SOIL CHARACTERIZATION AND EFFECTS OF N, P AND K ON THE GROWTH, YIELD AND ROOT QUALITY OF CASSAVA (*Manihot esculenta* Crantz) IN THE LAKE ZONE OF TANZANIA

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EXTENDED ABSTRACT

Cassava (*Manihot esculenta* Crantz) is a main staple food crop in many African countries including Tanzania, but to other countries in Asia is a cash and industrial crop. The major cassava growing areas in Tanzania includes the Lake Zone (Mwanza, Kagera, Mara, Simiyu, Geita and Shinyanga), Southern zone (Mtwara, Ruvuma and Lindi), Eastern zone (Coast, Tanga and Morogoro) and Zanzibar (Pemba and Unguja). In Tanzania cassava is cropped continuously in the same field with no or little addition of agricultural inputs and this has resulted in soil nutrients mining and consequently low yields. To increase and sustain cassava production and productivity, soil characterization, fertility status assessment and appropriate soil and crop management practices are inevitable. This will complement the breeding program efforts in generating improved cassava varieties. The main objectives of this study were to characterize, assess the initial soil fertility and the effects of N, P and K on growth, yield, and root quality of cassava (*Manihot esculenta* Crantz) in three selected cassava growing areas in the Lake Zone of Tanzania.

This study was conducted during 2016/17 and 2017/18 growing seasons, in three major cassava growing sites which were Runazi village in Biharamulo district, Kijuka village in Sengerema district and Nyakiswa village in Butiama district in the Lake Zone of Tanzania. One representative soil profile from each study site was excavated. The morphological soil properties were assessed and the soil profile described according to the FAO guidelines of soil profile description (FAO, 2006). Collected soil samples from each site were, air-dried, crushed and sieved to pass through 2 mm sieve then taken to the International Institute of Tropical Agriculture Laboratory in Dar es Salaam for analysis. The physical and chemical properties of soils were categorized and rated according to the Booker Tropical Soil Manual (Landon, 2014).

Soils were classified according to the Soil Survey Staff (2014) up to the subgroup level and to the IUSS Working Group WRB (2015) reference soil groups (RSG) to TIER 2 level using the soil morphological and laboratory data. The topsoil was used to assess the fertility status of each study sites and rated according to Landon (2014).

The effects of fertilizers on growth, yield, and root quality of cassava (*Manihot esculenta* Crantz) were assessed using eleven N, P and K treatments laid down in a randomized complete block design (RCBD) with four replicates in a form of nutrient omissions. Treatments consisted of the full rate NPK (150 $kgha^{-1}$ N, 40 $kgha^{-1}$ P and 180 $kgha^{-1}$ K), and half-rate NPK (75 $kgha^{-1}$ N, 20 $kgha^{-1}$ P and 90 $kgha^{-1}$). The test crop was "Mkombozi" cassava variety which is an improved high yielding and early maturing. Cassava growth, yield and root quality data were collected at twelve months (12 MAP) after planting. Cassava plants from the net plot were uprooted, weighed and grouped into above-ground biomass and below-ground biomass at harvest. The growth parameters namely the lignified stems, green stems, old planting stakes, and fresh leaves were weighed and expressed in kilograms (tha^{-1}). Plant height was measured in centimetre (cm) from the top of the ridges up to the top branches of the cassava plant.

Cassava yield and yield parameters namely the fresh root yield (tha^{-1}) were calculated as ratios of total root weights to the number of stands harvested from the net plot. The total biomass was calculated as the summations of the root and shoot weights (tha^{-1}). The root harvesting index (HI) was calculated in percentage as a ratio of the cassava root weights to the biomass multiplied by 100. Cassava root quality parameters namely the root dry matter content (DMC) was calculated using the specific gravity method and the cassava starch content (CSC) was determined by the underwater weight method.

The generated data from each site were statistically subjected to the analysis of variance (ANOVA) embedded in the general Linear regression model and the means between treatments were compared using the Student-Newman-Keuls test at P = 0.05 significance and performed using the Statistical Analysis Software (SAS version 9.4).

The soil physical and chemical properties data were rated and ranked according to Landon (2014)**.** The detailed soil profile descriptions of Runazi, Kijuka and Nyakiswa villages in Biharamulo, Sengerema and Butiama are as presented in Appendix 1, 2 and 3 respectively**.**

There was a significant growth increase between locations at $P < 0.05$ for all growth parameters. This corresponds to the variations of soil fertility and weather conditions observed between sites. However, all growth parameters were not significantly increased by the application of N, P and K at Biharamulo. Nevertheless, an overall increase in growth in all fertilizer treatment was observed compared to control plots. The growth of green stems and leaves were only increased by the growing seasons and was attributed to NPK in both seasons. The NPK (150:40:180 kg ha^{-1}) treatment increased the weights of lignified stems (8.35 tha^{-1}) compared to control with 5.36 tha^{-1} and the weight of green stems with 4.52 tha^{-1} compared to unfertilized (2.95 tha^{-1}) plots. The soil was deficient of nitrogen, therefore the application of half_K+P was found to have low growth on the old planting stakes fresh weights and plant height compared to control plots, and this signifies the importance of nitrogen in cassava growth and yield. Generally, significant growth differences between locations at ($P < 0.05$) were due to the variations of soil fertility across the sites. However, the aforementioned growth parameters at Biharamulo were not significantly affected by the application of N, P and K ($P > 0.05$); nevertheless, there was an increase in growth in fertilizer treatments. The growth of lignified stems, green stems and plant height were only affected by the growing seasons ($P < 0.05$) influenced by the climatic differences in both seasons. The NPK (150:40:180 kg ha^{-1}) observed to affect the weights of lignified stems (8.35 tha^{-1}) compared to control (5.36 tha^{-1}) and the weight of green stems (4.52 tha^{-1}) compared to control (5.9 tha^{-1}) plots. The soil was deficient in nitrogen, therefore the application of half_K+P was found to have lower old planting stakes fresh weights and plant height compared to control plots, and this signifies the importance of nitrogen in cassava growth and yield. The cassava root yield and yield components were significantly affected by treatments ($P < 0.05$).

The total fresh root yield (FRY) was significantly affected by treatments and seasons ($P < 0.05$) as well. The application of NPK (150:0:180 kg ha^{-1}) fertilizer was found to have the highest impact on fresh root yield 23.35 tha^{-1} which is equal to 77 % yield increase over the control plots compared to unfertilized plots 11.73 tha-1. Root harvesting Index was also significantly affected by fertilizer application (($P < 0.05$)5). Also, the NK (150:0:180 kg ha^{-1}) application was found to have the highest harvesting index (HI) of (60.46 %) while the control was 49.9 %. The application of NP at a ratio of 150:40:0 $kgha^{-1}$ was found to have low root harvesting index of 47.33 % compared to the control indicating that potassium was a limiting nutrient in the soil causing the decrease of the economic yield. The cassava biomass was significantly increased by fertilizer application at $P < 0.05$ where the NPK at the rate of 150:40:180 kg ha^{-1} was found to have the highest total biomass of 39.76 tha^{-1} compared to the control plot of 23.58 tha^{-1}. The marketable yield and total root weight were significantly increased by N, P and K ($P < 0.05$) applications. The NPK (150:0:180 $kgha^{-1}$) treatment was found to have a higher marketable root yield of 16.48 tha^{-1} compared to the control 7.4 tha^{-1}.

Additionally, cassava root quality was not significantly affected by the N, P and K applications ($P > 0.05$). The result ties with previous studies by Fermont *et al*. (2009), Adjei-Nsiah and Isaak (2013) where fertilizer application insignificantly increased cassava starch content (CSC) and dry matter content (DMC), contrary to Agbaje and Akinlosotu (2004), and Boateng and Boadi (2010) who reported an increase of cassava starch and dry matter content. However, other studies by Benesi *et al.* (2004) shows that cassava root starch and dry matter are influenced by the genotype and environmental factors such as rainfall during and before harvesting (Moreno and Gourdji, 2015). Although, fertilized plots were better than the control plots. The application of half_N+PK with the rate of 75:40:180 kg ha^{-1} was found to have a higher percentage of DMC and CSC of 35.68 % and 23.38 %, respectively while the lowest DMC and CSC of 28.04 % and 13.44 % were observed on half_K+ NP(150:40:90 kg ha^{-1}) fertilizer treatment.

At Sengerema, the fresh weight of cassava old planting stakes and stems were only affected by the growing season ($P < 0.05$), due to the environmental differences such as rainfall distributions. The weight of lignified stems, old planting stakes and green stems fresh weights (kg) were not significantly increased by the application of N, P and K ($P > 0.05$). However, the application of half_P+NK at a rate of 150:20:180 kg ha^{-1} was found to increase the fresh weights of lignified stems to 9.77 tha^{-1} compared to the control with 7.03 tha^{-1}). The half_P+NK (150:20:180 kg ha^{-1}) treatment was found to have higher old planting stake fresh weight of 3.86 tha^{-1} compared to control with 2.72 tha^{-1} whereas the green stems fresh weight was found to be high with 3.87 tha^{-1} due to N and P application at a rate of 150:40:0 kg ha^{-1} compared to the control plot with 3.46 tha^{-1}. The plant height was also found to be higher with 136.06 cm in the plot treated with half_P+NK at a rate of 150:20:180 $kgha^{-1}$ compared to control with 120.52 cm. The fresh root yield and yield components were not significantly affected by the application of fertilizers in this site. However, there was an increase in yield and yield components compared to control. The Higher harvesting index (HI) and total biomass were significantly affected by the growing seasons ($P< 0.05$) respectively. High HI was observed in the second season with 43.3 %

compared to the first season with 40.8%. The first season was found to have higher total biomass of 31.71 tha^{-1} compared to the second season with 25.79 tha^{-1}. The DMC and CSC were also not significantly affected by treatment as in Biharamulo site.

Cassava growth parameters at Butiama except plant height and old planting stakes were significantly increased by the growing seasons ($P < 0.05$). Fertilizer treatment had no significant effect on the fresh weight of growth parameters however, fertilizer plots were better than control plots. Green stems and leaves fresh weight were higher in the first season with 1.88 tha^{-1} and 3.02 tha^{-1} compared to the second season with 0.81 tha^{-1} and 1.51tha^{-1} respectively. The lignified fresh weight was higher in the second season with 7.6 tha^{-1} compared to the first season with 6.46 tha^{-1}.

The significant differences between treatments were observed in total fresh root yield, HI, marketable fresh root yield across all sites and seasons $P < 0.05$. The application of P and K at a rate of 0:40:180 $kgha^{-1}$ observed to have higher fresh root yield of 18.44 tha^{-1} compared to the unfertilized control plot with 9.73 tha^{-1}. The application of half_K+P at a rate of 0:20:180 $kgha^{-1}$ resulted to an increase of 63.51 % HI compared to N and P application at the rate of 150:40:0 $kgha^{-1}$ with HI of 37.21 % compared to control with HI of 39.79 % which means that the soil was deficient in nitrogen causing low cassava root yield. The application of P and K at a rate of 0:40:180 kg ha^{-1} observed to have a higher total fresh root weight of 46.1 tha^{-1}compared to control with 24.34 tha^{-1}. Also, higher marketable root yield of 19.93 tha^{-1} was observed due to N and K application at a rate of 150:0:180 kg ha^{-1} while the lowest marketable yield was observed on the control with 10.35 tha^{-1}. In the first season, the total fresh root yield, HI, marketable root yield and total biomass were high with 16.29 tha^{-1}, 52.51 %, 17.86 tha^{-1} and 31.18 tha^{-1} respectively compared to the second season with 11.87 tha^{-1}, 43.29%, 10.79 tha^{-1} and 25.29 tha^{-1}

respectively. The DMC and CSC were insignificantly affected by treatments as observed at Biharamulo and Sengerema sites. The first season was observed to have the higher DMC of 34.98 % and CSC of 22.27 % compared to the second seasons with the lowest DMC of 31.36 % and CSC with 17.77 % caused by the environmental factors such as rainfall differences during planting and harvesting periods.

The physical and chemical soil properties varied widely with the prevailing environmental conditions. The fertility status of Biharamulo, Sengerema and Butiama soils were low, and cassava positively responded to the application of N, P and K. Fertilized treatments were better compared to the control. The NPK (150-0-180) was the optimum rate with the highest tuber yield of 23.15 tha-1 when applied in a split of 60% at one month (1MAP) while the remaining 40% at three months after planting (3MAP) in Biharamulo. Yield variations were due to differences in soils fertility levels and environmental conditions. Therefore, there is a need to understand the soil constraints to fertilizer application.

DECLARATION

I, Dennis Wambura Ndare, do hereby declare to the Senate of the 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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Dennis Wambura Ndare **Date**

(MSc. Candidate)

The above declaration is confirmed by;

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Dr. A. K. Kaaya **Date**

(Supervisor)

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DEDICATION

I dedicate this study to the Almighty God, my source of wisdom, knowledge and understanding. He has been with me since, until now and he shall still be. I also dedicate this study to my lovely wife Edda Mushi, my son Derrick and daughters; Daniela and Dalice as they have been part and parcel of this study.

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LIST OF ABBREVIATIONS

AAS	Atomic absorption spectroscopy
ACAI	African Cassava Agronomy Initiative
AFSIS	Africa Soil Information Service
Al	Aluminium
ANOVA	Analysis of variance
Av. P	Available phosphorus
B	Boron
BD	Bulk density
BMLO-P1	Biharamulo soil profile number
BS	Base saturation
BTMA-P2	Butiama soil profile number
C	Clay textural class
C: N	Carbon to nitrogen ratio
Ca	Calcium
CBSD	Cassava brown streak disease
CEC	Cation exchange capacity
CMD	Cassava mosaic diseases
Cmol (+)/kg	Centimol per kilogram of soil
CSC	Cassava starch content
Cu	Copper
DMC	Dry matter content
FAO	Food Agricultural Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistics
Fe	Iron

GLM	Generalized Linear Model
GrnStmFwt	Green stems fresh weight
Half P+NK	Half Phosphorus treatment rate plus nitrogen and potassium
HI	Harvesting index
ICIPE	International Centre of Insect Physiology and Ecology
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
K	Potassium
K+NP	Potassium plus nitrogen and phosphorus fertilizer
kg	Kilogram
LS	Loam sandy textural class
M	Molarity
MAP	Month after planting
MFRWt	Marketable fresh root weight
Mg	Magnesium
Mn	Manganese
MOP	Muriate of potash
MrtWt	Marketable root weight
N	Nitrogen
n.d	Not determined
N+PK	Nitrogen plus phosphorus and potassium fertilizer
NH_4AC	Ammonium acetate
NK	Nitrogen and potassium fertilizer treatment
NMrtWt	Non-marketable root weight
NOT	Nutrient omission trial
NP	Nitrogen and phosphorus

NPK	Nitrogen, phosphorus and potassium
OC	Organic carbon
OM,	Organic matter
P	Phosphorus
P+half K,	Phosphorus plus half potassium treatment
PBS	Percentage base saturation
pH	Hydrogen activity
PK	Phosphorus Potassium
R	Correlation coefficient
RCBD	Randomized complete block design
RSG	Reference soil group
S	Sulphur
SAS	Statistical analysis software
SCL	Sandy clay loam
SENGM-P2	Sengerema soil profile number two
SG	Specific gravity
SL	Sandy loam
SNK	Student-newman-keuls test
TARI	Tanzania Agricultural Research Institute
TB	Total biomass
TEB	Total exchangeable bases
TFRtY	Total fresh root yield
tha^{-1}	Tonnes per hectare
TIER-2	Classification Level in World Soil Reference Base
TN	Total nitrogen
TShWt	Total shoot weight

TSP	Triple superphosphate
USA	United States of America
USDA	United States Department of Agriculture
WRB	World Reference Base for Soil Classification
Zn	Zinc

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a tropical root perennial crop of the *Euphorbiaceae* family (Alves, 2002; Howeler, 2002; Hillocks *et al.*, 2002), that originated in the Amazon forest of South America (Hillocks *et al.*, 2002; Burns *et al.*, 2010), and introduced to Africa in the 16^{th} century by Portuguese (Allem, 2002; Hillocks *et al.*, 2002), and was literally introduced to East Africa and to the shores of Lake Victoria in the 18^{th} and 19^{th} century respectively (Hillocks *et al.*, 2002).

