature and Properties of Soils*. 14th Edition. Pearson Education, Inc. pp.90-99.

Bremner, J. M. (2009). Nitrogen-total. *In: Methods of Soil Analysis Part 3: Chemical Methods: SSSA Book series no. 5.* (*Edited by Sparks D.L.*), Soil Science of America Inc. 5th Edition. pp. 1085-1121.

Carvalho, M. C. S. and van Raij, B. (1997). Calcium sulphate, phosphogypsum and calcium carbonate in the amelioration of acid subsoils for root growth. *Plant Soil* 192: 37 – 48.

Cordingley, J. (2010). *Soil fertility survey of Tanzania's smallholder coffee sector for developing lime and fertilizer recommendations.* Report to Tanzania Coffee Board. Crop nutrition laboratory services, Nairobi, Kenya. 60pp.

Cyamweshi, R. A., Tenywa, J. S., Ebanyat, P., Tenywa, M. M., Mukuralinda, A. and Nduwumuremyi, A. (2013). Phosphate Sorption Characteristics of Andosols of the Volcanic Highlands of Central African Great Lakes Region. *Journal of Environmental Science and Engineering A* 2: 89-96.

Deressa, A. (2013). Evaluation of soil acidity in agricultural soils of smallholder farmers in south western Ethiopia. *Science, Technology and Arts Research Journal* 2(2): 01-06.

Ernst, W. H. O. (1995). Sampling of plant material for chemical analysis. *Science of the Total Environment* 176(1-3): 15-24.

Fageria, N. K. and Baligar, V. C. (2008). Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. *Advances in Agronomy* 99: 345-399.

Fageria, N. K., Baligar, V. C. and Clark, R. B. (2002). Micronutrient in crop production. *Advances in Agronomy* 77: 185–268.

Folk, R. L and Land, L. S. (1975). Mg/Ca ratio and salinity: two controls over crystallization of dolomite. *AAPG Bulletin* 59(1): 60-68.

Kimaro, D. N., Msanya, B. M., Mwango, S. B., Kimbi, G. G. and Kileo, E. P. (2001). Land suitability evaluation for the production of the major crops in the Sourth West part of the Uluguru Mountains, Morogoro Rural District, Tanzania. Soils and Land Resources of Morogoro Rural and Urban Districts, Volume 2. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania.

Meda, A. R., Pavan, M. A., Cassiolato, M. E. and Miyazawa, M. (2002). Dolomite lime s reaction applied on the surface of a sandy soil of the Northwest Paraná, Brazil. *Brazilian Archives of Biology and Technology* 45(2): 219-222.

Melese, A., Yli-Halla, M. and Yitaferu, B. (2015). Effects of lime, wood ash, manure and mineral P fertilizer rates on acidity related chemical properties and growth and P uptake of wheat (*Triticum aestivum* L.) on acid soil of Farta District Northwestern Highlands of Ethiopia. *International Journal of Agriculture Crop Science* 8(2): 256-269.

Msanya, B. M., Wickama, J. M., Kimaro, D. N., Magoggo, J. P. and Meliyo, J. L. (1996). *Investigation of the environmental attributes for agricultural development in Kitanda village, Mbinga District, Tanzania*. Technical Report No 5. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania and Ministry of Agriculture, National Soil Service, Agricultural Research Institute, Mlingano, Tanga, Tanzania. pp. 38.

Naidu, R., Syers, J. K., Tillman, R. W. and Kirkman, J. H. (1990). Effects of liming and added phosphate on charge characteristics of acid soils. *European Journal of Soil Science* 41(1): 157-164.

Omogbohu, A. M. and Akinkunmi, A. E. (2007). Lime effectiveness of some fertilizers in a tropical acid alfisol. *Journal of Central European Agriculture* 8(1): 17-24.

Onwonga, R. N., Lelei, J. J. and Macharia, J. K. (2013). Comparative effects of soil amendments on phosphorus use and agronomic efficiencies of two maize hybrids in acidic soils of Molo County, Kenya. *American Journal of Experimental Agriculture* 3(4): 939-958.

Pierre, W. H. (1933). Determination of equivalent acidity and basicity of fertilizers. *Industrial and Engineering Chemistry Analytical Edition* 5(4): 229-234.

Reisenauer, H. M. (ed.) (1978). *Soil and Plant-Tissue Testing in California, Division of Agricultural Sciences,* University of California, Bulletin. 1879.

