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Assessing soil fertility status and pest infestation levels in selected banana growing regions of Tanzania

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ASSESSING SOIL FERTILITY STATUS AND PEST INFESTATION LEVELS IN SELECTED BANANA GROWING REGIONS OF TANZANIA

Shija Shilunga Lucas

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

A study was conducted between December, 2017 and April, 2018 in four regions namely Kagera, Mbeya, Arusha and Kilimanjaro, to assess the status of soil fertility, disease and insect pest infestations. A total of 560 banana fields were assessed for nematodes, banana weevil damages, black sigatoka disease, soil nutrient status and water conservation practices. A total of 5040 banana plants were assessed for nematodes and weevil damages, and black sigatoka. Moreover, 1168 composite soil samples each weighing 500g, were collected using soil auger at depths of 0-20 cm and 21-50 cm. The soil samples were analyzed using Alpha Spectrometer method which utilizes Mid-Infrared. The results showed that nematode and weevil damages, and black sigatoka disease were found in all surveyed districts. This is the first survey reporting the presence of black sigatoka in Kilimanjaro and Arusha. Weevil and nematode damages positively correlated with mulch cover ($P<0.05$). Nutrients like nitrogen, potassium, magnesium, calcium, zinc and boron in the soils were insufficient however; phosphorus was in medium levels in all districts except Arumeru and Misenyi. There was low percentage Organic carbon in all districts except in Misenyi (2.0%) and Bukoba rural (1.9%) which had medium levels. Soil pH was optimal for banana production in all soils of the study area. There was less use of water conservation practices except mulch in all surveyed districts. This result recommends that there is a need for developing quick interventions with regards to pests and soil fertility management so as to improve banana production in Tanzania.

DECLARATION

I, Shija Shilunga Lucas, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that, this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Shija Shilunga Lucas — Date

Name and Signature of candidate

The above declaration is confirmed

Dr. Ernest R. Mbega — Date

Principal Supervisor, NM - AIST

Dr. Mpoki Shimwela — Date

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CERTIFICATION

The undersigned certify that, they have read and hereby recommend for acceptance of the dissertation entitled "Assessing soil fertility status and pest infestation levels in selected banana growing regions of Tanzania" in fulfillment of the requirements for the degree of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

This work is dedicated to God Father, God son (Jesus Christ), God the Holy Spirit and to my wonderful family.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

AfSIS	Africa Soil Information Service
B	Boron
Ca	Calcium
Cmol (+) kg	Centimoles of positive charge per kilogram
Fe	Iron
GPS	Geographical Positioning System
K	Potassium
M.A.S.L	Meter above sea level
Mg	Magnesium
MMT	Million Metric Tonnes
NGO	Non-Governmental Organizations
NM-AIST	Nelson Mandela African Institution of Science and Technology
OC	Organic carbon
P	Phosphorus
PPM	Parts per million
SSA	Sub-Saharan Africa
TARI- MARUKU	Tanzania Agricultural Research Institute-Maruku
TARI-MAKUTUPORA	Tanzania Agricultural Research Institute-Makutupora
TN	Total Nitrogen
Zn	Zinc

CHAPTER ONE

INTRODUCTION

1.1 Background

Bananas (*Musa spp*.) are giant herbs related to lilies and orchids but the most cultivated monocot plants embracing the diploid, triploid and some tetraploid cultivars (Nelson *et al*., 2006; Pillay *et al*., 2012). The crop originated in Southeastern Asia and Pacific regions (Masanza, 2003; Castillo and Fuller, 2010, 2012). After their introduction to Africa, they diversified to more than 60 banana types in the East African Highlands and more than 120 plantain types in West and Central Africa (INIBAP, 2006). The edible cultivars were derived from two wild species; *Musa acuminata colla* L. (AA) alone or in combination with *Musa balbisiana colla* L. (BB), which are diploid and the origin of most commercial clones (De-Langhe, 1995; Nelson *et al*., 2006).