Cassava as a tropical crop, is adapted to different types of agro-climatic conditions ranging from 30^0 N to 30^0 S (Howeler *et al.*, 2001) with altitude ranging from sea level to above 1 800 ma.s.l with the minimum temperature of 20 ^{0} C to 35 ^{0} C (Okogbenin *et al.*, 2013; El-sharkawy, 2003) and well-distributed monthly rainfall of at least 50 mm (Hauser *et al.*, 2014). Cassava is adapted to a wide range of soils ranging from fertile to inherently low fertile soils (Cuvaca *et al.*, 2015; Kang and Okeke, 1984). Application of fertilizers and other soil amendments has been reported to boost yields, for example, application of N, P and K at a rate of 112 kg N, 68 kg P and 156 $kgha^{-1}$ increased yields from 30 to 54 tha^{-1} in Asia (Howeler, 2014).

Africa produces about half of the total world cassava production in more than 40 countries (FAO and IFAD, 2005). The largest cassava producers in Africa are Nigeria (35 %), D.R Congo (19%), Ghana (8 %), Tanzania (7 %) and Mozambique (6%) (Benesi *et al.*, 2004). Tanzania is ranked number thirteen in the world for cassava production and the major producing areas being the Lake zone (Mwanza, Kagera, Mara, Simiyu, Geita and

Shinyanga), Southern zone (Mtwara, Ruvuma and Lindi), Eastern zone (Coast, Tanga and Morogoro) and Zanzibar (Pemba and Unguja) (Mkamilo and Jeremiah, 2005).

Production of cassava varies depending on the variety, growing season and the fertility levels of the soil. In more than a decade, there has been a dramatic decrease of cassava root yield per unit area due to the declining of soil fertility levels and increase of pest and diseases pressure despite the fact that there has been an increase of cassava acreage production. According to Mkamilo and Jeremiah (2005), the average cassava yield is about 8 tha^{-1} in Tanzania, which is by far very low compared to the average cassava yield in Africa of about 30 t ha^{-1} (Fermont *et al*., 2009).

Cassava is both a major staple food crop (Roy *et al*. 2006; Mkamilo and Jeremiah, 2005) and cash crop (Nweke *et al*., 2004). Cassava is rich in carbohydrate content (Balagopalan, 2002) and good starch, the characteristics that have boosted interest as a raw material for industrial use in bakery, fuel, alcohol, pharmaceuticals and animal feed production (Bokanga, 1995). In Tanzania, for example, cassava is an important staple food crop after maize and rice for many households in rural and urban areas (MAFC, 2009) because it is cheap and easily accessible (Kapinga *et al*., 2005).

Cassava is a source of dietary energy for many families in Tanzania, consumed in different products such as cooked and roasted fresh roots, raw roots are eaten fresh, and flour made from dried cassava root chips (Kapinga *et al*., 2005), while the leaves are used as vegetables (Hillocks *et al*., 2002; Lenis *et al*., 2006).

However, cassava production has been constrained by various factors which have caused serious economic loss to farmers. The constraints to increased and sustainable cassava production among others include soil fertility deterioration, pests and diseases such as the cassava mealybug (CMB), cassava green mite (CGM) and the whitefly (*Bamicia tabaci*). Cassava diseases include the cassava mosaic viral (CMV), cassava brown streak (CBSD) and bacterial leaf blights (BLB). The CMV and CBSD have been the most devastating diseases in Tanzania causing more than 80% of yield losses (Coulson and Diyamett, 2012). Also, soil fertility deterioration as a result of continuous cultivation without replenishment depletes the soil nutrients and subsequently reduces yields (Howeler, 2014). Various improvement programs to address cassava production bottlenecks in Tanzania have been enacted to boost cassava root yields such as breeding resistant varieties against pest and diseases and high yielding cassava varieties. However, cassava yield per unit area is still decreasing attributed by mainly among other factors, low soil fertility.

However it has been established that ,cassava responds positively to N, P and K applications (Howeler, 2000; Uwah *et al*., 2013; Ukaoma and Ogbonnaya, 2013), whereby the N, P and K increase the photosynthetic rates of leaves and translocation of the photoassimilates from the leaves to storage roots (Ukaoma and Ogbonnaya, 2013). Additionally, the growth of cassava on fertile Alfisol and Vertisols soils coupled with fertilizers applications in Asia increased yield from 23.5 to 46.3 tha^{-1} (Howeler, 2000). In Tanzania including the Lake Zone, there is limited information on soil fertility status which could enable to quantify the yield potential of cassava in response to fertilizer application.

Given the growing importance of cassava crop, and inadequate data availability extensive cassava agronomy research is therefore required in order to improve growth performance on soils with different fertility status and therefore increase cassava production, and productivity. Soil fertility levels characterization and evaluation to develop recommendations are crucial for reducing soil fertility challenges facing cassava farmers. This will complement breeding efforts meant to improved cassava varieties. Therefore, this study aims to characterize soil fertility status and the effects of inorganic fertilizers applications in cassava growing areas so as to improve and sustain cassava productivity and marketability in the Lake Zone of Tanzania.

1.1 Overall Objective

The overall objective of this work was to characterize the soils of the major cassava growing areas in the Lake Zone of Tanzania, and assess the effects of different fertilizers rates on cassava growth, yield and root quality as a strategy for enhanced and sustainable cassava production so as to improve the food security status in the Lake Zone of Tanzania.

1.1.1 Specific Objectives of the Study

The specific objectives of this study were:

i. To characterize and classify the soils of cassava growing areas in the Lake Zone of Tanzania.

ii. To assess the current soil fertility status of the cassava growing areas in Lake Zone of Tanzania.

iii. To evaluate the effects of the application of mineral fertilizers on growth, yield and root quality of cassava (*Manihot esculenta* Crantz) in the studied soils of cassava growing areas in the Lake zone of Tanzania.

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CHAPTER TWO

2.0 SOIL CHARACTERIZATION, CLASSIFICATION AND SOIL FERTILITY ASSESSMENT OF THE MAJOR CASSAVA GROWING AREAS OF THE LAKE ZONE, TANZANIA

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ABSTRACT

A study was carried in the Lake Zone of Tanzania to characterize and assess the soil fertility levels in three cassava growing districts which are Biharamulo, Sengerema, and Butiama in the Lake Zone, Tanzania. One representative soil profile from each district was excavated and sampled for soil characterization. The soil fertility levels were assessed using the topsoil of each profile. The soil fertility status of Runazi, Kijuka and Nyakiswa at Biharamulo, Sengerema and Butiama respectively was low with low soil pH, low available P, low TN, low OC and low OM, low exchangeable bases, low levels of CEC, and high to moderate base saturation. According to the USDA (Soil Survey Staff, 2014) and IUSS Working Group WRB (2015), soils of Runazi and Kijuka at Biharamulo and Sengerema were classified as Fluventic Dystrustepts, and Fluvic Dystric Cambisol (Ochric) respectively and that of Nyakiswa Butiama as Kanhaplic Haplustults and Haplic Abruptic Alisol (Cutonic, Ochric), which were generally low fertile. Application of fertilizer to boost fertility status is vital to increase cassava production and productivity; therefore, there is a need to study the response fertilizer on cassava, yield and root quality.

Keywords: *Physical and chemical characteristics, Soil fertility, Soil Classification, Lake zone of Tanzania*.

2.1 INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is of increasing importance among the staple food crops in Tanzania. Currently, in Tanzania, it is the third staple food and cash crop after maize and rice. About 84 % of total cassava production in the country is for food, and 16 % is for animal feed and starch production (Bennett *et al*., 2019). According to Howeler (1991), cassava is grown by resource-poor farmers in marginal soils where other crops fail because it is a drought-tolerant crop (Bull *et al.*, 2011) growing in different agro-ecological zones across the tropics from 30°N to 30°S latitude in different altitudes from sea level to 2 000 m asl. However, cassava grows well in areas with a well-distributed annual rainfall of less than 600 mm to more than 1500 mm and a minimum temperature of less than 29°C (Alves, 2002).

Soil fertility decline is one of the major constraints to agricultural production in smallholder farmers in Sub Saharan Africa (SSA) (Reynolds *et al*., 2015). This has increased the degradation of the physical and chemical fertility of the soils (Bekunda *et al.*, 2002; and Makoi, 2016 Smalling *et al*., 1997). Most cassava farms in Africa are cropped continuous without addition of inputs because of the inaccessibility of fertilizers due to high costs. This has led to a decrease in soil productivity and consequently low yields (Howeler, 1991). According to Fermont *et al.* (2009), cassava yield production per unit area in East Africa has been decreasing, and actually most croplands in Tanzania produce below their productive potential (Senkoro *et al*., 2017) as a result of declining soil fertility due to decline in soil fertility (Bekunda *et al.*, 2002). Currently, the average cassava yield is estimated to be below 8 tha^{-1} (Mkamilo and Jeremiah, 2005) and this is by far lower than average cassava yield in Africa which is more than 30 tha^{-1} (Fermont *et al*., 2009) being attributed to low soil fertility being among the factors.

Because of the increase of population and intensification of agriculture, soil classification and characterization were inevitable so as to generate information on the soils potential and constraints to ensure the use of appropriate soil management practices. Therefore, there was a need to characterize the soils, for better understanding of constraints limiting cassava growth and production in the Lake Zone of Tanzania. This study therefore aimed at characterizing, classifying and establishing the soil fertility status of t cassava growing areas in the Lake Zone of Tanzania.

2.2 Materials and Methods

2.2.1 Description of the study area

The study was carried in three cassava growing districts in the Lake Zone of Tanzania. The zone surrounds Lake Victoria in Tanzania, and by extending from Latitudes 1^{o} 00' to 3^{o} 00' S and Longitude 30^{o} 25' to 35^{o} 15'E (Fig. 2.1). The area experiences bimodal type of rainfall pattern that is short and long rains. Short rains (*Vuli*) starts from September to January and long rains (*Masika*) starting from February to early June. The annual rainfall ranges from 500 to 1 250 mm and the mean temperature of 28^{0} C. The soils vary from sandy to clayey black cotton (*Mbuga* or Vertisols) soil (Mafuru, 1999). Figure 2.1 indicates the areas of soil profiles excavation.

2.2.2 Soil profile description and sampling

The study areas were selected based on the potential of cassava intensifications, access to inputs, markets, and coverage of extension networks. Other criteria used to select the study sites were chosen based on climate, soils, and land cover information. Three study sites were selected, each from the cassava growing areas of Runazi, Kijuka and Nyakiswa villages in Biharamulo, Sengerema, and Butiama districts respectively in the Lake Zone of Tanzania.

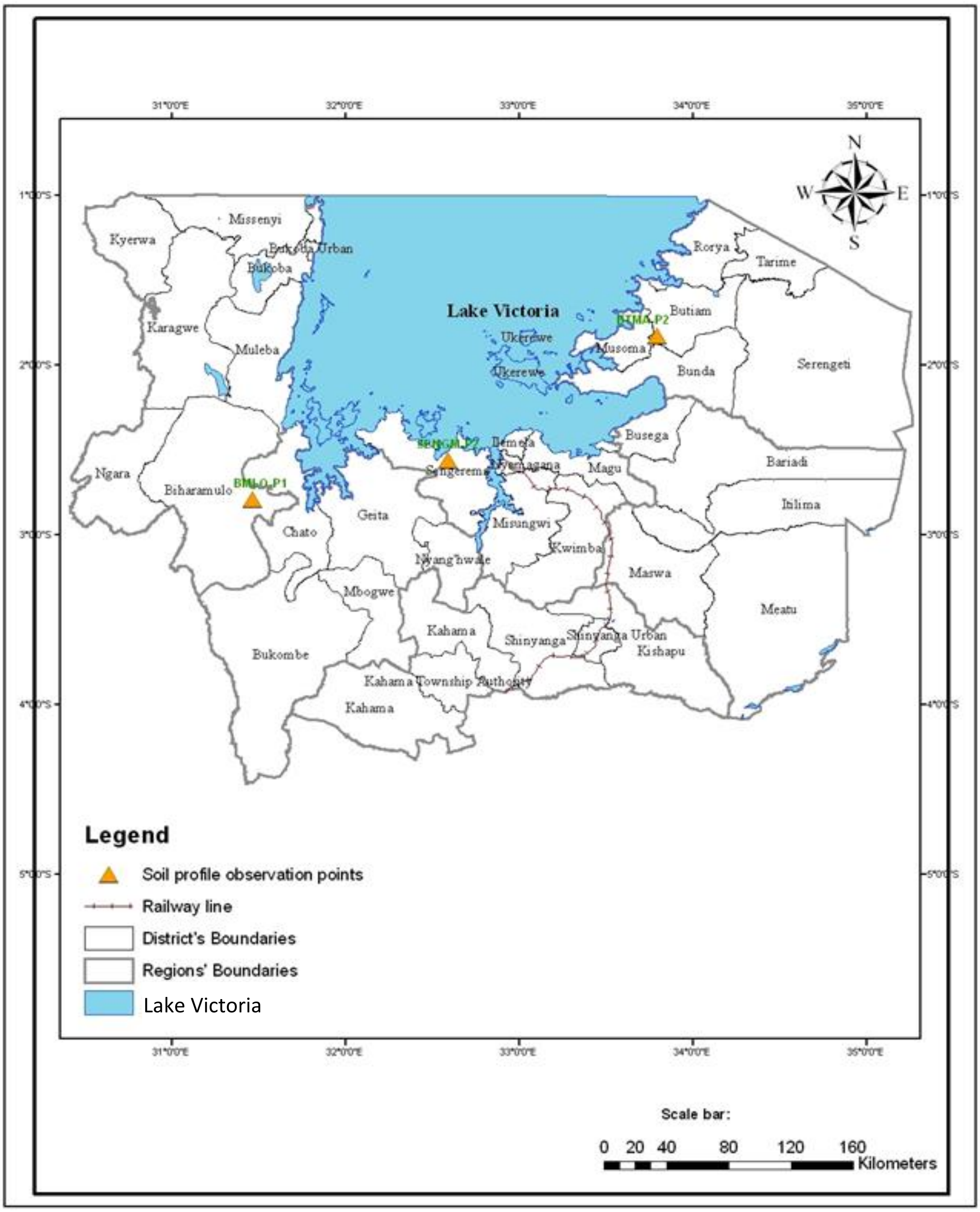

Figure 2.1: The map of Lake Zone area in Tanzania indicating the studied soil profiles

Therefore three representative soil profiles were excavated, described, and sampled according to the FAO Guidelines for Soil Profile Description (FAO, 2006). Soil colour was determined using the Munsell Soil Colour Charts (1992). Both disturbed and undisturbed (core) soil samples were collected from the middle of each identified genetic soil horizon in the soil profile. The soil samples collected were taken to the International Institute of Tropical Agriculture (IITA) laboratory in Dar es Salaam for the analysis of the selected physical and chemical properties.

2.2.3 Laboratory analysis of the physical and chemical soil properties

Total N was determined by the Kjeldahl- digestion- distillation method (Nelson and Sommers, 1982) was used to determine total soil nitrogen. Available phosphorus was determined using Bray methods as described by Okalebo *et al*. (2002). Soil organic carbon was determined using the Walkley and Black method (Nelson and Sommers, 1982). The pH was determined using soil-water suspensions (1:2.5) and 1N KCl in a ratio of 1N (1:2.5) soil/KCL suspension (Okalebo *et al*., 2002). The cation exchange capacity and exchangeable basic cations were extracted using 1.0 N ammonium acetate solution then Na^+ and K^+ were analyzed by using flame photometer while Ca^{2+} and Mg^{2+} were determined using atomic absorption spectrophotometer (AAS) (Hendershot *et al*., 1993). The total exchangeable bases (TEB) were calculated using the sum of the four bases (Ca^{2+}, Mg^{2+}, Na^+, and K^+). Soil particle size analysis was determined using the hydrometer method, and the bulk density was gravimetrically determined as described by Okalebo *et al*. (2002).