Rutherford, M. A. and Phiri, N. (2006). Pests and diseases of coffee in Eastern Africa: a technical and advisory manual. *Wallingford, UK: CAB International*.

Sagi, M., Dovrat, A., Kipnis, T. and Lips, H. (1997). Ionic balance, biomass production, and organic nitrogen as affected by salinity and nitrogen source in annual ryegrass. *Journal of Plant Nutrition* 20: 1291–1316.

Silberbush, M. and Lips, S. H. (1991). Potassium, nitrogen, ammonium/nitrate ratio, and sodium chloride effects on wheat growth. I. Shoot and root growth and mineral composition. *Journal of Plant Nutrition* 14: 751–764.

Somner, M. E. and Miller, W. P. (1996). Cation exchange capacity. In: *Methods of soil analysis. Part 3, Chemical Methods* (Ed.: Sparks, R.L.). Soil Science Society of America, Madison. pp.475-490.

Thomas, G. W. (2009). Soil pH and soil acidity. In: *Methods of Soil Analysis Part 3—Chemical Methods: SSSA Book series no. 5.* (*Edited by Sparks D.L.*), Soil Science of America Inc. 5th Edition. pp. 475-490.

Uchida, R. and Hue, N. V. (2000). Soil acidity and liming. In: (Silva, J.A. and Uchida, R). (eds): *Plant nutrient management in Hawaiian soils: Approaches for tropical and subtropical agriculture*. CTAHR, University of Hawaii at Manoa. pp.101-112.

Van Wambeke, A. (1991). Criteria for classifying tropical soils by age. *Journal of Soil Science* 13(1): 124-132.

CHAPTER FOUR

4.0 EVALUATION OF THE EFFECT OF $CaMg(CO_3)_2$ LIME ON THE GROWTH (VIGOR) OF COFFEE SEEDLING

ABSTRACT

Soil acidity is among the major constraints to coffee productivity in Mbimba Mbozi District, Tanzania. An experiment was conducted in 2017 - 2018 to evaluate the effect of dolomite lime + NPK (22.6.12+3S) fertilizer on vegetative growth of *Coffea arabica* grown on acid soils of Mbozi District. The experiment was set in a randomized complete block design with lime treatment $CaMg(CO_3)_2$ applied at different levels of 2500 $kgha^{-1}$, 2000 $kgha^{-1}$, 1000 $kgha^{-1}$ and 0 $kgha^{-1}$ with and without coffee pulp mulch application. Results showed that lime increased soil pH between 0.22 and 0.97 units in the limed plots while control plot had the same pH ranging between 4.72 and 5.46. Lime rate of 2000 $kgha^{-1}$ gave high number of branches and internodes compared to lime rate of 0 $kgha^{-1}$ and 2500 $kgha^{-1}$. Plant height increased from 60.4 - 64.8 cm, branches 29 – 31, internodes 23 – 27, canopy 74.7 - 79.5 cm and girth 8.2 – 9 cm. Plots which received lime, positively correlated with coffee branches at R^2 = 0.5562, plant height at R^2 = 0.0247, plant canopy R^2 = 0.2005, plant internodes R^2 = 0.7301 and plant girth R^2 = 0.152. Application of lime in coffee plantations is recommended to improve nutrient availability and coffee yield on acid soils of Mbimba Mbozi District, Tanzania.