Bananas are fourth most important global dietary staple food crop after rice, wheat and maize (Nelson *et al*., 2006; Perrier *et al*., 2011; Li *et al*., 2013). To date, bananas are the world's leading fruit crop and important export commodity for several agricultural based economies (Aurore *et al*., 2008, Kilimo Trust, 2012; Ploetz and Evans, 2015). The growing urban markets, contribute to the importance of the crop as a source of cash in many African countries. East Africa is the largest producer and consumer of bananas in Africa (Smale, 2006). The region has per capita consumption rate exceeding 200 Kg, which is the highest in the world (Karamura *et al*., 1999). They constitute a major source of calories and vitamins A, B6 and C among poor resource farmers in rural areas (Ekesa *et al*., 2015). Bananas' ability to produce fruits all-year around, puts them above other crops especially in bridging the hunger gap (Aurore *et al*., 2009). The crop is reflected as poor man's apple and it is the inexpensive among all other fruits in many Sub-Saharan Africa (SSA) countries including Tanzania (Heslop-Harrison and Schwarzacher, 2007). The crop therefore, contributes significantly to food and income security of people engaged in its production and trade, particularly in developing countries.

Tanzania is the second bananas producer in Africa, after Uganda (Kilimo Trust, 2012). It is estimated that, 80% of bananas produced in Tanzania are cooking bananas, 10% beer bananas, 8% dessert bananas and 2% plantains (Kalyebara *et al.*, 2007). Tribes like the Haya in Kagera, the Chagga in Kilimanjaro and the Nyakyusa in Mbeya regions, relay exclusively on bananas as their major staple food (Maruo, 2002, 2007). The average bananas yield in the country is 4.5 tonnes per hectare per year (FAO, 2012). The major banana producing regions include Kagera, northern highlands of Kilimanjaro and Arusha regions, southern highlands of Mbeya and Ruvuma regions and eastern/coastal areas such as Morogoro region and Zanzibar Island (MAFC, 2001).

Despite its importance, there is yield fluctuation marked by declining trend of bananas production in the country from 18 t/ha in 1960s to 5-7 t/ha/year in 2005 (Kilimo trust, 2012; FAOSTAT, 2017). The yield is far below the crop's potential yield of more than 70 tonnes per hectare per year in the tropical areas (Van Asten *et al.,* 2005; Wairegi and Van Asten, 2011). Many authors reported that, poor inherent soil fertility, leaching of nutrients from agricultural fields, nutrient mining, volatilization, poor management practices, pests and diseases, and drought played a major role as production constraints to smallholder farmers (Jones 2000a; Ploetz, 2003; Van Asten *et al*., 2005; Baijukya *et al.*, 2005; Szilas *et al.*, 2005; Ndakidemi and Semoka, 2006; Swennen *et al*., 2013). Several strategies have been used to curb these challenges including, application of organic manure, mulches, use of pesticides to control pests, crop rotation, intercropping and the introduction of high yielding and disease resistant cultivars. Despite the endeavors to improve production, Ndakidemi and Semoka, (2006) and Ahamuza *et al*. (2015) reported that, nutrient deficiencies in the soil have remained a major concern in the banana agricultural industry around the globe. Similarly, Viljoen *et al*. (2016) reported that, pests have played a significant role in reducing banana production. Therefore, this research focused on assessing the status of soil nutrients and pest infestation levels in Kagera, Mbeya, Kilimanjaro and Arusha.

1.2 Problem statement

Banana continues to yield low, despite the efforts to improve its yield in Tanzania. The overall banana production in the country is less than 10% of its potential i.e. 70 tone/ ha/ year (Van Asten *et al*., 2005; NBS, 2012). The decline in production is reported to be triggered by biotic and abiotic stresses (Nyombi, 2010). Biotic stresses include insect pests and diseases which have been reported to reduce banana yields up to 100% (Gold *et al*., 2004, Luambano *et al*., 2018), whereas abiotic stresses such as nutrient deficiencies alone in the soil can cause a potential yield decline of up to 70% (Wairegi *et al*., 2010; Taulya, 2015). Water stress as other abiotic factors causes more than 50% reduction in photosynthesis, consequently reduced biomass accumulation and crop yield (FAO, 2012; Surendar *et al*., 2013). However, it is reported that, proper pests and disease management, nutrients and water application can significantly increase yield (Nyombi *et al*., 2010; Kablan *et al*., 2012; Surendar *et al*., 2013). This implies that, nutrients, water and proper insect pest and disease management play a significant role in improving banana yields. In Tanzania, biotic factors such as banana weevils, parasitic nematode and black sigatoka disease, have been considered as the major constraints in banana production. Similarly, water and nutrient deficiency in the soil, have been considered as serious problems of banana producers. However, limited information exists on current soil status in relation to the above mentioned constraints in a particular site or location (Ndakidemi and Semoka, 2006). No clear information on infestation levels by banana weevils, parasitic nematodes and black sigatoka disease and their management practices. Likewise little information is available on soil nutrients and water conservation practices particularly in banana growing areas of Kagera, Mbeya, Kilimanjaro and Arusha. Thus, this study aimed at gathering the above-mentioned information as the pre-requisite for the development of site specific recommendations that will reduce banana yield gaps in Tanzania.