2.2.4 Soil classification

The morphological description information from the field and the soil physical and chemical characteristics data from the laboratory were used to identify the diagnostic characteristics and horizons according to the United States Department of Agriculture (Soil Survey Staff, 2014) and the World reference base for soil classification working group (IUSS Working Group WRB, 2015). These were then used to classify the soils up to the subgroup level according to Soil Survey Staff (2014) and Tier 2 name of the World Reference Base for Soil Classification System (IUSS Working Group WRB, 2015).

2.2.5 Soil fertility assessment

The fertility status of each soil in the study sites was assessed using the physical and chemical analysis data from the surface horizons from each soil profile, and the fertility levels were rated according to Landon (2014).

2.3 Results and Discussion

2.3.1 Soil morphological and physical characteristics of the cassava growing areas in Lake Zone, Tanzania

The selected morphological characteristics and physical properties of the studied representative soil profiles of Biharamulo, Sengerema and Butiama at cassava growing areas of the Lake Zone of Tanzania are presented in Table 2.1 and appendices 1, 2 and 3, respectively.

2.3.1.1 Soils of Runazi village in Biharamulo District

Biharamulo (BMLO-P1) soils were deep (> 150 cm) and well-drained having dark brown topsoil. Soils were characterized by weak to moderate structure due to excessive ploughing breaking the soil aggregates stability making the soil vulnerable to erosion especially in areas of continuous cassava production in Lake Zone. Soil consistency was hard when dry to very friable when moist, slightly sticky and slightly plastic when wet which enhance workability in all conditions. The topsoil texture was sand loamy which was deep and friable to allow cassava tubers development (Zemba *et al*., 2017), underlying the sandy clay loam subsurface horizons with abrupt textural change as shown by the increasing clay content with depth.

The soil bulk density was increasing with depth from the topsoil to the subsoil with a bulk density range of 1.6 – 1.8 g/cm^3 in the topsoil and subsurface horizons respectively due to compactness and low organic matter (Chaudhari *et al*., 2013). According to McKenzie *et al*. (2004) moderately compacted soils provide good rooting conditions for plant root growth and anchorage. According to Chaudhari *et al*. (2013) and McKenzie *et al.* (2004) soils with high BD of >1.6 g/cm^3 restrict crop root growth. Additionally, high bulk density soil inhibits water infiltration and due to low porosity and compactness.

2.3.1.2 Soils of Kijuka village in Sengerema District

Sengerema soils represented by profile number SENGM-P2 were deep > 150 cm, well-drained due to dark brown to reddish yellowish colourations in the topsoil when moist. The soil structure was weak, the same to Biharamulo soils due to tillage and cultivation. Soil consistency was hard when dry; very friable when moist, slightly-sticky and slightly-plastic when wet which means that the soil can be worked easily. The soil texture was sandy clay loam underlying the sandy loam subsurface horizons favourable for cassava root growth and development. Apparently, the soil was compacted as shown by high bulk density ranging from 1.6 – 1.8 g/cm^3 throughout the profile restricting root development and this could be improved through the addition of organic matter through planting cover crops and crop residue incorporations.

2.3.1.3 Soils of Nyakiswa village in Butiama District.

Butiama soils represented by profile BTMA-P2 were also deep > 150 cm, well-drained

Table 2.1: Selected morphological characteristics and physical properties of representative soil profiles of the cassava growing areas in the Lake Zone, Tanzania

Site	Profile no	Horizon	Depth (cm)	Particle size analysis % Clay	% Silt	% Sand	Textural class	BD (kg/m^3)	Munsel Soil colour Moist	Dry	Consistency	Structure
Biharamulo district	BMLO-P1	Ap	0-45	8.4	10.8	80.8	LS	1.60	db(10YR 3/3)	db(10YR 4/3)	ha,vfr,ns,np	w,fandc,sbk
		BA	45-85	20.4	8.8	70.8	SCL	1.70	sb(7.5YR 4/6)	db(7.5YR 4/6)	nd	nd
		B1	85-110	32.4	12.8	54.8	SCL	1.88	yr(5YR 4/6)	nd	nd	nd
		B_2w	110-170+	34.4	10.8	54.8	SCL	1.89	nd	nd	nd	nd
Sengerema district	SENGM-P2	Ap	0-10	23.2	4.0	72.8	SCL	1.79	vdgb(10YR 3/2	b(10YR 5/3)	vha,vfr,ns,np	w,sandc,asbk
		BA	10-50+	15.2	12.0	72.8	SL	1.73	db(7.5YR 4/4)	sb(7.5YR 5/6)	vha,vfr,ns,np	w,sandc,asbk
		B_1	50-110	17.2	12.0	70.8	SL	1.81	yr(5YR 4/6)	ry(7.5YR 6/8)	vha,vfr,ns,np	w,sandc,asbk
		B_2	110-140	15.2	12.0	72.8	SL	1.87	ry(7.5YR 6/8)	ry(7.5YR 6/8)	ha,vfr,ss,sp	w,fandc,sbk
		Bcrw	140-180+	n.d	n.d	n.d	n.d	n.d	nd	nd	LO,ss,sp	w,mc
Butiama district	BTMA-P2	Ap	0-20	53.2	30.0	16.8	C	1.53	drb(5YR 2.5/2)	nd	s,fr,vs,vp	mo,m,gr
		BA	20-37	63.2	24.0	12.8	C	1.54	(5YR 3/3)	nd	s,fr,vs,vp	s,m,ab
		Bt_1	37-79	65.2	26.0	8.8	C	1.56	(2.5YR 3/4)	nd	s,firm,vs,vp	s,m,ab
		Bt_2	79-135	63.2	22.0	14.8	C	1.67	(2.5YR 3/6)	(2.5YR 4/6)	firm, vs,vp	s,m,ab
		Bt_3	135-160+	61.2	22.0	16.8	C	1.47	(2.5YR 3/4)	(2.5YR 3/6)	s,firm,vs,vp	s,m,ab

1. Texture: SL = sandy loam, LS = loamy sand, SCL = sandy clay loam, C = clay. 2. Colour: db = dark brown, sb = strong brown, yr = yellowish red, vdgb = very dark greyish brown, rd = reddish brown, vdb =very dark brown, gb = greyish brown, drb = dark reddish brown, dyb = dull yellowish brown. 3. Consistence: eha = extremely hard, ha= hard, vfr = very friable, vha = very hard, Lo= loose, fr = friable, fir = firm, vs =very stick, vp =very plastic, s = sticky, p= plastic, ss = slightly sticky, sp = slightly plastic, ns = non-sticky, np = non-plastic. 4. Structure: w =weak -fandm = fine and medium, fandc = fine and coarse, m-fandm = moderate fine and medium, s-mandc = strong medium and coarse, m-mandc = moderate medium and coarse, sbk = sub angular blocky

with dark reddish-brown colour topsoil when moist. The topography was gently sloping with a slope of < 2% and the altitude of 1353 m.a.s.l favourable for cassava production (Howler *et al*., 2001). The soil structure and consistency were moderately strong. The latter being friable to firm when moist, very stick and plastic when wet hard to plough when the soil is completely wet. Additionally, the profile had a presence of common and distinct clay cutans in the subsurface indication of actively soil development processes (Tenga *et al*., 2018). The soil was clay dominated throughout, and topsoil was moderately compacted with a bulk density range of 1.4 – 1.6 g/cm^3 satisfactory for cassava root growth and penetration.

2.4 Selected Chemical Properties of Representative Soil Profiles of the Cassava Growing areas in the Lake Zone, Tanzania

The selected chemical properties of the representative study soil profiles of Biharamulo, Sengerema and Butiama at cassava growing areas of the Lake Zone of Tanzania are presented Table 2.2 and appendices 1, 2 and 3.

2.4.1 Runazi - Biharamulo soil profile

Most mineral plant nutrients are readily available when soil pH ranges between 6.0 and 7.5 (Hazelton and Murphy, 2016). Additionally, cassava grows best in a pH range of 5.5–6.5 (Titus and Seesahai, 2011). The soils pH ranged from 5.24 – 5.68 which is favourable for cassava cultivation (Titus and Seesahai, 2011). According to the rating of Hazelton and Murphy (2016), the topsoil with a pH of 5.5 was rated as strongly acidic indicating the leaching of the basic cations and weathering processes. The same was observed in Nigeria by Abah and Petja (2016) and Akpan-Idiok *et al.* (2013). Cassava is an acid-tolerant crop (Salami and Sangoyomi, 2013); therefore soil pH would not be a constraint to growth (Adeyolanu *et al*., 2017). Although, yield production will decrease due to the fact that low pH soils affect the availability of most essential plant nutrients (Jones, 2012).

The soil available phosphorus ranged from 1.00 - 4.35 mg/kg soil decreasing with the increase in depth from topsoil to subsoil. According to Landon (2012) the available phosphorus of <15 mg/kg soil is considered deficient due to continuous cultivation without replenishment. Fertilizer response is most likely and yield is expected to increase upon adequate phosphate fertilizer application especially for early cassava root development and enhance water uptake in moisture stress conditions (Imakumbili *et al*., 2019).

The exchangeable calcium was decreasing with the increase of depth from the topsoil to the subsoil. Calcium was 5.37 cmol (+)/kg in the topsoil while the subsoil was 1.72 cmol (+)/kg soil. Based on Hazelton and murphy (2016) rating, exchangeable calcium was rated moderate sufficient to sustain cassava production. The soil exchangeable Magnesium was varying the profile in a range of 0.11 cmol (+)/kg soil to 0.34 cmol (+)/kg soil. The topsoil was rated as low with 0.24 cmol (+)/kg soil. Based on Landon (2014) low level of magnesium might have been associated with calcium and potassium interactions in the soil. The soil Potassium was in a range of 0.2 - 0.49 cmol (+)/kg increasing with depth from the topsoil to subsoil due to leaching. According to Hazelton and murphy (2016) and Landon (2014) potassium was rated as low with 0.2 cmol (+)/kg.

The soil total nitrogen was rated according to Hazelton and murphy (2016) and Landon (2014) as very low which was < 0.10 % N in both the topsoil and subsoil. The soil organic carbon and organic matter were also very low with < 0.6 OC % and < 1.0 OM % respectively. The low-level of soil organic matter answers the question of low soil nitrogen due to high rate of decomposition. The low level of nitrogen and soil organic carbon might have contributed by a high rate of mineralisation and mining of nitrogen reserves due to continuous cassava production. This has been observed in other studies in

Nigeria by Abah and Petja (2016) and Akpan-Idiok *et al.* (2013). The C: N ratio measures the amount of reserved nitrogen content of organic materials (Hazelton and Murphy, 2014), The C: N ratio was low (<10) implying that the rate of decomposition of soil organic matter is high and N is available for the plant use.

The CEC of this soil was in a range of 9.00 to 15.00 cmol (+)/kg soil. The topsoil and subsoil were rated moderately with 13.00 cmol (+)/kg soil and 15.00 cmol (+)/kg soil respectively. The percentage base saturation was also rated as moderate with 53.25 % in the topsoil and low percentage base saturation of 25.33 % in the subsoil. According to Uwingabire *et al.* (2016), percentage potentially basic cations (PBS) above 20% is an indicator of the number of soluble forms of basic nutrients in the soil. This indicates the potentially basic cations in the soil exchange site despite the low nutrient reserve in the soil environment (Gbadegesin *et al*., 2011) and should not be used for fertilizer or lime recommendations (Horneck *et al*., 2011). A low percentage base saturation level is the characteristic of leachable acid soils with the presence of potentially toxic elements such as aluminium and manganese (Rahman *et al*., 2018).

2.4.2 Kijuka - Sengerema soil profile

The soil pH in water ranged from 5.04 to 6.48 and the topsoil was 5.43 (Table 2.2). The pH was rated as strongly acidic with the possibilities of Aluminium, copper, zinc and iron (Landon, 2014). Although cassava tolerates low soil pH, application of lime is inevitable for high cassava growth and productivity. Based on the rating of Hazelton and Murphy (2016) and London (2014) extractable soil P was rated low with 3.26 mg/kg soil. The low soil phosphorus can be explained by soil fixation attributed to low pH and crop removal.

Table 2.2: Selected chemical characteristics of representative soil profiles of the cassava growing areas in the Lake Zone, Tanzania

Site/profile No.	Horizon	Depth (cm)	pH		SOC %	SOM %	C: N ratio	Total N (%)	Extractable P. (mg/kg)	Exchangeable cations cmol (+)/kg Soil				CEC cmol (+)/kg Soil	TEB cmol (+)/kg	% BS
			H_2O	KCl						Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}			
Biharamulo	Ap	0-45	5.47	4.82	0.28	0.48	5.6	0.05	4.35	2.69	0.24	1.11	0.20	13.0	6.92	53.3
(BMLO-P1)	BA	45-85	5.68	4.55	0.34	0.59	8.5	0.04	2.30	4.01	0.34	1.09	0.29	12.8	5.73	44.8
	B1	85-110	5.24	4.23	0.28	0.48	9.3	0.03	1.00	2.22	0.11	1.08	0.39	15.0	3.80	22.7
	B2w	110-170+	2.654	4.15	0.36	0.62	7.2	0.05	1.05	1.72	0.21	1.05	0.49	9.0	3.47	38.6
Sengerema	Ap	0-10	6.48	5.43	0.68	1.18	9.7	0.07	3.26	5.75	0.26	1.09	0.35	14.0	7.45	53.2
(SENGM-P2)	BA	18537	5.70	4.47	0.28	0.48	5.6	0.05	3.50	2.21	0.19	1.05	0.17	16.2	3.61	22.3
	B1	50-110	5.21	4.15	0.38	0.66	9.5	0.04	2.40	1.57	0.23	1.08	0.12	6.0	3.01	50.1
	B2	110-140	5.04	4.12	0.32	0.55	8.0	0.04	2.00	0.76	0.13	1.07	0.12	10.0	1.04	20.8
	Bcw	140-180+	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Butiama	Ap	0-20	5.93	5.05	2.73	2.35	14.4	0.19	4.10	17.34	1.34	1.06	0.95	32.0	20.69	62.4
(BTMA-P2)	BA	20-37	5.70	4.47	1.62	2.80	10.8	0.15	0.90	10.62	0.58	4.40	0.35	35.6	15.94	44.8
	Bt1	37-79	5.80	4.59	0.76	1.31	6.3	0.12	0.55	10.59	0.58	1.07	0.31	24.8	12.55	50.6
	Bt2	79-135	6.30	4.79	0.84	1.45	8.4	0.10	0.60	10.15	0.58	1.09	0.33	22.0	12.14	55.2
	Bt3	135-160+	6.64	5.04	0.76	1.31	8.4	0.09	0.75	10.90	0.57	1.09	0.28	26.4	11.42	48.7

This is consistent with the study reported by Gbadegesin *et al.* (2011) in the coastal area of cassava production in Nigeria. Cassava response and yield increase is expected with an adequate and balanced phosphate fertilizer application (Imakumbili *et al*., 2019).

The soil organic carbon is considered nutrient reserve and binding sites especially for plant nutrients (Salami and Sangoyomi, 2013). The soil organic carbon was rated very low with 0.68 % due to the rapid microbial activities and crop removal. The low soil organic carbon is related to low total nitrogen of < 0.10 % N as in Biharamulo soils. The ratio of carbon to nitrogen (C: N) was low (< 10) indicating good quality organic materials and there is high rate of decomposition activities resulting to nitrogen mineralization (Hazelton and Murphy, 2016).