Keywords: Acid soils, Arabica coffee, vegetative growth, lime

4.1 Introduction

Plants require 17 elements or essential nutrients for optimal growth and development (Rice, 2007). Nutrients are required for maintaining a tree in good health and yield is stimulated by the application of nitrogen. However, higher yield and vegetative growth require correspondingly higher amounts of all other nutrients (Willson, 1985). Coffee plant growth and mycorrhizal activity are severely constrained in the soil which has low organic matter content, low pH, very high extractable aluminum (Al), and low availability of phosphorus (P), boron (B), calcium (Ca), magnesium (Mg), and potassium (Osorio *et al.*, 2002). Coffee vigor depends on the capacity of the root system to provide the required amount of plant food from the soil (Robson, 1964). Nutrient content of soil can vary greatly with depth. The top 4 - 6 inches, the zone into which most fertilizer is placed and most crop residue is incorporated, often has much higher levels of organic matter, nitrogen (N), phosphorus (P), potassium (K) and available micronutrients than the soil below (Hartz, 2007). Adequate liming eliminates soil acidity and toxicity of Al, Mn, and H; improves soil structure (aeration); improves availabilities of Ca, P, Mo, and Mg, pH, and N_2 fixation; and reduces the availabilities of Mn, Zn, Cu, and Fe and leaching loss of cations (Fageria and Baligar 2008). Lime alleviates plants from Al toxicity, reduces P fixation and increases Ca and P availabilities as described by The *et al.* (2006). In line with this, Kisinyo *et al.* (2013) indicated that growth of plants in acidic soil is enhanced with additions of lime and P fertilizers. Similarly, Fageria and Moreira (2011); Felipe *et al*. (2014); Kaio *et al.* (2015) reported that application of lime and phosphorus at the optimum rates gives the maximum fresh shoot and root biomass compared to untreated ones. The plant canopy structure is related to the spatial distribution of its organs above the soil surface (Campbell and Norman, 1989). Plant canopy has an important role in growth and productivity. The canopy architecture is also important to define branch and leaf distribution, altering the interception of available radiation and its use. Silva *et al.* (2010) reported that, using phosphorus fertilization for coffee seedlings increases height, girth, internode length, number of nodes, leaf number and leaf area. It is noted that the application of phosphorus results in a linear increase of the stem height and stem diameter (girth) (Poorter *et al*., 2011). Thus, it was reported that lime and phosphorus promote plant growth through improved soil conditions such as increased soil pH, nutrient availability, soil organic matter, soil solution P concentration and decreased aluminum toxicity and micronutrient accumulation (Uzoho *et al.,* 2010).

4.2 Materials and Methods

4.2.1 Description of study sites

The study was conducted in Mbozi District, Songwe Region Tanzania. The study area is located within $9^0$05’35.97”S and $9^0$05’13.10”E and longitudes $32^0$57’14.51”E and $32^0$57’22.32”E. The field trial was carried out at Mbimba substation found in Mlowo ward, Mbimba Village, and 1 km from the headquarters of Mbozi District and Songwe Region along Mbeya - Zambia highway. The average altitude is 1400 m.a.s.l. and the rain season starts between November and December. Climate data for the last 8 years was obtained from Mbimba TMA station. Soil temperature at a depth from 0 – 50 cm ranged between19 - 22^0C. The study area experiences monomodal rainfall pattern with mean annual rainfall ranging between 1000 and 1500 mm.

4.2.2 Experimental design and treatments

The experimental design used was randomized complete block design with three replications (Table 3.1). The maximum possible application rate of lime per hectare was given the value X and the other rates were derived to figures rounded up to nearest decimal point through the following equations:

T1 =No lime (control)

T2 = 0.5X

T3 = 0.75X and

T4 = X

Application rate of lime per hectare (X) was calculated by using Adams and Evans Single Buffer Method (1962) whereby 10 ml of Adams- Evans buffer solution was added to each soil sample whose previously pH was determined in water. The contents were stirred and allowed to settle for 15 minutes. The Adams -Evans pH was determined and then compared with Adams - Evans standard. The value of X determined by this procedure was 2 500 kgha^{-1}. The treatments were calculated as T1 = 0 lime, T2 = 1 000 kgha^{-1}, T3 = 2 000 kgha^{-1}and T4 = 2 500 kgha^{-1}. The treatments were assigned to the experimental plots of 2m x 2m by size in an area of 0.25 ha.

Table 4.1: Treatments and description

Replication	Treatments	Lime rate (kgha^{-1})
1	1	0
	2	1000
	3	2000
	4	2500
2	5	2500
	6	2000
	7	0
	8	1000
3	9	0
	10	2000
	11	1000
	12	2500

4.2.3 Data collection, processing and analysis

At vegetative growth stage prior to flowering season, in the sixth month since application of lime was done, data on plant branches, internodes, canopy, girth and plant height were recorded (Table 4.2). One pair of branches at the mid of the stem was used to determine internodes as representative branch. Data obtained was processed in excel sheet then subjected to analysis of variance (ANOVA) with GenStat version 13.1. Significant treatment means were separated using Duncan Multiple Range Test. Moreover, linear correlations between dolomite lime applied and vegetative coffee growth parameters were also performed and presented in graphical form.

4.3 Results and Discussion

4.3.1 Soil pH

The results show soil pH before lime application ranged from 4.72 to 5.74 (Table 4.2) while pH results after application of lime ranged between 5.23 and 6.66 (Table 4.3). Mean values of pH increased with increases of lime level up to 2500 kgha^{-1} while the control plot remained with the lowest mean value (Table 4.4). The results showed a positive response of soil pH to lime application increasing between 0.22 and 0.92units in the respective level of treatments and there were significant differences between the control and plots that received different levels of lime (Table 4.4). According to Kimaro *et al.* (2001), soil with pH ranging between 4.5 and 5.0 is considered as very acidic soil. Richard (2001) indicated that acidic soil with soil pH between 3 and 5, require liming as necessity at 1 to 3 tha^{-1} and it is important that fertilizers are added so as not to upset the pH balance.