1.3 Objectives

1.3.1 General objectives

To assess insect pests (banana weevils and parasitic nematodes) and disease (black sigatoka) infestation levels, water conservation practices and fertility status of soils in major banana growing areas so that, the information gathered can be used to develop recommendations for steps towards banana yield improvement in Tanzania.

1.3.2 Specific objectives

(i) To evaluate pest infestation level and determine the current pest control practices used by farmers in the regions of Kagera, Kilimanjaro, Mbeya and Arusha.

(ii) To assess the fertility status of soil and identify soil and water conservation practices (SWCP) used by farmers in selected locations of Tanzania.

1.4 Research questions

(i) What are the infestation levels of parasitic nematodes, banana weevils and black sigatoka diseases in the main banana growing regions?

(ii) What is the status of macro and micro nutrients of soils in the main banana producing regions of Tanzania?

(iii) What are the soil and water conservation practices used by farmers in Tanzania?

1.5 Significance of the study

This study will contribute to the improvement of bananas productivity and production by guiding the Government officials, NGO, researchers, farmers and other banana stakeholders to take appropriate measures towards initiatives for improving banana production in the country.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Bananas (*Musa spp.*) are the fourth most important cultivated monocot herbs that embrace the diploid, triploid and some tetraploid cultivars (Nelson *et al.*, 2006; Perrier *et al.*, 2011; Pillay, 2012). Several ethnic groups in East Africa rely exclusively on bananas. For example, the Ganda and the Haya people in the North and West of Lake Victoria, the Gishu people of Mount Elgon, the Chagga people of southeastern Kilimanjaro and the Nyakyusa people of Rungwe (Simmonds, 1966, Mpangala, 1992; Maruo 2002, 2007). The region has the highest consumption rate of 500–1500 kg per head (Yamaguchi, 2004). Uganda is the leading banana producer among African countries, third in the world ranking with 11.8 MMT followed by Cameroon (4.94 MMT) which is ninth in the world ranking and Tanzania (4.08 MMT) which tenth in world ranking (Fig. 1) (Phumelele, 2016).

Statistics shows that, Tanzania produces banana on 403 000 hectares of bananas with consumption rate between 280-500 kg/person (Kilimo Trust, 2012). Over 900 000 farming households are engaged in banana production for food and market (NBS, 2012). In the comprehensively banana-based agricultural systems, about 70–95% of households grow bananas for food and/or economic reasons (Byabachwezi and Mbwana, 1999; Kilimo Trust, 2012). More than 70% of bananas are grown in Kagera, Kilimanjaro, Mbeya and Arusha regions. However, most banana producers in the country embrace their native farming systems (Yamaguchi, 2004). As a result, banana production in the country have remained very low i.e. 5-7 tonnes/ ha/ year compared with its full potential that is estimated to be 60-70 tonnes/ ha/ year (Van Asten *et al.,* 2005; NBS, 2012).