The soil exchangeable sodium (Na^{+}) was rated high with 1.09 cmol (+)/kg soil in the topsoil. It's the fact that Magnesium (Mg^{2+}) deficiency in the soil is not common and can be attributed by the interaction of calcium and potassium in the exchange site (Landon, 2014). The soil exchangeable magnesium and potassium was rated low with 0.26 cmol (+)/kg soil and moderate with 0.35 in the topsoil both decreasing with the increase in depth respectively (Landon, 2014 and Hazelton and murphy, 2016). The soil cation exchange capacity (CEC) is the measures of soil capability to retain plant nutrients in the exchange site (Horneck *et al*., 2011). The CEC varied in the soil profile with a range of 6.00 to 14.00 cmol (+)/kg soil (Table 2.2). The cation exchange capacity at the topsoil was 14.00 cmol (+)/kg soil and that of the subsoil was found to be 16.00 cmol (+)/kg soil. High clay or organic matter content the soil contains the higher the CEC (Horneck *et al*., 2011). According to Hazelton and Murphy (2016), the CEC of this soil was high in both topsoil and subsoil. The percentage base saturation was also rated as moderate with 53.20 % in the topsoil and low percentage base saturation of 22.33 % in the subsoil. This indicates the potentially basic cations in the soil exchange site, weakly leachable despite the low nutrient reserve in the soil environment due to the adsorption capacity of the soil (Gbadegesin *et al*., 2011).

2.4.3 Nyakiswa - Butiama soil profile

The soil pH in water was moderately acidic with 5.93 in the topsoil while the subsoil was slightly acidic with 5.70 that are within tolerable ranges of cassava production (Titus and Seesahai, 2011). However, application of lime is inevitable for high cassava growth and productivity (Roy *et al.*, 2006). This is consistent with other studies reported by Roy *et al.* (2006) that cassava is grown in acidic soil of < 4.5 pH. The available soil P was low with < 7 mg/kg soil in the topsoil and subsoil respectively. The low level of the soil is due to fixation attributed to the low soil pH. The soil organic carbon was high with 2.73 % in the topsoil and moderate with 1.62 % at the subsurface soils, slightly decreasing with the increasing soil depth (Hazelton and Murphy (2016). The soil organic matter also ranged from high with 4.70 % topsoil to medium with 2.80 % in the subsurface soils implying that the soil is in goo healthy. However, the soil nitrogen was low with 0.19 % in the top and 0.15 % in the subsoil respectively. The soil is deficient of nitrogen and needs to be replenished for cassava production (Abah and Petja, 2016). The carbon to nitrogen ratio low (<10) in the topsoil indicating good organic materials for decomposition, despite the low level of nitrogen in the soil as it is attributed to nitrogen removal through cropping, volatilization and leaching (Abah and Petja, 2016).

According to Landon (2014), calcium deficiency is induced by low soil pH of < 5.5 and a large amount of natural potassium or input. The exchangeable calcium was in a ranged from 10.15 cmol (+)/kg soil to 17.35 cmol (+)/kg. Calcium in the topsoil was 17.35 cmol (+)/kg and the subsoil was 10.62 cmol (+)/kg. Based on the rating according to Hazelton and Murphy (2016) was high throughout the profile. There were no significant differences between the topsoil and subsoil values. Magnesium deficiency is believed to be induced by cation imbalances with calcium, potassium and high ratio of Mg: Ca > 5.1(Landon, 2014). The exchangeable magnesium varied from moderate in the topsoil with 1.34 cmol (+)/kg soil to low with 0.58 cmol (+)/kg soil in the upper and subsurface soils. Soil exchangeable sodium (Na^+) was also high (> 2 cmol (+)/kg soil) in the top and subsoil.

The soil exchangeable potassium ranged from 0.28 cmol (+)/kg soil to 0.95 cmol (+)/kg soil. Potassium was high in the topsoil with 0.95 cmol (+)/kg soil decreasing along with the profile with depth. Potassium is very important in cassava root tuber formation through transporting the photosynthates and assimilates to the storage tuberous root (Howeler, 2011). Without adequate K^+ application, cassava yield is reduced. Despite low soil plant nutrients, the soil had a high cation exchange capacity (CEC) of 32.00 cmol (+)/kg soil in topsoil and moderate percentage base saturation of 64.65 (Table 2.2) indicating the potentially basic cations in the soil exchange site.

2.5 Soil Classification

using the Soil Survey Staff , United States Department of Agriculture (Soil Survey Staff, 2014) soils of were classified to the subgroup level, and the world reference soil base (IUSS Working Group WRB, 2015) reference soil groups (RSG) (TIER 2) level by using the soil morphological and laboratory data (Table 2.1 and 2.2). The diagnostic horizons and features which were identified and used for classification into the two systems are presented in Table 2.3. According to Soil Survey Staff (2014), the soil profile at Runazi village at Biharamulo district site was characterized by an abrupt textural change, an ochric epipedon and cambic subsurface surface horizon.

Table 2.3: The identified salient diagnostic horizons and features used for soil classification of the study sites of the cassava growing soils of the Lake Zone, Tanzania according to USDA Soil Taxonomy (Soil Survey Staff, 2014) and IUSS Working Group WRB (2015)

Site/profile	**USDA Soil Taxonomy (Soil Survey Staff, 2014)**					**IUSS Working Group WRB (2015)**				
	Diagnostic horizon/Features	Soil order	Suborder	Great group	Sub group	Diagnostic horizons	RSG - Tier-1	Principal qualifiers	Supplementary qualifiers	WRB soil name Tier- 2
Runazi village - Biharamulo (BMLO-P1)	Ochric epipedon; Cambic subsurface horizon	Inceptisols	Ustepts	Dystrustepts	Fluventic Dystrustepts	*Ochric A Horizon; Kandi Cambic B horizon*	Cambisol	Fluvic, Dystric.	Ochric	Fluvic, Dystric Cambisol (Ochric)
Kijuka Village - Sengerema (SENGM-P2)	Ochric Epipedon; CAMBIC subsurface	Inceptisols	Ustepts,	Dystrustepts	Fluventic Dystrustepts	*Ochric A Horizon; Cambic B horizon*	Cambisol	Fluvic, Dystric.	Ochric	Fluvic, Dystric Cambisol (Ochric)
Nyakiswa village - Butiama (BTMA-P2)	Ochric epipdedon; Argillic horizon	Ultisol	Ustults	Haplustults,	Kanhaplic Haplustults	*Cambic A Horizon; ferralic B horizon*	Alisol	Abruptic, Haplic	Cutonic Ochric	Haplic, Abruptic, Alisol (Cutonic Ochric)

The soil had Ustic moisture and Isohyperthemic soil temperature regime. The profile was also characterized by weathered mineral below the subsurface soil horizon. Based on these properties, the soil was classified as Fluventic Dystrustepts according to soil taxonomy of Soil Survey Staff (2014) and as Fluvic Dystric Cambisol (Ochric).according to IUSS Working Group WRB (2015).

According to Soil Survey Staff (2014), the soil profile of Kijuka village at Sengerema district was characterized by an ochric epipedon and cambic subsurface surface horizon. The soil had Ustic moisture and Isohyperthemic soil temperature regime. The profile was also characterized by petroferic contact (lateritic materials) at 140 cm depth subsurface soil horizon. Based on these properties, the soil was classified as Fluventic Dystrustepts according to soil taxonomy of Soil Survey Staff (2014) and as Fluvic Dystric Cambisol (Ochric) according to IUSS Working Group WRB (2015).

According to Soil Survey Staff (2014), the soil profile of Nyakiswa village at Butiama site was characterized by an ochric epipedon and argillic subsurface surface horizon. The soil had Ustic moisture and Isohyperthemic soil temperature regime. The profile was also characterized by weathered mineral below the subsurface soil horizon. Based on these properties, the soil was classified as Kanhaplic Haplustults according to soil taxonomy of Soil Survey Staff (2014) and as Haplic Abruptic Alisol (Cutonic, Ochric) according to IUSS Working Group WRB (2015).

2.6.1 Fertility status of cassava growing soils of Runazi village in Biharamulo District

The chemical properties of the representative soil profiles used to assess the fertility status of soils in cassava growing areas in Lake Zone, Tanzania are presented in Table 2.5.

The soil bulk density is the measure of compactness to root growth and developments. According to Arshad and Grossman (1996), it reflects soil's ability for structural support, water and solute movement, and soil aeration. The ideal bulk density for crop growth is < 1.6 g/cm^3 (Arshad and Grossman, 1996). Biharamulo soils were within the range of acceptable ideal bulk density of 1.6 g/cm^3 for cassava growth. According to McKenzie *et al*. (2004), soils with high BD (>1.6 g/cm^3) restrict crop root growth and subsequently low yield. High soil bulk density decreases soil porosity, restricts root growth, and impairs water and air movement through the soil (Arshad and Grossman, 1996).

Soil pH is an important parameter that controls most of the chemical and biochemical processes in the soil (Oshunsanya, 2018). Soil pH regulates the availability of essential plant nutrients (Jones, 2012), through controlling their available chemical forms. According to Oshunsanya (2018), the optimum range of soil pH for most agricultural crops is between 5.5 and 7.5, however, cassava is known to thrive to a wide range of soil pH (Salami and Sangoyomi, 2013). The soil pH of Biharamulo site was rated as acidic with a pH value of 5.5 which is favourable for cassava cultivation (Titus and Seesahai, 2011). Acidic soils with a pH value of 5.5 are known to be susceptible to leaching of the basic cations, fixation of soil phosphorus, nitrification and impaired some of the microbial processes (Akpan-Idiok *et al.,* 2013).

Adequate P in the soil is essential for cassava growth and productivity as it plays major roles in the phosphorylation, photosynthesis, respiration and the synthesis of carbohydrates (Howeler, 2011). It is believed that cassava makes good use of available P in the due to its efficient root uptake (Roy *et al.*, 2006). According to Landon (2012) the available phosphorus of < 15 mg/kg soil is considered deficient due to continuous cultivation without replenishment; however, cassava can still grow with minimum yield. It is the fact that cassava requires a high amount of P for growth and productivity. This has been observed elsewhere in Mozambique by Cuvaca *et al*. (2017) where P application increased tuber yield. Fertilizer response is most likely and yield is expected to increase upon adequate phosphate fertilizer application (Imakumbili *et al*. 2019). Based on Hazelton and murphy (2016) rating, exchangeable calcium was sufficient to sustain cassava production. The soil magnesium was low with 0.24 cmol (+)/kg soil. Based on Landon (2014) low level of magnesium is attributed to cation imbalances especially calcium and potassium in the soil. However, the nature of the parent material on which soil has formed can contribute to low magnesium in the soil (Uwingabire *et al*., 2916).

Exchangeable potassium level in this soil was low with 0.2 cmol (+)/kg. Cassava is known as a nutrient miner extracting more nutrients from the soil especially K^+ than any other crop (Howeler, 2011). This suggests that the crop will not be supported for productions and crop response to potassium fertilizer application is possible. The total nitrogen was also low < 0.10 % N. This is explained by the low level of soil pH of 5.5, reduced rate of microbial decomposition and low organic matter. The results are consistent with the results obtained by Uwingabire *et al*. (2016). The soil organic carbon was low < 0.6 OC % as well as organic matter with < 1.0 OM %. The low levels of SOC and SOM observed may be attributed to low pH with reduced microbial activities in the soil. The ratio of carbon to nitrogen (C: N) was observed to be low <10 implying that the rate of decomposition is high and N is easily released for plant uptake. The cation exchange capacity of the soil (CEC) of the soil was moderate with 13 cmol (+)/ kg^{-1} soil). The moderate CEC may be attributed to the type of clay in the soil. The percentage base saturation was also moderate (40 - 60 %) which indicates that the soil is moderately leached. This indicates the potential basic cations in the soil exchange site despite the low nutrient reserve in the soil environment which may be attributed to the adsorption capacity of the soil (Gbadegesin *et al*., 2011).

Table 2.4: Chemical characteristics used to assess fertility status of soils in cassava growing areas in Lake Zone, Tanzania

Parameters		Sites Runazi-Biharamulo	Kijuka-Sengerema	Nyakiswa-Butiama
pH	(in H_2O)	5.50	6.50	5.90
Particle size	Clay (%)	8.40	23.20	53.20
analysis	Silt (%)	10.80	4.00	30.00
	Sand (%)	80.80	72.80	16.80
Textural class		SL	SCL	C
Bulk density	(kgm^{-3})	1.60	1.79	1.50
Organic carbon (%)	(%)	0.28	0.68	2.70
Organic matter (%)	(%)	0.48	1.18	2.40
C: N ratio		5.60	9.70	14.40
Total N	(%)	0.05	0.07	0.20
Extractable P	(mg/kg)	4.35	3.26	4.10
Exchangeable	Ca^{2+}	2.69	5.75	17.30
cations	Mg^{2+}	0.24	0.26	1.30
(cmol (+) kg-1	Na^{+}	1.11	1.09	1.10
	K^{+}	0.20	0.35	1.00
CEC by NH4OAc	(cmol(+)kg^{-1}	13.00	14.00	32.00
TEB	(cmol(+)kg^{-1}	6.92	7.45	20.70
Base saturation	(%)	53.25	53.20	62.40

Textural classes: SL = Sandy loam; SCL = Sand clay loam; C = clay
CEC = Cation exchange capacity; TEB = Total exchangeable bases

2.6.2 Fertility status of cassava growing soils of Kijuka in Sengerema District

The ideal bulk density for crop growth is < 1.6 g/cm^3 (Arshad and Grossman, 1996). Sengerema soils were compacted with a bulk density of 1.79 g/cm^3 restricting cassava growths. Soils with high BD (>1.6 g/cm^3) restrict crop root growth and subsequently low yield (McKenzie *et al*., 2004). High soil bulk density decreases soil porosity, restricts root growth, and impairs water and air movement through the soil (Arshad and Grossman, 1996).

Soil pH regulates the availability of essential plant nutrients (Jones, 2012). According to Oshunsanya (2018), the optimum range of soil pH for most agricultural crops is between 5.5 and 7.5, however, cassava is known to thrive to a wide range of soil pH (Salami and Sangoyomi, 2013). The soil pH of Sengerema was acidic with a pH value of 6.48 which is within the of cassava growth (Titus and Seesahai, 2011). However, acidic soils are susceptible to leaching of the basic cations, fixation of soil phosphorus, nitrification and microbial activities are reduced (Akpan-Idiok *et al.*, 2013).

The soils of Sengerema were low in soil P with 3.26 mg/kg soil. This may be due to fixation attributed by low soil pH, crop removal through continuous cropping without adequate replenishment. Phosphorus plays major roles in the Phosphorylation, photosynthesis, respiration and the synthesis of carbohydrates (Howeler, 2011). It is believed that cassava makes good use of available P in the due to its efficient root uptake (Roy *et al.*, 2006). According to Landon (2012) the available phosphorus of < 15 mg/kg soil is considered deficient due to continuous cultivation without replenishment; however, cassava can still grow with reduced yield. Cassava requires a high amount of P for growth and productivity. This has been observed elsewhere in Mozambique by Cuvaca *et al.* (2017) where P application increased tuber yield. Fertilizer response is most likely and yield is expected to increase upon adequate phosphate fertilizer application (Imakumbili *et al.*, 2019). Based on Hazelton and murphy (2016) rating, exchangeable calcium was sufficient to sustain cassava production. The soil magnesium was low with 0.26 cmol (+)/kg soil. Based on Landon (2014) low level of magnesium can be attributed by interactions between calcium and potassium in the soil. Also, crop removal and the parent material on which soil has formed can contribute to low magnesium in the soil (Uwingabire *et al.*, 2916).