Table 4.2: Initial soil and plant characteristics before application of lime

S/No	pH (H_2O)	Height (cm)	Girth (cm)	Canopy (cm)	No. of branches	Internodes
1	4.88	54	6	52.3	20	18
2	4.93	50	6	36	24	22
3	4.99	42	5	42.5	17	14
4	4.85	50	6.5	62	21	21
5	5.01	38	5.2	43	14	16
6	5.12	43	6.3	50	19	19
7	5.46	44	5.8	45.3	23	20
8	5.47	57	7	68	24	20
9	4.72	48	5.4	48.3	16	11
10	5.74	51	4.6	56	14	17
11	5.02	44	6	52.3	19	20
12	5.52	44	5.1	44	19	20

Table 4.3: Soil and plant characteristics after application of lime

S/No	pH (H_2O)	Height (cm)	Girth (cm)	Canopy (cm)	No. of branches	No, of Internodes
1	4.87	64	5.9	52.3	20	18.3
2	5.68	60	6.3	68	23.5	24.5
3	5.89	43	5.1	42.5	17	15
4	5.23	56	6.5	46.3	20.5	21.3
5	5.31	40	5.2	42.5	12.5	15.80
6	5.37	47	6.3	50	19	19
7	6.43	48.7	5.9	45.3	18	20.3
8	6.19	67	7.1	68	23.5	19.8
9	5.52	47.8	5.4	48.3	18.8	11
10	6.34	61	5.6	56	18.8	19
11	5.98	52.5	6.0	52.3	21.3	19.8
12	6.66	52.5	5.6	48.3	22.8	18

Table 4.4: Effect of lime on soil acidity and vegetative growth of coffee plant

Parameter	pH (H_2O)	Height (cm)	No. of branches	No. of internodes	Canopy (cm)	Girth (cm)
Control	5.113^{a}	63.25^{a}	27.33^{a}	23.00^{a}	73.50^{a}	9.000^{a}
$1000Kgha^{-1}$ Lime	5.680^{b}	69.42^{b}	32.00^{b}	25.67^{a}	84.75^{a}	8.667^{a}
$2000Kgha^{-1}$ Lime	5.757^{b}	65.42^{ab}	32.67^{b}	25.83^{a}	79.00^{a}	8.167^{a}
$2500Kgha^{-1}$ Lime	6.133^{b}	65.75^{ab}	32.83^{b}	26.00^{a}	80.33^{a}	8.833^{a}
F pr.	<0.001	0.021	0.051	0.532	0.212	0.723

Table 4.5: Chemical composition of the lime materials used in the study (%)

MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Na_2O	SO_3
9.78	0.12	6.44	0.04	28.39	0.02	0.07	0.07	0.16	6.44

The result in Table 4.5 show lime material used had CaO (28.39%), MgO (9.78%), Sio_2 (6.44%) and SO_3 (6.44%) while concentration of Al_2O_3, K_2O, TiO_2, MnO, F_2O_3 and Na_2O are less than 0.16%. Folk and Land (1975) pointed out that in caves, dolomite and other assorted magnesian carbonates can form if the Mg/Ca ratio exceeds 1:1. The ratio of values of Mg to Ca in the table 4.5 is nearly to 1:3 which conform to Folk and Land findings.

4.3.2 Plant height

Results show that plant height varied from 38 - 57cm before application of lime and increased from 43 – 60 cm after application of lime plus (NPK 22.6.12 +3S) fertilizer. High mean value was recorded in plots that received 1 000 $kgha^{-1}$ of lime followed by both 2 000 $kgha^{-1}$ and 2 500 $kgha^{-1}$ which were not significantly different. This indicate that lime rate of 1 000 $kgha^{-1}$ and NPK fertilizer favor plant height growth significantly at $p = 0.02$ compared to other levels of lime (Table 4.4). The results indicate that control plants were significantly shorter than the plants which received lime. The results are in line with Uzoho *et al*. (2010) who reported that lime and phosphorus promote plant growth through improved soil conditions such as increased soil pH, nutrient availability, soil organic matter, soil solution P concentration and decreased aluminum toxicity and micronutrient accumulation. Lime may have induced nutrient availability and improved nutrient uptake by coffee and substantial increase in coffee plant height. Similarly, Mendonca *et al.* (2007) pointed out that, different doses of lime promote plant height growth and development if fertilization is done. Mendonca *et al.* (2007) indicated that, coffee plants deficient in Ca and Mg have reduced development up to 50%, compared to plants cultivated in limed soils with low acidity and normal Ca and Mg levels. The variability of response observed in the coffee trees under field conditions, may be due to different levels of lime (Jaramillo-Botero *et al.*, 2010).