Exchangeable potassium level in this soil was also low with 0.35 cmol (+)/kg. Cassava extracts more nutrients from the soil especially K^+ than any other crop (Howeler, 2011). This suggests that the soil will not support cassava productions unless replenishment is done, and crop response to potassium fertilizer application is possible. The total nitrogen was also low < 0.10 % N. This is explained by the low level of soil pH of 5.5, reduced rate of microbial decomposition and low organic matter. The soil organic carbon (SOC) was low with 0.68 % as well as organic matter (SOM) with < 1.0 %. The low levels of SOC and SOM observed may be attributed to low pH with reduced microbial activities in the soil (Uwingabire *et al*., 2916). The ratio of carbon to nitrogen (C: N) was observed to be low <10 implying that the rate of decomposition is high and N is easily released for plant uptake. The cation exchange capacity of the soil (CEC) of the soil was moderate with 14 cmol (+)/ kg soil). The moderate CEC may be attributed to the type of clay in the soil. The percentage base saturation was also moderate (40 - 60 %) which indicates that the soil is moderately leached. This indicates the potential basic cations in the soil exchange site despite the low nutrient reserve in the soil environment which may be attributed to the adsorption capacity of the soil (Gbadegesin *et al*., 2011).

2.6.3 Fertility status of cassava growing soils of Nyakiswa village in Butiama District

The soils bulk density (BD) reflects soil's ability for structural support, water and solute movement, and soil aeration (Arshad and Grossman, 1996). The ideal bulk density for crop growth is < 1.6 g/cm^3 (Arshad and Grossman, 1996). Butiama soils were within the range of acceptable ideal bulk density of 1.53 g/cm^3 for cassava growth. According to McKenzie *et al*. (2004), high soils BD >1.6 g/cm^3 impairs root crop growth. High soil bulk density decreases soil porosity and impairs water and air movement through the soil (Arshad and Grossman, 1996).

According to Oshunsanya (2018), soil pH controls most of the chemical and biochemical processes in the soil. Soil pH regulates the availability of essential plant nutrients (Jones, 2012). According to Oshunsanya (2018), the optimum range of soil pH for most agricultural crops is between 5.5 and 7.5, however, cassava can grow in low soil pH (Salami and Sangoyomi, 2013). The soil pH of Butiama was acidic with a pH value of 5.93 which is within the range of cassava growth (Titus and Seesahai, 2011). Acidic soils with a pH value of 5.93 are known to be susceptible to leaching of the basic cations, fixation of soil phosphorus, nitrification and impaired some of the microbial processes (Akpan-Idiok *et al.*, 2013).

Adequate P in the soil is essential for cassava growth and productivity as it plays major roles in starch synthesis (Howeler, 2011). According to Landon (2014) the available phosphorus of <15 mg/kg soil is considered deficient. The deficient may be due to continuous cultivation without replenishment and fixation. The soil needs to be replenished with phosphate fertilizer for normal cassava production. This has been observed elsewhere in Mozambique by Cuvaca *et al*. (2017) that P application increased tuber yield. Fertilizer response is most likely and yield is expected to increase upon adequate phosphate fertilizer application (Imakumbili *et al*., 2019). Based on Hazelton and murphy (2016), exchangeable calcium was sufficient with 17.34 cmol (+)/kg soil to sustain cassava production. The soil magnesium was low with 0.24 cmol (+)/kg soil. The low level of magnesium may be attributed to cation imbalances especially calcium and potassium in the soil, crop removal and erosion (Landon, 2014). However, the parent material on which soil has formed can contribute to low magnesium in the soil (Uwingabire *et al*., 2916).

Exchangeable potassium level in this soil was high with 0.95 cmol (+)/kg. Cassava requires balanced nutrients with most K^+ than any other crop (Howeler, 2011). This suggests that crop response to potassium fertilizer application is possible. The total nitrogen was high with 0.19 % N. This is explained by the low level of soil pH of 5.93, reduced rate of microbial decomposition and low organic matter (Uwingabire *et al*., 2016). The soil organic carbon was low with 2.73 OC % as well as organic matter with 4.7 OM %. The low levels of SOC and SOM observed may be attributed to low pH with reduced microbial activities in the soil. The ratio of carbon to nitrogen (C: N) was observed to be good which is 14 implying high rate of decomposition and N is easily released for plant uptake. The cation exchange capacity of the soil (CEC) of the soil was moderate with 32.0 cmol (+)/ kg^{-1} soil. The high CEC may be attributed to the type of clay in the soil. The percentage base saturation was also high with 60 % indicating that the soil is weakly leached. This indicates the potential basic cations in the soil exchange site despite the low nutrient reserve in the soil environment which may be attributed to the adsorption capacity of the soil (Gbadegesin *et al*., 2011).

2.7 Conclusions and Recommendations

The soils of Biharamulo and Sengerema were classified as Fluventic Dystrustepts of the Soil Survey Staff (2014) and as Fluvic Dystric Cambisol (Ochric) according to the IUSS Working Group WRB (2015). This is because the soil profile was characterized by an abrupt textural change, an ochric epipedon and cambic subsurface surface horizon. The soils had Ustic moisture regime and Isohyperthemic soil temperature regime. Also, the soils of Sengerema were characterized by petroferic contact (lateritic materials) at 140 cm depth subsurface soil horizon. The soil of Butiama was classified as Kanhaplic Haplustults of the Soil Survey Staff (2014) and as Haplic Abruptic Alisol (Cutonic, Ochric) of IUSS Working Group WRB (2015). The profile is characterized by ochric epipedon and argillic subsurface with Ustic moisture regime and Isohyperthemic temperature regime.

Although cassava production has been reported to do well in soils with low fertility, however, application of fertilizer to boost the fertility is inevitable among the management options in order to increase cassava root yield and quality in the Lake Zone. The soils of the study area were low fertile with high to moderate bulk density, low soil pH, low available P, low TN, low OC and low OM, low exchangeable bases, low levels of CEC, and high to moderate base saturation. Therefore there is a need to study the response of fertilizer application on cassava growth, yield and root quality for soil fertilizer management options in the Lake Zone of Tanzania. Since the findings of this study were based on identified representative soil profiles, a more detailed study on the characteristics of the soils of study area including composite topsoil sampling is recommended.

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CHAPTER THREE

3.0 THE EFFECTS OF N, P, and K ON GROWTH, YIELD AND ROOT QUALITY OF CASSAVA (*Manihot esculenta Crantz*) IN THE LAKE ZONE OF TANZANIA

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ABSTRACT

A study was carried out in the Lake Zone to evaluate the effects of N, P and K on the growth, yield and root quality of cassava (*Manihot esculenta* Crantz). Eleven treatments in a form of nutrient omission were laid down in a randomized complete block design with four replications at each site. The treatments were control, full NPK (150-40-180 Kg/ha), half_NPK (75-20-90 Kg/ha), NPK (150-40-180)+ S + Ca+ Mg+ Zn +B (16.6-10-10-5-5), PK (0-40-180), NK (150-0-180), NP (150-40-0), half_N+PK (75-40-180), half_P+NK (150-20-180), half_K+NP (150-40-90), and half_ K+ P (0-40-90). There was a significant increase of cassava root yield and yield components at $P < 0.05$ across all sites. In Runazi-Biharamulo site, the application of NPK treatment at the rate of 150:0:180 kg ha^{-1} significantly increased fresh root yield to 23.35 tha^{-1} equal to 77 % compared to unfertilized plots with 11.73 tha^{-1}. The marketable fresh root yield was also significantly increased by the application of N, P and K treatments at $P < 0.05$. At Sengerema, the fresh root yield, and yield components were not significantly increased by the application of N, P and K at $P > 0.05$. However, fertilizer application plots were better than the control. At Butiama, there was a significant increase in growth between treatments on fresh root yield, Harvesting index and marketable at $P < 0.05$. In all sites, tuber root yield was observed to be higher at Biharamulo with 23.15 tha^{-1} compared to Butiama with 18.88 tha^{-1} and Sengerema with 17.64 tha^{-1}. Yield response to fertilizers between sites varied due to the variations of soils and environmental conditions. Therefore, there is a need to carry out more research on soil constraints limiting the response of cassava to fertilizer application.

Keywords: *Fertilizer application, Cassava growth, yield, and root quality*.

3.1 INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is commonly grown by smallholder farmers for its starchy tuberous roots (El-sharkawy, 2003), and perform well, even under marginal soils across the tropics and sub-tropics (Howeler, 1991). According to Agbaje and Akinlosotu (2004), cassava is grown continuously without external inputs but still produces reasonable yields. However, the addition of fertilizers increases growth and root yield (Howeler, 2002).

Cassava has the ability to extracts more nutrients from the soils than other crops (Howeler, 2002). However, for high cassava root production, adequate and balanced mineral nutrients application is compulsory (Howeler, 2002). However, fertilizer use in cassava production is rare because of farmers considering it uneconomical (Fermont *et al.*, 2009). Recent researches in Africa by Fermont *et al*. (2009), Howeler (2002), Ukaoma and Ogbonnaya (2013) and Uwah *et al*. (2013) showed that cassavas respond well to N, P and K applications. There is however limited information on the response of cassava to mineral fertilizers especially in the Lake Zone of Tanzania. Therefore, the objectives of this study were to evaluate the response of cassava root yield to N, P and K fertilizer rates coupled by micronutrients and determine the effects of fertilizer on the growth parameters and crop quality to the smallholder cassava farmers in the Lake Zone of Tanzania.

3.2 Materials and Methods

3.2.1 Description of the study area

The experiments were planted in October to September of 2017 and 2018 in the cassava growing areas in the Lake Zone of Tanzania. The area experiences bimodal type of rainfall patterns that are short rains season (*Vuli*) which starts from September to January, and long rains seasons (*Masika*) which starts from February to early June. The annual rainfall ranges from 500 to 1 250 mm, and an average daily temperature of 28^{0}C. Using geospatial analysis the representative sites were selected based on climate, soils, and land cover information.

3.2.2 Experimental design

A total of eleven treatments in a form of nutrient omission trials (NOT) were laid in a randomized complete block design (RCBD) with four replicates so as to study the effectiveness of indigenous soil fertility and ascertain the limiting soil nutrients. The treatments comprised of two full rate of NPK (150 kg/ha N, 40 kg/ha P and 180 kg/ha K), half rate of NPK (75 kg/ha N, 20 kg/ha P and 90 kg/ha), NPK with addition of secondary nutrients (S, Ca, and Mg) at the rate of 16.6 kg/ha S, 10 kg/ha Ca, 10 kg/ha Mg, 5 kg/ha Zn, and 5 kg/ha, Three treatments with omission of N, P and K from NPK, control (without fertilizer addition), half N plus PK (N_{75}+$P_{40}K_{90}$), half K plus NP (K_{90}+$N_{150}P_{40}$), half P+NK (P_{20}+$N_{150}K_{180}$) and half_K+P (K_{90}+P_{80}) and the experimental plot size was 7 x 8 m = 56 m^2.

The test crop was “Mkombozi” cassava variety which is an improved high yielding, disease tolerant and early maturing cassava variety. This was planted on ridges 1 × 1 m giving a plant population of 10 000 ha^{-1}. The sources of N, P, and K were Urea, triple superphosphate (TSP 46% P_2O_5), and muriate of potash (KCL 50-62% K_2O) respectively whereas the sources of secondary macronutrients and micronutrients namely Ca $^{2+}$, S, Mg^{2+}, Zn^{2+} and B were $CaCO_3$, $MgSO_4$, $ZnSO_4$ and Borax respectively. All fertilizer treatments were applied in splits, except P, where 60 % was applied at one month after planting and the remaining 40% was at three months after planting. The phosphate fertilizer was applied as a basal dressing during planting. Fertilizers were banded around the plant stand to about 10-15 cm away from the plant stand and covered with soil to avoid volatilizations.

3.3 Data Collection

3.3.1 Climatic data

Climatic (rainfall and temperature) data were extracted from the NASA website using the GPS coordinate points obtained from each study site.

3.3.2 Cassava growth parameters

Harvested plant stands from the net plot (30 m^2) were used for assessing cassava growth, yield and root quality data during harvesting at twelve (12) months after planting. Plants were uprooted and separated into above-ground biomass (lignified, green stems, old planting stake, and fresh leaves), and below-ground biomass (the root weight). The average fresh weights of lignified stems, green stems, old planting stakes, and leaves were recorded using a digital beam balance in kilograms (kg). Plant height was taken using a graduated pole in centimetre (cm) from the top of the ridges to the top branches.

3.3.3 Fresh root yield assessment

Plants in a net plot were uprooted and weighed to obtain the average cassava fresh root weight in kilograms (kg) from the harvested stands using a digital weighing balance. Root size and shape was used as a criterion to separate the roots into marketable and non-marketable roots and weighed (kg). The weights from each plot were used to determine the fresh root yield in tha^{-1} using the following formula where 10 is a conversion factor:

$$Freshrootyield(t/ha) = \frac{10xF\text{resh root weight from cassava harvested stands}}{\text{Number of cassava plant stands harvested}}$$

3.3.4 Cassava dry matter and starch content assessment

The root dry matter contents (DMC) were estimated using at least 3kg cassava fresh roots randomly sampled from each harvested net plot (30 m^2) using the specific gravity method developed by Teye *et al.* (2011) and then calculated as DMC = 158.3 x Specific gravity – 142. Starch content (SC) was determined using the underwater weight method using the following formula as; CSC% = (SG-1.00906)/0.00485 % (Sungzikaw, 2008). Where CSC is cassava starch content and SG is the specific gravity.

3.3.5 Total Biomass (TB) and Harvesting Index (HI)

The root weight and total shoot weight (kg) were summed to total biomass (TB) where the root harvesting index (HI) was determined as a ratio using the cassava root weight to the total cassava biomass (roots plus shoots weight) multiplied by 100.

3.4 Statistical Data Analysis

The generated data were statistically subjected to the analysis of variance (ANOVA), and linear regressions were performed using the Generalized Linear Model (GLM). Treatment means for each site and season were separated and compared using the Student-Newman-Keuls Test (SNK) at P = 0.05 significance of Statistical Analysis Software (SAS version 9.4).

3.5 Results and Discussion

3.5.1 Rainfall and temperature variations at the study sites

Rainfall distribution at Biharamulo in the first season of 2017 was low with the annual average of 56 mm compared to the second season of 2018 with 132.67 mm and an average temperature of 24 ^{0}C (Fig. 3.1).

In Sengerema, annual rainfall distribution was low with 91.58 mm in the first season compared to 134 mm in the second season. Rainfall distribution slightly was increasing from short to long rain in both seasons with the annual average temperature of 24 ^{0}C (Fig. 3.2).

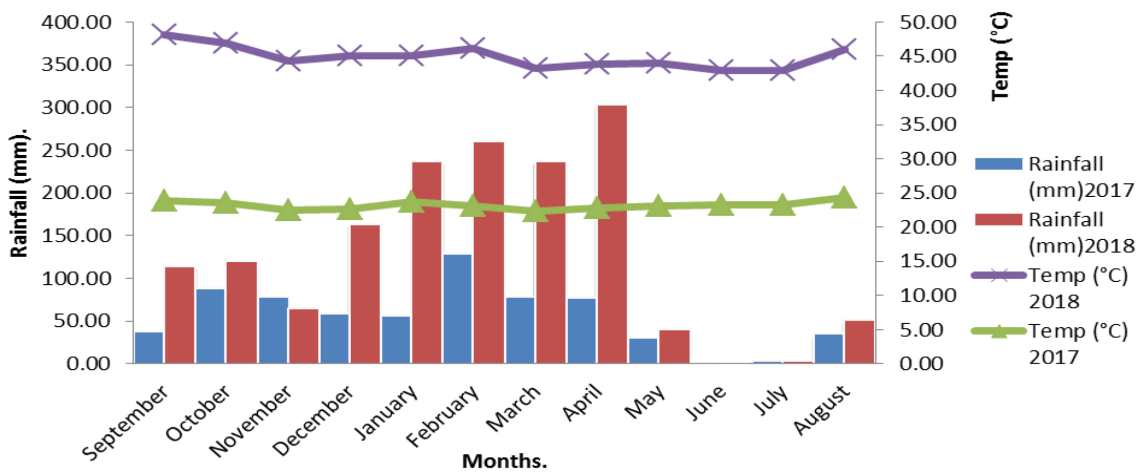

Figure 3.1: Annual rainfall and temperature at Runazi-Biharamulo site during the study period

The annual rainfall at Butiama was low with an average of 134 mm in the first season and high in the second season with an average of 191mm and an average temperature of 24 ^{0}C. Monthly rainfall was well distributed and was high at planting in the short rain, and slightly decreasing towards the long rain season. During the second season, rainfall was low at planting but slightly increasing towards *Masika* (Fig. 3.3).