4.3.3 Plant girth, internodes and canopy

The results show that plant girth ranged between 4.6 – 7 cm, internodes by 11 - 22 cm and canopy 36 – 68 cm before application of lime (Table 4.2). Application of dolomite lime and fertilizer (22:6:12+3s) have adjusted the size of plant girth by 5.1 - 7.1 cm, internodes by 11 - 24.5 cm and plant canopy by 42.5 - 68 cm (Table 4.3). Mean values of girth, internodes and canopy for all levels of lime as shown in the Table 4.4 are not significantly different at p=0.05. In the first six months after lime application, the girth, internodes and canopy development did not change significantly for one-year old coffee plants. The same results were obtained by Braccin *et al.* 1998 and Braccin, 2000), for coffee variety UFV3880 that showed no response to lime application on plant girth, internodes and canopy. This may be due to the fact that time interval from lime application to data collection was too short to show significant differences.

Table 4.6: Average plant vegetative parameters before application of lime and NPK fertilizer

Lime rate (kgha^{-1})	**Plant parameter**				
	Height (gm)	**No. of branches**	**No. of internodes**	**Canopy (cm)**	**Girth (cm)**
0	48.4	19	17	48.6	5.7
1000	48.3	19	20	50.8	6.5
2000	45.5	18	17	49.5	5.3
2500	46.7	19	18	49.8	5.7

Table 4.7: Average plant vegetative development after application of lime and NPK fertilizer

Lime rate ($kgha^{-1}$)	Plant parameter				
	Height (cm)	No. of branches	No. of internodes	Canopy (cm)	Girth (cm)
0	64.2	29	23	74.7	9
1000	67.1	30	27	75.2	8.7
2000	60.4	32	27	77.23	8.2
2500	64.8	31	26	79.5	8.9

Plate 4.1: Coffee plants before liming

Plate 4.2: Coffee plants after liming

4.3.4 Number of branches

The results show that average number of branches for 0 $kgha^{-1}$ was 19, lime rate of 1 000 $kgha^{-1}$was 19, 2 000 $kgha^{-1}$was 18 and 2 500 $kgha^{-1}$was 19 before application of lime (Table 4.5). Effect of lime showed average number of branches for 0 $kgha^{-1}$ as 29, 1 000 $kgha^{-1}$ as 30, 2 000 $kgha^{-1}$ 30 and 2 500 $kgha^{-1}$as 31. The results in Table 4.4 indicate that there is significant difference between plots that received different levels of lime and control plot at ($P = 0.05$). High number of branches was recorded in the plot that received 2 500 $kgha^{-1}$followed by 2 000 $kgha^{-1}$, 1 000 $kgha^{-1}$and 0 $kgha^{-1}$respectively. Similar results were obtained by Mendonca *et al.* (2007), who used IAC 15 variety to determine effect of lime on coffee branches. The results showed that there were increases in the number of plagiotropic branches, with the doses of 2300 $kgha^{-1}$and 1100 $kgha^{-1}$lime rate (Dzung *et al.*, 2013). The study pointed out that improvement of the soil fertility and nutrient uptake in the leaves led to increase in the growth of coffee branches and crop yield.

4.3.5 Correlation between coffee vegetative growth parameters and dolomite lime $CaMg(CO_3)_2$ applied at different levels

The results (Figure 4.1) showed that, there was a direct influence of lime on coffee vegetative growth. Lime application gave positive weak correlation of vegetative growth parameters. Similarly, Hue (2005) reported that lime amendments were positively correlated with a good growth of coffee plants.