3.5.2 Effect of N, P and K application on cassava growth, yield and root quality

From the analysis of variance ANOVA (Table 3.2a), all growth parameters were significantly increased by the application of N, P and K treatments across all locations at $P< 0.05$. There were significant differences between treatments on the increase of total fresh root yield, marketable root yield and total biomass at $P < 0.05$.

The dry matter and starch content were not significantly increased by the application of fertilizer at $P > 0.05$. However, they were significant differences were between sites and growing seasons at $P < 0.05$.

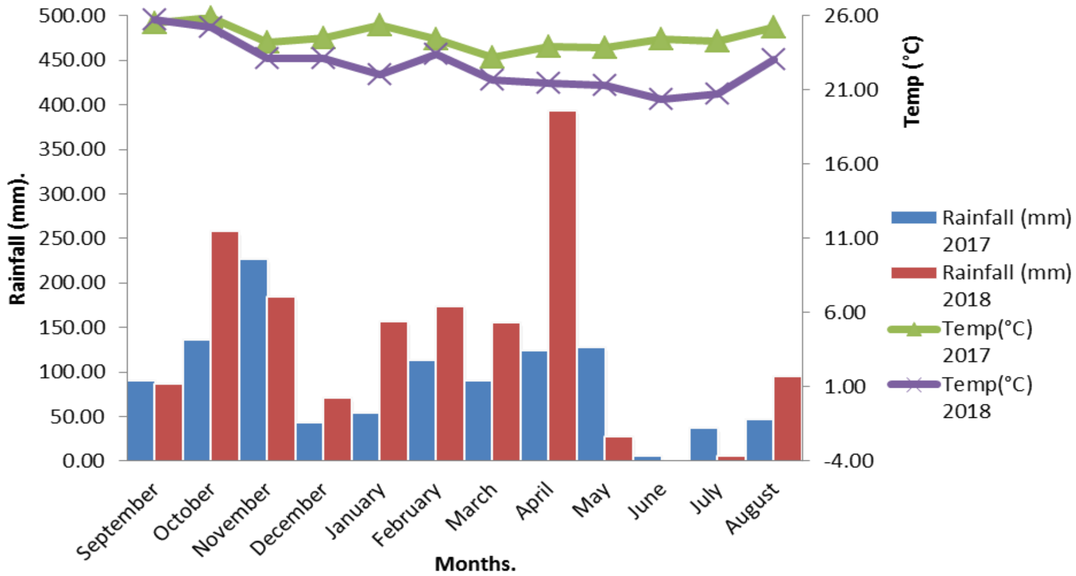

Figure 3.2: Annual rainfall and temperature at Kijuka-Sengerema site during the study period

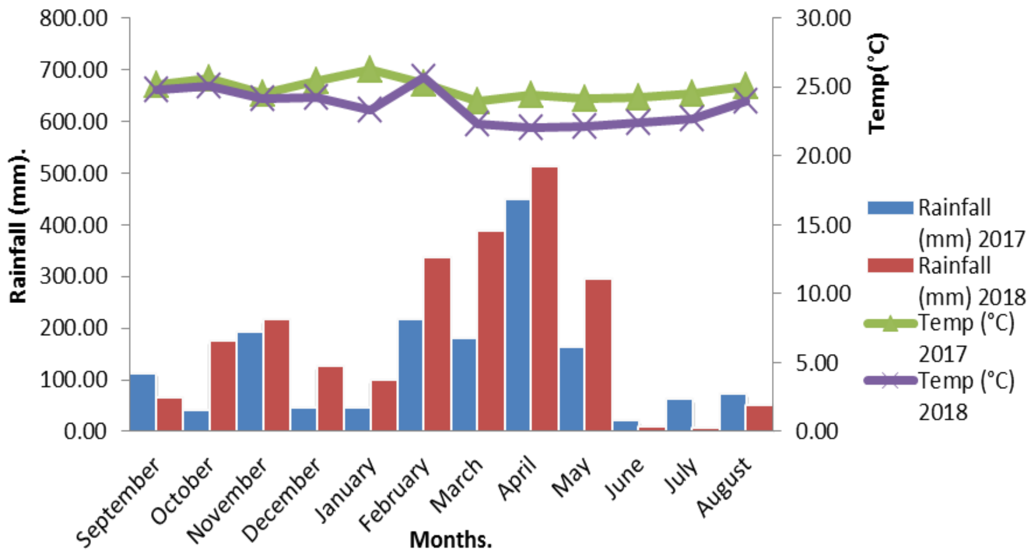

Figure 3.3: Annual rainfall and temperature at Nyakiswa-Butiama site during the study period

The results are consistent with previous studies by Fermont *et al*. (2009), Adjei-Nsiah and Isaak (2013) where NPK applications insignificantly increased the cassava starch and dry matter content, contrary to other findings by Agbaje and Akinlosotu (2004), and Boateng and Boadi (2010) which reported an increase of cassava starch and dry matter content. However, other studies by Benesi *et al.* (2004) stated that cassava root starch and dry matter are influenced by the genotype and environmental factors such as rainfall during the first three months before harvesting and when there is drought (Moreno and Gourdji, 2015). The first season was found to have the highest DMC and CSC of 33.23 % and 19.95 % respectively compared to the second season with 27.21 % and 12.36 %.

3.5.3 Runazi site at Biharamulo district

Cassava green stems, leaves, lignified stems and plant height were not significantly increased by the application of N, P and K at $P > 0.05$. This is attributed to environmental conditions, especially low rainfall distribution. Similar results were reported by Fermont *et al*. (2010) where there was low response to fertilizer on cassava growth with low rainfall distribution. Nevertheless, there was a relative increase in growth for N, P and K treatment compared to control (Table 3.3). This is also, attributed to inherently low soil fertility status of Biharamulo. The growth of lignified stems, green stems and plant height were only affected by the growing seasons at $P < 0.05$. This is also due to rainfall and temperatures differences in the two seasons. The applications NPK at a rate of 150:40:180 (kg ha^{-1}) in the first season increased the weight of lignified stems and green stems significantly from 7.26 tha^{-1}, and 5.03 tha^{-1} compared to the second season with 5.26 tha^{-1} and, 2.69 tha^{-1} respectively (Table 3.2). The application of half_P+NK at a rate of 150:20:180 kg ha^{-1} increased the leaves fresh weights from 1.25 tha^{-1} in the control plots

Table3.1a: The analysis of variance (ANOVA) for the effect of fertilizer application on cassava growth, yield and root quality for the 2016/17 and 2017/2018 growing seasons in the Lake Zone , Tanzania

Source of variation	DF	FRY t/ha	HI (%)	TFRtWt (t/ha)	Total biomass (t/ha)	DMC (%)	CSC (%)	Markt Yield (t/ha)	LgnStmFW (t/ha)	OldPltFW (t/ha)	LeavesFW (t/ha)	GrnStmFW (t/ha)
Trtments (T)	10	66.5*	3.1***	308.0*	320.3***	6.5ns	6.5ns	141.7***	4.01ns*	1.7*	0.8ns	0.6ns
Location (L)	2	445.4***	650.6***	2001.5***	220.7ns	380.1***	380.1***	600.9***	41.4**	22.4***	13.8***	139.1***
Season (S)	1	8.7ns	191.6**	8.2ns	690.6**	889.5***	889.5***	41.6ns	1.5ns	1.8ns	44.4***	230.1***
Rep(Trtments)	11	12.1ns	17.6ns	57.6ns	45.8ns	7.3ns	7.3ns	23.0ns	3.14ns	0.3ns	1.3ns	0.5ns
T*S	10	150.9***	122.0***	589.5***	233.1**	8.2ns	8.2ns	116.3***	3.5ns	0.2ns	0.84ns	2.02ns
T*L	20	29.4ns	43.7ns	169.6ns	53.3ns	8.5ns	8.5ns	26.1ns	5.5ns	0.5ns	0.53ns	1.1ns
T*L*S	20	90.0***	106.7***	497.6***	110.7ns	49.7***	49.7***	98.3***	9.3ns	0.1ns	2.4***	1.5ns

Note: *= significant, ***= highly significant.
LgnStmFW (tha^{-1}) = Lignified stem fresh weight; OldPltFW (tha^{-1})= Old Cassava Planting stake fresh weight (kg); LeavesFW (tha^{-1}) = Leaves fresh weight(kg); GrnStmFW (tha^{-1}) = Green stems fresh weight($tha^{-1)}$; Markt Yield tha^{-1} = marketable fresh root yield tha^{-1}; Ptheight (cm) = plant height in cm; TFRtWt (tha^{-1})= Total fresh Root weight (tha^{-1}); Tbiomass (tha^{-1}) = total biomass; HI = Harvesting Index %; FRY tha^{-1} = Fresh root yield tha^{-1}, DMC = Dry matter content % and CSC% = Cassava Starch Content.

Table 3.2b: Effect of N, P and K application on cassava growth, yield, and root quality at the study sites in the during the study period

Variables	**Sites**					
	Runazi-Biharamulo		**Kijuka-Sengerema**		**Nyakiswa-Butiama**	
Season	2016/17	2017/18	2016/17	2017/18	2016/17	2017/18
LgnStmFW (tha^{-1})	7.26	5.26	7.85	7.93	6.46	7.60
OldPltFW (tha^{-1})	2.36	2.56	3.38	2.62	3.53	3.49
LeavesFW (tha^{-1})	1.42	1.52	2.71	1.17	3.02	1.51
GrnStmFW (tha^{-1})	5.03	2.69	4.00	1.59	1.88	0.81
Ptheight (cm)	187.70	134.6	123.93	133.61	106.21	.nd
Markt Yield (tha^{-1})	9.64	14.38	9.1	9.02	17.86	10.79
Tbiomass (tha^{-1})	30.49	32.17	31.71	25.79	31.18	25.29
% HI	46.66	61.69	42.8	47.17	52.51	43.29
FRY(tha^{-1})	14.43	21.10	13.77	12.94	16.29	11.87
% DMC	38.62	24.34	26.14	25.84	34.98	31.36
% CSC	27.12	8.61	10.51	10.57	22.27	17.77

LgnStmFW (tha^{-1}) = Lignified stem fresh weight; OldPltFW (tha^{-1}) = Old Cassava Planting stake fresh weight tha^{-1}); LeavesFW (tha^{-1}) = Leaves fresh weight(tha^{-1}); GrnStmFW (tha^{-1}) = Green stems fresh weight(kg); Markt Yield (tha^{-1}) = marketable fresh root yield tha^{-1}; Ptheight (cm) = plant height in cm; Tbiomass (tha^{-1}) = total biomass; HI = Harvesting Index %; FRY tha^{-1} = Fresh root yield tha^{-1}, DMC = Dry matter content % and CSC% = Cassava Starch Content.

to 1.51 tha^{-1} in the fertilized plots. The soil was in deficient of plant nutrients especially nitrogen (Chapter Two, Table 2.5), application of half_K+P fertilizer at a rate of 0:40:90 kg ha^{-1} was found to have low growth on the old planting stakes and plant height compared to the control plots, this signifies the importance of nitrogen for cassava growth. Similar trends reported in Asia by Howeler *et al*. (20001) where there was progress decrease in growth and yield when N and P were omitted.

The fresh root yield (FRY) was significantly increased by N, P and K applications fertilizer and seasons at $P < 0.05$ (Table 3.3). The application of N and K at a rate of 150:0:180 kg ha^{-1} was found to increase fresh root yield to 23.35tha^{-1} by 77 % yield increase over the control 11.73 tha^{-1}. These results are consistent with what has been reported by Santo and Sarkodie-Addo (2017), where the application of NPK fertilizer at the rate of 15:15:15 kg ha^{-1} increased yield from 15.1 tha^{-1}in control plot to 23.6 tha^{-1}in fertilized plots. Similarly, the results from Colombia reported that the application of NPK fertilizer at the rate of 100: 200:150 kgha^{-1} increased yield from 32 tha^{-1} to 40 tha^{-1} (Howeler, 2002). Root harvesting index was also significantly affected by fertilizer application and seasons at $P < 0.05$.

The NK fertilizer application at the ratio of 150:0:180 kg ha^{-1} was found to have a higher harvesting index (HI) of 60.46 % compared to control with harvesting index (HI) of 49.9 %. This confirms the fact that high HI indicates a good transfer of plant photosynthates from leaves to the storage tuberous root. This is true with the study of Boateng and Boadi (2010) that, the HI of more than 41% was high tuberous root growth. The application of NPK with 150:40:0 kg ha^{-1} ratios were found to have low root HI of 47.33 % compared to the control plots indicating that K^+ was the limiting nutrient in the soil causing low cassava yield. The cassava biomass was significantly ($P < 0.05$) increased by application of NPK at a ratio 150:40:180 kg ha^{-1}and was found to have higher biomass of 39.76 tha^{-1}

than the control with 23.58 tha^{-1} that signifies the importance of NPK nutrients in cassava vegetative growth. Marketable fresh root yield and root weights were significantly increased by treatment and seasons at $P < 0.05$. The NPK (150:0:180 kg ha^{-1}) application treatment rate increased marketable yield to 16.48 tha^{-1} compared to control with 7.4 tha^{-1}, indicating the efficient transfers of photoassimilates from the sources to affect the root yield (Howeler, 2011).

During harvesting in September, the time when there was a considerable drought in the last three months (Fig. 3.1), cassava root quality was not significantly increased by the application of NPK ($P > 0.05$). These results are consistent with previous studies by Fermont *et al*. (2009) and Adjei-Nsiah and Isaak (2013) where fertilizer applications insignificantly increased the cassava starch (CSC) and dry matter content (DMC). These results were contrary to findings by Agbaje and Akinlosotu (2004) and Boateng and Boadi (2010) who reported an increase of CSC and DMC with fertilizer applications.

However, other studies by Benesi *et al.* (2004) and Moreno and Gourdji (2015) stated that CSC and DMC are influenced by the genotype and environmental factors such as rainfall. Additionally, in this study the fertilized plots were better than the control with DMC of 35.68 % and CSC of 23.38 % was high in the half_N+PK (75:40:180 kg ha^{-1}) treatment, while the lowest DMC of 28.04 % and CSC of 13.44 % was observed on the half_K+ NP at a ratio of 150:20:180 kg ha^{-1} treatment compared to 34.72% DMC and 22.12% CSC in control respectively. It was however observed that high rate of fertilization, especially N contributes to lowering of cassava root starch and root dry matter content and increases the cyanide compounds in the roots (Cuvaca *et al*., 2015).

Table 3.2: Effects of N, P and K on cassava growth, yield, and root quality at Runazi-Biharamulo in 2016/17 and 2017/18 growing seasons

	VARIABLES										
TREATMENTS	**LgnStmFW (t/ha)**	**OldPltFW (t/ha)**	**LeavesFW (t/ha)**	**GrnStmFW (t/ha)**	**Markt Yield tha^{-1}**	**Ptheight (cm)**	**Tbiomass (t/ha)**	**% HI**	**FRY (t/ha)**	**% DMC**	**% CSC**
Control	5.36[a]	2.30[a]	1.25[a]	2.95[a]	7.40[b]	155.38	23.58[a]	49.92[ab]	11.73[c]	34.72[a]	22.12[a]
NK	5.71[a]	2.21[a]	1.34[a]	3.95[a]	16.48[a]	164.11	36.36[a]	60.46[a]	23.15[a]	33.62[a]	20.67[a]
NP	5.73[a]	2.49[a]	1.43[a]	4.01[a]	7.27[b]	166.87	24.48[a]	47.33[b]	12.35[bc]	32.70a	19.45[a]
NPK	8.35[a]	2.53[a]	1.60[a]	4.52[a]	16.09[a]	189.89	39.76[a]	53.6[ab]	22.76[ab]	29.30[a]	15.03[a]
NPK+micro	6.32[a]	2.63[a]	1.80[a]	4.34[a]	13.17[ab]	168.07	34.31[a]	55.15[ab]	19.22[abc]	31.52[a]	17.91[a]
PK	6.25[a]	2.65[a]	1.49[a]	3.47[a]	14.72[ab]	165.65	34.75[a]	59.96[ab]	20.90[abc]	32.03[a]	18.60[a]
half_K+NP	7.48[a]	2.69[a]	1.46[a]	4.22[a]	13.60[ab]	168.45	34.71[a]	54.15[ab]	22.01[abc]	28.09[a]	13.44[a]
half_K+P	4.46[a]	1.99[a]	1.46[a]	3.87[a]	8.27[ab]	151.49	23.91[a]	51.21[ab]	12.13[bc]	29.70[a]	15.51[a]
half_N+PK	6.00[a]	2.30[a]	1.40[a]	3.40[a]	9.44[ab]	160.57	26.75[a]	51.53[ab]	13.59[abc]	35.68[a]	23.38[a]
half_NPK	6.28[a]	2.42[a]	1.41[a]	3.61[a]	11.74[ab]	162.88	31[a]	55.9[ab]	17.27[abc]	29.92[a]	15.82[a]
half_P+NK	6.96[a]	2.85[a]	1.51[a]	3.97[a]	14.41[ab]	189.00	35.55[a]	54.86[ab]	20.27[abc]	29.17[a]	14.83[a]
MEANS	7.2	2.5	1.5	3.8	12.1	167.5	31.4	54.0	17.8	31.5	17.9
LSD	2.40	0.70	0.60	2.10	6.68	38.50	10.60	11.70	8.20	9.70	12.60
CV	38.20	29.20	40.50	54.90	53.90	22.00	32.90	21.90	45.10	30.00	68.00

Note: Means with the same letter are not significantly different.
LgnStmFW (tha^{-1}) = Lignified stem fresh weight; OldPltFW (tha^{-1}) = Old Cassava Planting stake fresh weight tha^{-1}); LeavesFW (tha^{-1}) = Leaves fresh weight(tha^{-1}); GrnStmFW (tha^{-1}) = Green stems fresh weight(kg); Markt Yield (tha^{-1}) = marketable fresh root yield tha^{-1}; Ptheight (cm) = plant height in cm; Tbiomass (tha^{-1}) = total biomass; HI = Harvesting Index %; FRY tha^{-1} = Fresh root yield tha^{-1}, DMC = Dry matter content % and CSC% = Cassava Starch Content..

3.5.4 Kijuka site at Sengerema District

Table3.4. summarizes the growth, yield, and root quality of cassava as affected by the application of NPK fertilizer application at Sengerema. The fresh weight of cassava old planting stakes, lignified, and green stems; were increased by the growing season ($P < 0.05$) (Table 3.2a) due to the differences of rainfall distributions.

The application of fertilizer increased the growth of cassava; however, was not statistically significantly different. Reduced growth of cassava may be explained by the moisture stress and inherent low soil fertility of the area. According to Fermont *et al*. (2010), the response of cassava to fertilizer application is determined by the soil fertility status. The application of NK at a rate of 150: 0:180 kg ha^{-1} increased lignified stems fresh weights to 8.67 tha^{-1} compared to control with 7.03 tha^{-1}. The half_P+NK application at a ratio of 150:20:180 kg ha^{-1} treatments were found to have high old planting stake fresh weight of 3.86 tha^{-1} compared to control with 2.72 tha^{-1}. The green stems fresh-weight was also high with 3.87 tha^{-1} with NP fertilizer at a rate of 150:40:0 kg ha^{-1} compared to the control plot with 3.46 tha^{-1}. Plant height was higher with 136.06 cm with an application of half_P+NK at a ratio of 150:20:180 kg ha^{-1} than the control with 120.52 cm (Table 3.4).

Cassava yield and yield component were not increased by fertilizer treatments applied but the response was not statistically significantly different. This is consistent with another study in Benin reported by Carsky, and Toukourou (2005), that there was no response to NPK fertilizer application on fertile sedimentary soil. This can be explained by the low annual rainfall below 150 mm in both seasons and low soil fertility. Based on Fermont *et al*. (2010), higher yield response to NPK responses correlated with high rainfall. The root dry matter and starch content were also not significantly increased by the application of N, P and K and as in Biharamulo site.

Table3.3: The effect of N, P and K fertilizer application on cassava growth, yield, and root quality at Kijka-Sengerema in the 2016/17 and 2017/18 growing seasons

TREATMENTS	VARIABLES										
	LgnStmFW (tha^{-1})	**OldPltFW (tha^{-1})**	**LeavesFW (tha^{-1})**	**GrnStmFW (tha^{-1})**	**Markt Yield (tha^{-1})**	**Ptheight (cm)**	**Tbiomass (tha^{-1})**	**% HI**	**FRY (tha^{-1})**	**% DMC**	**% CSC**
Control	5.36^{a}	2.30^{a}	1.25^{a}	2.95^{a}	7.40^{b}	155.38	23.58^{a}	49.92^{ab}	11.73^{c}	34.72^{a}	22.12^{a}
NK	5.71^{a}	2.21^{a}	1.34^{a}	3.95^{a}	16.48^{a}	164.11	36.36^{a}	60.46^{a}	23.15^{a}	33.62^{a}	20.67^{a}
NP	5.73^{a}	2.49^{a}	1.43^{a}	4.01^{a}	7.27^{b}	166.87	24.48^{a}	47.33^{b}	12.35^{bc}	32.70a	19.45^{a}
NPK	8.35^{a}	2.53^{a}	1.60^{a}	4.52^{a}	16.09^{a}	189.89	39.76^{a}	53.60^{ab}	22.76^{ab}	29.30^{a}	15.03^{a}
NPK+micro	6.32^{a}	2.63^{a}	1.80^{a}	4.34^{a}	13.17^{ab}	168.07	34.31^{a}	55.15^{ab}	19.22^{abc}	31.52^{a}	17.91^{a}
PK	6.25^{a}	2.65^{a}	1.49^{a}	3.47^{a}	14.72^{ab}	165.65	34.75^{a}	59.96^{ab}	20.9^{abc}	32.03^{a}	18.60^{a}
half_K+NP	7.48^{a}	2.69^{a}	1.46^{a}	4.22^{a}	13.60^{ab}	168.45	34.71^{a}	54.15^{ab}	22.01^{abc}	28.09^{a}	13.44^{a}
half_K+P	4.46^{a}	1.99^{a}	1.46^{a}	3.87^{a}	8.27^{ab}	151.49	23.91^{a}	51.21^{ab}	12.13^{bc}	29.70^{a}	15.51^{a}
half_N+PK	6.00^{a}	2.30^{a}	1.40^{a}	3.40^{a}	9.44^{ab}	160.57	26.75^{a}	51.53^{ab}	13.59^{abc}	35.68^{a}	23.38^{a}
half_NPK	6.28^{a}	2.42^{a}	1.41^{a}	3.61^{a}	11.74^{ab}	162.88	31.00^{a}	55.90^{ab}	17.27^{abc}	29.92^{a}	15.82^{a}
half_P+NK	6.96^{a}	2.85^{a}	1.51^{a}	3.97^{a}	14.41^{ab}	189.00	35.55^{a}	54.86^{ab}	20.27^{abc}	29.17^{a}	14.83^{a}
MEANS	**7.2**	**2.5**	**1.5**	**3.8**	**12.1**	**167.5**	**31.4**	**54.0**	**17.8**	**31.5**	**17.9**
LSD	**2.40**	**0.7**	**1.24**	**4.30**	**6.73**	**38.50**	**20.90**	**11.80**	**8.35**	**9.70**	**12.60**
CV	**38.20**	**29.20**	**40.90**	**54.60**	**54.20**	**22.00**	**32.40**	**21.30**	**45.80**	**29.90**	**68.00**

Note: Means with the same letter are not significantly different.
LgnStmFW (tha^{-1}) = Lignified stem fresh weight; OldPltFW (tha^{-1}) = Old Cassava Planting stake fresh weight tha^{-1}); LeavesFW (tha^{-1}) = Leaves fresh weight(tha^{-1}); GrnStmFW (tha^{-1}) = Green stems fresh weight(kg); Markt Yield (tha^{-1}) = marketable fresh root yield tha^{-1}; Ptheight (cm) = plant height in cm; Tbiomass (tha^{-1}) = total biomass; HI = Harvesting Index %; FRY tha^{-1} = Fresh root yield tha^{-1}, DMC = Dry matter content % and CSC% = Cassava Starch Content.

3.5.5 Nyakiswa site at Butiama District

Fertilizers increased cassava growth and yield parameters but were not statistically significantly different (Table 3.5). Cassava growth parameters except plant height and old planting stakes were significantly increased by the growing seasons (Table 3.2a) due to the differences in climatic conditions. The first season increased the green stems and leaves fresh weight to 1.88 tha^{-1} and 3.02 tha^{-1} compared to the second season with 0.81tha^{-1} and 1.51tha^{-1} respectively. Also, the lignified fresh weight was higher in the second season with 7.6 tha^{-1} compared to the first season with 6.46 tha^{-1} (Table 3.5).

Significant differences were observed between treatments in marketable, root yield and HI at $P < 0.05$. The application of P and K at a ratio of 0:40:180 kg ha^{-1} increased cassava root yield to 18.44 tha^{-1} nearly doubling the control plot with 9.73 tha^{-1}. The Half_K+P (0:40:90 kg ha^{-1}) application resulted in a higher HI of 63.51 % compared to NP application at a ratio of 150:40:0 kg ha^{-1} with 37.21 % and control with 39.79 % suggesting that N and P nutrients favoured luxuriant cassava growth at the expense of root (Howeler, 2011). The application of NK at a ratio of 150: 0:180 kg ha^{-1} increased marketable root yield to 19.93 tha^{-1} compared to control with 10.35 tha^{-1}. Also, significant differences were observed between growing seasons in root yield, Marketable root yield, total fresh root weight, total biomass and HI at $P < 0.05$

The first season contributed to high fresh root yield of 8.15 tha^{-1}, HI of 52.51% indicating tuberous root formation than above ground mass growth (Boateng and Boadi, 2010), marketable root weight of 4.47 tha^{-1}, total root weight 20.36 $tha^{-1}$and total biomass of 38.98 tha^{-1} compared to the second season with fresh root yield of 11.88 tha^{-1}, HI of 43.29 %, marketable root weight of 5.40 tha^{-1}, total root weight of 14.27 $tha^{-1}$and and total biomass of 31.61 tha^{-1} respectively due to the environmental factors. At harvest, cassava root quality was not affected by the application of fertilizers like in Biharamulo and Butiama site. However, fertilized plots were better than the control plot (Table 3.3). The cassava starch and dry matter content were significantly higher in the first growing season at $P < 0.05$. The CSC in the first season was 22.27 % and DMC of 34.98 % compared to with the lowest CSC of 17.77 % and DMC of 31.36 % in the second seasons.

3.6 Conclusions and Recommendations

There were fertilizer application responses across all sites; however, there were no statistically significant differences to some of the growth and yield parameters. For example, there was no fertilizer response on growth parameters at Biharamulo, Sengerema and Butiama due to environmental differences especially rainfall and inherently low soil fertility status.

Application of NPK at a rate of 150: 0:180 kg ha^{-1} was observed to high yield at Biharamulo and Sengerema with 23.15 tha^{-1} and 17.64 tha^{-1} respectively whereas PK at a rate of 0: 40:180 kg ha^{-1} was found to have a high yield of 18.44 tha^{-1} at Butiama. These fertilizers are recommended for higher yield at each site and it should be applied in a split of 60% at one month after planting and 40% at three months after planting (MAP) for the *Mkombozi* cassava variety.

However, cassava requires balanced for growth and yield, therefore further fertilizer studies are needed to obtain appropriate fertilizer blends for optimum and higher yields specific to each site. It can be concluded that N, P and K fertilizer application at 150-40-180 $kgha^{-1}$ rate can be used to increase cassava tuberous yield for improved yield. Cassava yield varies because of the variations of soils and weather under similar and different environmental conditions. However; more in-depth insight of these areas is required to understand the soil constraint governing the response of cassava to fertilizer application

Table3.4: Effect of N, P and K fertilizer application on cassava growth, yield, and root quality at Butiama in the 2016/17 and 2017/18 growing seasons

	VARIABLES										
Treatment	**LgnStmFW (tha^{-1})**	**OldPltFW (tha^{-1})**	**LeavesFW (tha^{-1})**	**GrnStmFW (tha^{-1})**	**Markt Yield (tha^{-1})**	**Ptheight (cm)**	**Tbiomass (tha^{-1})**	**% HI**	**FRY (tha^{-1})**	**% DMC**	**% CSC**
Control	7.03[a]	2.72[a]	2.57[a]	3.46[a]	8.36[a]	120.52[a]	27.95[a]	45.22[a]	14.61[a]	28.15[a]	13.29[a]
NK	8.67[a]	3.0[a]	1.98[a]	2.63[a]	12.58[a]	126.89[a]	33.91[a]	50.11[a]	17.64[a]	25.05[a]	9.26[a]
NP	7.97[a]	3.13[a]	2.27[a]	3.87[a]	8.80[a]	123.68[a]	29.87[a]	42.07[a]	12.62[a]	28.25[a]	13.41[a]
NPK	7.51[a]	2.98[a]	1.72[a]	2.94[a]	9.63[a]	131.44[a]	28.29[a]	45.58[a]	13.14[a]	24.82[a]	8.93[a]
NPK+micro	7.0[a]	3.15[a]	2.09[a]	3.14[a]	6.91[a]	127.35[a]	27.54[a]	43.98[a]	12.16[a]	27.07[a]	11.90[a]
PK	7.7[a]	3.09[a]	2.76[a]	3.35[a]	9.24[a]	126.02[a]	29.97[a]	43.56[a]	13.02[a]	24.71[a]	8.81[a]
half_K+NP	8.27[a]	3.29[a]	2.61[a]	2.82[a]	10.20[a]	129.41[a]	31.32[a]	45.88[a]	14.32[a]	23.50[a]	7.22[a]
half_K+P	7.62[a]	3.44[a]	2.25[a]	3.56[a]	8.08[a]	130.16[a]	29.07[a]	41.85[a]	12.21[a]	27.20[a]	11.91[a]
half_N+PK	7.34[a]	2.61[a]	1.28[a]	2.38[a]	7.89[a]	116.68[a]	25.25[a]	44.43[a]	11.65[a]	24.82[a]	8.98[a]
half_NPK	7.56[a]	2.81[a]	1.5[a]	2.6[a]	8.16[a]	125.48[a]	26.57[a]	43.02[a]	12.11[a]	28.89[a]	14.37[a]
half_P+NK	9.77[a]	3.86[a]	2.31[a]	3.32[a]	9.38[a]	136.06[a]	33.38[a]	41.82[a]	14.13[a]	26.16[a]	10.75[a]
MEANS	**7.9**	**3.1**	**2.1**	**3.1**	**9.0**	**126.7**	**29.4**	**44.3**	**13.4**	**26.2**	**10.8**
LSD(0.05)	**3.1**	**1. 0**	**1.40**	**1.90**	**5.2**	**25.80**	**11.00**	**10.50**	**6.13**	**6.0**	**7.46**
CV (%)	**33.30**	**26.70**	**55.60**	**51.20**	**47.40**	**16.60**	**30.70**	**19.35**	**39.83**	**18.93**	**61.80**

Note: Means with the same letter are not significantly different.
LgnStmFW (**tha^{-1}**) = Lignified stem fresh weight; OldPltFW (**tha^{-1}**)= Old Cassava Planting stake fresh weight (**tha^{-1}**); LeavesFW (**tha^{-1}**) = Leaves fresh weight(**tha^{-1}**); GrnStmFW (**tha^{-1}**) = Green stems fresh weight(**tha^{-1}**); Markt Yield (**tha^{-1})**= marketable fresh root yield (**tha^{-1})**; TFRtWt (**tha^{-1}**)= Total fresh Root weight (**tha^{-1}**); Tbiomass (**tha^{-1}**) = total biomass; HI = Harvesting Index %; FRY (**tha^{-1})** = Fresh root yield (**tha^{-1})**, DMC = Dry matter content % and CSC% = Cassava Starch Content

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CHAPTER FOUR

4.0 GENERAL CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

Using the morphological and laboratory data, the soils were classified to subgroup level according to USDA soil taxonomy (Soil Survey Staff, 2014) and to Tier -2 of the IUSS Working Group WRB (2015).