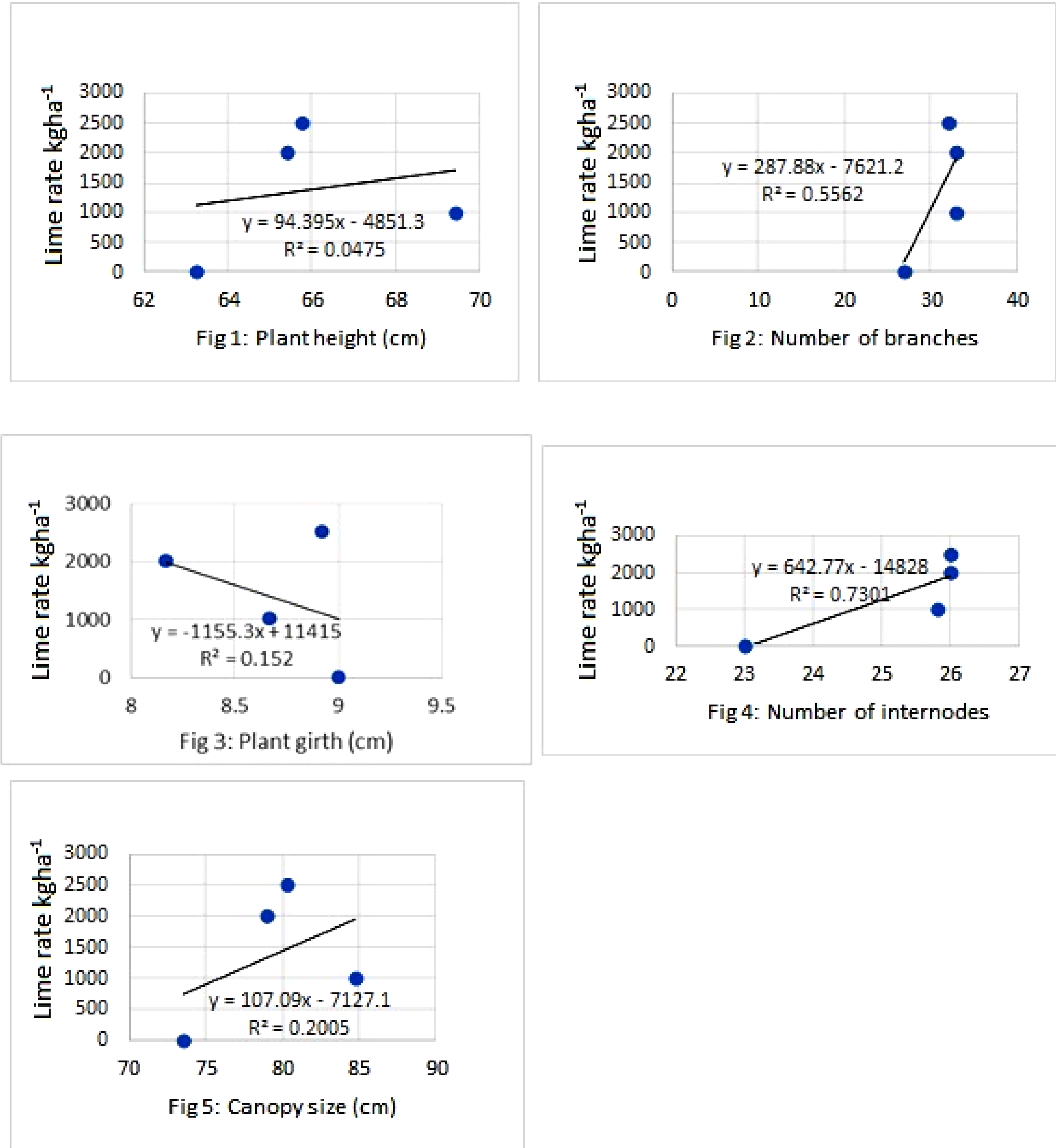

Figure 4.1: Correlation between lime and vegetative growth parameters of coffee plants

In the first six months of the study, correlation between coffee height and lime levels recorded was R^2 = 0.0475, between plant girth and lime levels was R^2 = 0.152, between branches and lime levels was R^2 = 0.5562, between internodes and lime levels was R^2=0.7301 and between canopy lime levels was R^2 = 0.2005. This indicates that there is positive moderate correlation between number of branches and internodes increase with dolomite lime application. Furthermore, the results indicated weak correlation between plant height and lime levels, girth and lime levels, and between canopy development and lime levels. Thus, with increase of dolomite lime application up to 2500 $kgha^{-1}$, good response was recorded for branches and internodes in the first six months. The apparent reason may be due to increase in soil pH and the availability of other essential nutrient elements. The improved nutrient uptake following liming of the acidic soil of Mbimba Mbozi District might in most cases have improved coffee root growth and stimulatory effect of lime on the activities of microorganisms which release nutrients.