The soils of Runazi and Kijuka villages in Biharamulo and Sengerema were classified as Fluventic Dystrustepts of the (Soil Survey Staff (2014) and as Fluvic Dystric Cambisol (Ochric) (IUSS Working Group WRB, 2015) respectively. The soil of Butiama was classified as Kanhaplic Haplustults (Soil Survey Staff, 2014) and as Haplic Abruptic Alisol (Cutonic, Ochric) of IUSS Working Group WRB (2015).

The topsoil's of each soil profile was used to assess the fertility status of each study sites. The Fluventic Dystrustepts soil of Runazi and Kijuka village in Biharamulo and Sengerema respectively and the Kanhaplic Haplustults soils of Nyakiswa village in Butiama were low fertile with high to moderate bulk density, low soil pH, low available P, low TN, low OC and low OM, low exchangeable bases, low levels of CEC, and high to moderate base saturation.

Cassava responded to fertilizer application on growth yield and root quality in all study site soils; however, there were no statistically significant increase differences to some of the growth and yield parameters. For example, there was no fertilizer response on growth parameters at Biharamulo, Sengerema and Butiama due to environmental differences especially rainfall and inherently low soil fertility status.

Application of NPK at a rate of 150: 0:180 kg ha^{-1} was observed to high yield in low fertile Fluventic Dystrustepts soils of Runazi and Kijuka villages in Biharamulo and Sengerema districts with 23.15 tha^{-1} and 17.64 tha^{-1} respectively whereas application of NPK at a rate of 0: 40:180 kg ha^{-1} was found to have a high yield of 18.44 tha^{-1} in low fertile Kanhaplic Haplustults soils of Kijuka village in Butiama districts.

4.2 Recommendations

This study recommends the following in order to improve soil productivity and sustain cassava production of smallholder farmers in the Lake Zone of Tanzania.

i. Since the findings of this study were based on identified representative soil profiles, a more detailed study on the characteristics of the soils of study area including composite topsoil sampling is recommended.
ii. Although cassava production has been reported to do well in soils with low fertility, application of fertilizer to boost the fertility in low fertile soils is inevitable among the management options in order to increase cassava root yield and quality in the Lake Zone.
iii. Application of NPK at a rate of 150: 40:180 kg ha^{-1} is recommended for higher yield at each site and it should be applied in a split of 60% at one month after planting and 40% at three months after planting (MAP) for the *Mkombozi* cassava variety depending on the availability of rainfall to minimize crop injury.
iv. Cassava requires balanced nutrients for higher growth and yield, therefore further fertilizer studies are needed to obtain appropriate fertilizer blends for optimum and higher yields specific to each site.
v. It can be concluded that N, P and K fertilizer application at 150-40-180 $kgha^{-1}$ rate can be used to increase cassava tuberous yield for improved yield.
vi. More research is recommended to study the soil constraints governing the response of cassava to fertilizer application.

APPENDICES

Appendix 1: Discription of Runazi - Biharamulo soil profile

Profile no: BMLO-P1/2018/10
Location: Runazi village, Kabindi ward, Biharamulo district, Kagera region.
Coordinates: 2.788060ºS 31.46731ºE. Elevation: 1351 m absl. Parent material: Colluvial from granitic rock. Landform: Gentle undulating. Slope: 2-5% straight. Surface characteristics: Erosion: Water Deposition: none.
Natural drainage class: Well-drained

Described by Ndare D.W and. Kabon E.L on 01/10/2018

Soils: Very deep, moderately well-drained, brown sand loamy topsoil to yellowish sand clay subsoil

Ap 0 – 45 cm: Dark brown (10YR 3/3, moist; sandy loam; weak, coarse, sub-angular blocky; hard when dry, very friable when moist, non-sticky and non-plastic when wet; many very fine to coarse pores; many very fine to , fine roots; field pH 5.0; abrupt and smooth boundary towards BA.

BA 45 - 85 cm: Yellowish red (5YR 4/6) moist; sandy clay to clay loam; moderately fine to medium structure; very hard when dry, friable when moist, sticky and plastic when wet; many very fine to coarse pores; few very fine roots; field pH 4.5; abrupt and smooth boundary towards B_1.

B_1 85 - 110 cm: Yellowish red (5YR 4/6) moist; sandy clay to clay loam; moderately fine to medium structure; very hard when dry, friable when moist, sticky and plastic when wet; many very fine to coarse pores; few very fine roots; field pH 5.0; abrupt and smooth boundary towards to B_2w

B_2w 110 - 170 cm: Yellowish red (10YR 5/8) moist; sandy clay to clay loam; moderately fine to medium structure; hard when dry, very friable when moist, sticky and plastic when wet; many very fine to fine pores; very few very fine roots; field pH 5.0; abrupt and smooth boundary.

SOIL CLASSIFICATION
World Reference Soil base (IUSS Working Group WRB (2015) Tier 2: Fluvic Dystric Cambisol (Ochric) USDA Soil Taxonomy (Soil Survey Staff 2014): Fluventic Dystrustepts

ANALYTICAL DATA FOR PROFILE BMLO-P1/2018/10

Horizon	**Ap**	**BA**	**B_1**	**B_{2W}**
Depth (cm)	0 - 45	45 - 85	85 - 110	110 - 170
Clay %	8.40	20.40	32.40	34.40
Silt %	10.80	8.80	12.80	10.80
Sand %	80.80	70.80	10.80	54.80
Textural class	SL	SCL	SCL	SCL
pH H_2O	5.47	5.68	5.24	2.65
pH KCl	4.82	4.55	4.23	4.15
Organic C %	0.28	0.34	0.28	0.36
Total N %	0.05	0.04	0.03	0.05
C/N	5.6	8.50	9.30	7.20
Bray Avail. P mgkg^{-1}	4.35	2.30	1.00	1.05
CECNH4OAc (cmol(+)kg^{-1})	13.0	12.80	15.0	9.0
Exch. Ca^{2+} (cmol(+)kg^{-1})	2.69	4.01	2.22	1.72
Exch. Mg^{2+} (cmol(+)kg^{-1})	0.24	0.34	0.11	0.21
Exch. K^+ c(cmol(+)kg^{-1})	0.20	0.29	0.39	0.49
Exch. Na^+ (cmol(+)kg^{-1})$^{-1}$	1.11	1.09	1.08	1.05
TEB (cmol(+)kg^{-1})	6.92	5.73	3.80	3.47
Base saturation %	53.25	44.75	22.65	38.57

Note: SCL= sandy clay loam, SL = Sandy loam

Appendix 2: Discription of Kijuka - Sengerema soil profile

Profile no: SENGM-P2/2018/10
Location: Kijuka village, Nyamazugo ward, Sengerema district, Mwanza region.
Coordinates: 2.56197ºS 32.59090º E. Elevation: 1209 masl. Parent material: Colluvial from granitic rocks. Landform: Undulating. Slope: 2-5% straight. Surface characteristics: Erosion: Sheet water erosion. Deposition: Sand deposition.
Natural drainage class: Well-drained

Described by Ndare D.W and. Kabon E.L on 04/10/2018

Soils: Very deep (150 + cm), well-drained, very dark brown sand when dry to reddish yellowish when moist topsoil. Loam sandy to sandy clay loam textured soil.

Ap 0 – 10 cm: Very dark brown (10YR 3/2) moist; loam sandy to sandy loam; weak, fine to coarse sub-angular blocky; hard when dry, very friable when moist, slightly-sticky and slightly-plastic when wet; many very fine to coarse pores; many very fine to fine roots; field pH 4.5; abrupt and smooth boundary towards to AB.

AB 10 - 50 cm: Strong brown (7.5YR 4/6) dry, Dark brown (7.5YR 4/4) moist; sandy loam; weak, fine to coarse structure; hard when dry, friable when moist, slightly sticky and plastic when wet; many very fine to coarse pores; many very fine roots; field pH 5.0 clear and wave boundary towards to B1.

B_1 50 - 110 cm: Reddish yellow (7.5YR 6/8) dry,yellowish-red (5YR 4/6) moist; sandy loam to sandy clay loam; weak, fine to medium structure; hard (dry), friable when moist, slightly-stick and slightly plastic when wet; many very fine to coarse pores; common fine roots; field pH 5.0; abrupt and smooth boundary towards B2.

B_2 110 - 140 cm: Reddish yellow (7.5YR 6/8) dry, reddish-yellow (7.5YR 4/6) moist; sandy loam to sandy clay loam; weak, very fine to fine structure; hard (dry), very friable when moist, slightly-stick and slightly plastic when wet; many fine to medium pores; common fine roots; field pH 4.5; clear and smooth boundary towards Bcw.

Bcrw 140 – 180+ cm: Lateritic granules with irregular shape; loose (dry), loose (moist); slightly sticky, slightly plastic, wet; very hard granulated structures; non-calcareous; many fines to coarse pores; few fine roots; field pH 4.5.

SOIL CLASSIFICATION
World Reference Soil base IUSS Working Group WRB (2015) Tier 2: Fluvic Dystric Cambisol (Ochric) USDA Soil. Taxonomy (Soil Survey Staff 2014): Fluventic Dystrustepts

ANALYTICAL DATA FOR PROFILE SENGM-P2/2018/10

Horizon	**Ap**	**AB**	**B_1**	**B_2**	**Bcrw**
Depth (cm)	0 - 10	10 -50	50 - 110	110 - 140	140 - 180+
Clay %	23.20	15.20	17.20	15.2	n.d
Silt %	4.0	12.0	12.0	12.0	n.d
Sand %	72.80	72.80	70.80	72.8	n.d
Textural class	SCL	SL	SL	SL	n.d
pH H_2O	6.48	5.70	5.21	5.04	n.d
pH KCl	5.43	4.47	4.15	4.12	n.d
Organic C %	0.68	0.28	0.38	0.32	n.d
Total N %	0.07	0.05	0.04	0.04	n.d
C/N	9.70	5.60	9.50	8.00	n.d
Avail. P mgkg-1Bray	3.26	3.50	2.40	2.00	n.d
CECNH4OAc (cmol(+)kg^{-1})	14.0	16.2	6.0	10.0	n.d
Exch. Ca^{2+} (cmol(+)kg^{-1})	5.75	2.21	1.57	0.76	n.d
Exch. Mg^{2+} (cmol(+)kg^{-1})	0.26	0.19	0.23	0.13	n.d
Exch. K^+ (cmol(+)kg^{-1})	0.35	0.17	0.12	0.12	n.d
Exch. Na^+ (cmol(+)kg^{-1})	1.09	1.05	1.08	1.07	n.d
TEB (cmol(+)kg^{-1})	7.45	3.61	3.01	1.04	n.d
Base saturation %	53.20	22.30	50.13	20.82	n.d

Note: nd= not determined, SCL= sandy clay loam, SL = Sandy loam.

Appendix 3: Discription Nyakiswa - Butiama soil profile

Profile no: BTMA-P2/2018/10
Location: Nyakiswa village, Kyanyari ward, Butiama district, Mara region.
Coordinates: 51º 49’ 36.4” S 33º 47̀ 49.9” E. Elevation: 113 masl. Parent material: granitic and feldspars. Landform: Gently sloping. Slope: < 2 % linear.
Position slope:mid-slope. Soil moisture regime: Ustic. Surface characteristics: Erosion: slight sheet water erosion. Deposition: none; Natural drainage class Well-drained

Described by Ndare D.W., A.K. Kaaya, D.P Mlay, V. Uzokwe and J. Kabisa on 26/03/2018

Soils: Very deep,well-drained, dark reddish-brown soils when moist to dark red when dry. Loam sandy to sandy clay loam textured soil.

Ap 0 – 20 cm: Reddish Brown (5YR 5/3) moist; clay loam; moderate sub-angular blocky; strong when dry, friable when moist, very stick and very plastic when wet; many fine pores; non-calcareous; few very fine roots; abrupt and smooth boundary towards to AB.

BA 20 - 37 cm: Dark reddish-brown (5YR 3/3) moist; clay; strong to moderate structure; strong when dry, firm when moist, very stick and very plastic when wet; common fine pores; non-calcareous; few very fine roots; gradual and smooth boundary towards to Bt1.

Bt_1 37-79 cm: Dark Brown (5YR 3/4) moist; clay; strong to moderate structure; strong when dry, firm when moist, very stick and very plastic when wet; common distinct clay cutans; non-calcareous; common to few, fine to medium pores; few very fine roots; gradual and smooth boundary towards to Bt2.

Bt_2 79-135 cm: Red (2.5YR4/6) dry, Dark red (2.5YR3/6) moist; clay; strong to moderate structure; strong when dry, firm when moist, very stick and very plastic when wet; common distinct clay cutans; non-calcareous; common to few moderate to fine pores; few very fine roots. Gradual and smooth boundary towards to Bt3

Bt_3 135-160+ cm: Dark red (2.5YR3/6) dry, dark reddish-brown (2.5YR 3/4) moist; clay; strong to moderate structure; strong when dry, firm when moist, very stick and very plastic when wet; common distinct clay cutans;

World Reference Soil base IUSS Working Group WRB (2015) Tier 2: Haplic Abruptic Alisol (Cutonic, Ochric). USDA SoilTaxonomy (Soil Survey Staff 2014): Kanhaplic Haplustults

ANALYTICAL DATA FOR PROFILE BTMA-P2/2018/10

Horizon	**Ap**	**AB**	**Bt_1**	**Bt_2**	**Bt_3**
Depth (cm)	0 - 20	20 - 37	37 - 79	79 - 135	135 - 160
Clay %	53.2	63.2	65.2	63.2	61.2
Silt %	30.0	24.0	26.0	22.0	22.0
Sand %	16.8	12.8	8.8	14.8	16.8
Textural class	C	C	C	C	C
pH H_2O	5.93	5.70	5.80	6.30	6.64
pH KCl	5.05	4.47	4.59	4.79	5.04
Organic C %	2.73	1.62	0.76	0.84	0.76
Total N %	0.19	0.15	0.12	0.1	0.09
C/N	14.40	10.80	6.30	8.40	8.40
Bray Avail. P mgmgkg^{-1}	4.10	0.90	0.55	0.60	0.75
CECNH4OAc (cmol(+)kg^{-1})	32.0	35.60	24.80	22.0	26.40
Exch. Ca^{2+} (cmol(+)kg^{-1})	17.34	10.62	10.59	10.15	10.90
Exch. Mg^{2+} (cmol(+)kg^{-1})	1.34	0.58	0.58	0.58	0.57
Exch. K^+ (cmol(+)kg^{-1})	0.95	0.35	0.31	0.33	0.28
Exch. Na^+ (cmol(+)kg^{-1})	1.06	4.40	1.07	1.09	1.09
TEB (cmol(+)kg^{-1})	20.69	15.94	12.55	12.14	11.42
Base saturation %	62.35	44.77	50.61	55.16	48.65

Note: C= Clay.