4.4 Conclusions and Recommendations

The following conclusions and recommendations can be made for soils under arabica coffee cultivation in Mbimba Mbozi plantations in Southern Tanzania: -

- The soil under coffee cultivation in Mbimba Mbozi District is strongly acidic soil with pH ranging from 4.8 - 5.7.
- Application of lime have improved the size of plant girth by 5.1 - 7.1cm, internodes by 11 - 24.5 cm and plant canopy by 42.5 - 68 cm
- The study concluded that application of $CaMg(CO_3)_2$ lime at 2000 $kgha^{-1}$ proved effective in reducing soil acidity and increased number of coffee primary branches and internodes.

- Application of lime ($CaMg(CO_3)_2$) in combination with fertilizer (NPK+3S) increases plant height, girth, internodes, canopy and number of branches.

The following are the recommendations for Mbimba Mbozi soils:-

- Application of 2000 $kgha^{-1}$ of dolomite lime is recommended to soils of Mbimba to raise soil pH from strongly acidic to slightly acidic (5.2 - 6.6) that will favor plant nutrients' availability and plant growth.
- Application of nitrogenous and phosphorus rich fertilizers is needed to supplement the deficient levels in the soil that will increase nutrient availability and increase coffee productivity in Mbimba Mbozi area.

REFERENCES

Adams, F. and Evans, C. E. (1962). A Rapid Method for Measuring Lime Requirement of Red-Yellow Podzolic Soils 1. *Soil Science Society of America Journal* 26(4): 355-357.

Braccin, M. and Do, C. L. (2000). Aluminum tolerance of coffee genotypes in nutrient solution and in soil. Viçosa, MG. D.Sc. Thesis for Award degree of - UFV-Universidade Federal de Viçosa, Viçosa, MG. 102pp.

Braccin, M. and Do, C. L., Martinez, H. E. P., Pereira, P. R. G., Sampaio, N. F. and Silva, E. A. M. (1998). Aluminum tolerance of coffee genotypes in nutrient solution. II - P, Ca and Al concentrations and P and Ca efficiencies. *Revista Brasileira de Ciência do Solo* 22: 443–450.

Campbell, G. S. and Norman, J. M. (1989). The description and measurement of plant canopy structure. *Cambridge University Press* 31: 1-19.

Duursma, E. K. and Dawson, R. (1981). *Marine Organic Chemistry: Evo-lution,* composition, interactions and chemistry of organic matter in seawater. Elsevier. pp. 521.

Dzung, N. A., Dzung, T. T. and Khanh, V. T. P. (2013). Evaluation of coffee husk compost for improving soil fertility and sustainable coffee production in rural central highland of Vietnam. *Resources and Environment* 3(4): 77-82.

Fageria, N. K. and Baligar, V. C. (2008). Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. *Advances in Agronomy* 99: 345-399.

Fageria, N. K. and Moreira, A. (2011). The Role of Mineral Nutrition on Root Growth of Crop Plants. *Advances in Agronomy* 110(1): 251-331.

Felipe, S., Gustavo, C., Tiago, O., Tavares, R. and DeMello, P. (2014). Doses of Phosphorus Associated with Nitrogen on Development of Coffee Seedlings. *Coffee Science* 9(3): 419-426.

Hartz, T. K. (2007). *Soil Testing for Nutrient Availability Procedures and Interpretation for California Vegetable Crop Production*. Dept. of Plant Sciences, UC Davis. pp 1-7.

Hue, N. V. (2005). Responses of coffee seedlings to calcium and zinc amendments to two Hawaiian acid soils. *Journal of Plant Nutrition*. 27: 261 - 274.

Jaramillo-Botero, C., Santos, R. H. S., Martinez, H. E. P., Cecon, P. R. and Fardin, M. P. (2010). Production and vegetative growth of coffee trees under fertilization and shade levels. *Scientia Agricola* 67(6): 639-645.

Kaio, G., Lima, E., Paulo, T., Gontijo, G. and Pereira, R. (2015). Coffee yield and phosphate nutrition provided to plants by various phosphorus sources and levels. *Clenc. Agrotec.* 39(2): 110–20.

Kimaro, D. N., Msanya, B. M., Mwango, S. B., Kimbi, G. G. and Kileo, E. P. (2001). Land suitability evaluation for the production of the major crops in the sourth west part of the Uluguru Mountains, Morogoro Rural District, Tanzania. S*oils and Land Resources of Morogoro Rural and Urban Districts, Volume* 2.

Department of Soil Science, Facult of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania. 69pp.

Kisinyo, P. O., Othieno, C. O., Gudu, S. O., Okalebo, J. R., Opala, P. A., Maghanga, J. K., Ngetich, W. K., Agalo, J. J. and Opile, R. W. (2013). Phosphorus Sorption and Lime Requirements of Maize Growing Acid Soils of Kenya. *Sustainable Agriculture Research* 2(2): 116-124.

Mendonça, S. M. D., Martinez, H. E. P., Neves, J. C. D. L., Guimarães, P. T. G. and Pedrosa, A. W. (2007). Coffee tree (*Coffea arabica* L.) response to limestone in soil with high aluminum saturation. pp112-122.

Nelson, D. W. and Sommers, L. E. (1982). Total carbon, organic carbon and organic matter. In: *Methods of Soil Analysis.* Part 2 2nd Ed. (eds. Page, A. L., Mil-ler R. H. and Keeney, D. R.) *American Society of Agronomy*, SSSA Monograph No. 9, Madison, Wisconsin, USA. pp. 539 – 579.

Osorio, N. W., Alzate, J. M. and Ramirez, G. A. (2002). Coffee seedling growth as affected by mycorrhizal inoculation and organic amendment. *Communications in Soil Science and Plant Analysis* 33(9-10): 1425-1434.

Poorter, H., Niklas, K. J., Reich, P. B., Oleksyn, J., Poot, P. and Mommer, L. (2012). Biomass allocation to leaves, stems and roots: meta-analyses of interspecific variation and environmental control. *New Phytologist* 193(1): 30-50.

Rice, R. W. (2007). *The Physiological Role of Minerals in the Plant.* Mineral nutrition and plant disease. APS Press, St. Paul, MI. pp. 9-29.

Richard, C. (2001). *Simply Coffee.* Cannon Press Harare Zimbabwe. 90pp.

Russel, G., Marshall, B., Jarvis, P. G. (1989). *Plant Canpies: Their Growth, Form and Function.* Cambridge: Cambridge University Press. pp1-20.

Silva, L. D., Marchiori, P. E. Maciel, C. P. Machado, E. C. and Ribeiro, R. V. (2010). Photosynthesis, water relations and growth of young coffee plants according to phosphorus availability. *Pesquisa Agropecuária Brasileira* 45(9): 965-972.

The, C., Calba, H., Zonkeng, C., Ngonkeu, E. L. M. and Adetimirin, V. O. (2006). Response of maize grain yield to changes in acid soil characteristics after soil amendment. *Plant Soil* 284: 45–57.

Uzoho, B. U., Osuji, G. E. Onweremadu, E. U. and Ibeawuchi, I. I. (2010). Maize (Zea mays L.) response to phosphorus and lime on gas flare affected soils. *Life Science Journal* 7: 77-82.

Willson, K. C. (1985). *Coffee: Botany, Biochemistry and Production of Beans and Beverage.* Croom Helm, London and Sydney. pp 97-107.

CHAPTER FIVE

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From this study the following conclusions can be made for soils under arabica coffee cultivation in Mbimba Mbozi Tanzania: -

i. The textural class of Mbimba Mbozi soils is clay with a potential of high nutrient and water holding capacity.

ii. The soils of Mbimba Mbozi have been classified as *Typic Palehumults* under USDA and Haplic *Alisols* under WRBS systems respectively.

iii. Mbimba Mbozi soils are very acidic with pH ranging between 4.25 and 5.72 with low to very low levels of exchangeable cations that could have implications on the CEC, nutrient uptake and consequently nutrient imbalances, induced toxicities and coffee yield.

iv. The soils of Mbimba Mbozi are deficient in N, P, Ca and Mg while concentrations of Fe and Mn were in excess or toxic level.

v. Results indicated that liming at a rate of 2 000 $kgha^{-1}$ gave the best results in terms of P, K, Ca, Mg, Cu, Zn and pH concentration as well as increase number of coffee branches.

6.2 Recommendations

i. Application of 2 000 $kgha^{-1}$ of dolomite lime is recommended to soils of Mbimba to raise soil pH from strongly acidic to slightly acidic (5.2 - 6.6) that will favor plant nutrients' availability and plant growth.

ii. Application of nitrogenous and phosphorus rich fertilizers is needed to supplement the deficient levels in the soil that will increase nutrient availability and increase coffee productivity in Mbimba Mbozi area.