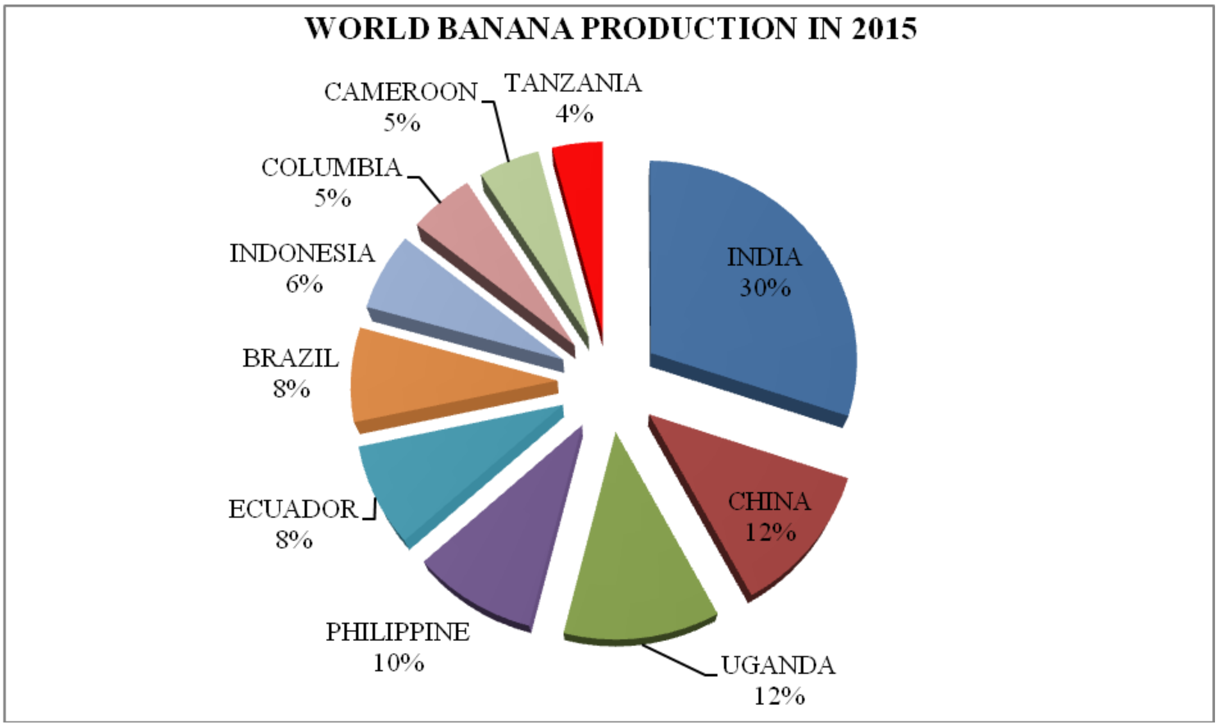

Figure 1: World banana production in 2015 (Phumelele, 2016).

2.2 Main banana production areas in Tanzania

In Tanzania, bananas are produced by small holder framers who own less than 0.5 ha. The production areas are divided into major and minor producing regions. Major producing regions are the highlands of Kagera region in the Lake Zone, followed by Kilimanjaro, Arusha, and Tanga regions in the Northern Zone; Mbeya region, in the Southern Highlands; Coast and Morogoro regions in the Eastern Zone; and Zanzibar Islands (NBS, 2012; Kilimo Trust, 2012). Minor producing regions are Kigoma, Mara, and Ruvuma. Popular banana varieties grown in all regions include the East Africa Highland banana (Matooke), Mchare, Kisukari, Mzuzu, Kimalindi, Ndizi Ng'ombe, Bokoboko and Cavendish group (Williams, Grand nain and Mtwike) (De Langhe *et al*., 2001; Karamura *et al*., 2012). The crop is grown in association with various other crops, such as coffee, beans, maize, cocoa yams and fruit trees (MAFC, 2009).

2.3 Constraints to banana production in Tanzania

Banana production is hampered by a number of challenges in Tanzania. The main challenges are drought, pests and diseases, poor soil fertility, land degradation, use of low yielding cultivars, use of susceptible cultivars, variety preferences, improper post-harvest handling and poor marketing (Mgenzi *et al*., 2005; Nkuba *et al*., 2015; Shimwela *et al*., 2016). Of these challenges, insect pests and diseases, poor soil fertility and moisture stress have been cited to be the main limiting factors for banana production in the country (Nkuba *et al.,* 2015).

2.3.1 Pests and Diseases

Banana can be attacked by a wide range of insect pests and diseases (Nkuba and Mgenzi, 2002; Nelson *et al*., 2006). The main insect pests and disease in Tanzania have been reported to be the weevils (*Cosmopolites sodidus*) (Mbwana and Rukazambuga, 1999; Gold *et al.,* 2001; Viljoen *et al.,* 2016), nematodes (e.g. *Rodopholussimilis*) (Sikora *et al.,* 1989; Viljoen *et al.,* 2016), black sigatoka disease (*Mycosphaerellafijiensis*) Viljoen *et al.,* 2016), Fusarium wilt (*Fusarium oxysporum*) (Ploetz, 2015; Gallez *et al*., 2004; Viljoen *et al.,* 2016) and banana xanthomonas wilt (BXW) (*Xanthomonas campenstris* pv *musacearum*) (Swennen *et al.,* 2013; Nkuba *et al.,* 2015; Shimwela *et al.,* 2016).

According to Speijer *et al*. (1999) and Wairegi *et al*. (2010) banana weevils and nematodes can reduce yields by 30-70%. It has been reported that banana weevils has resulted into decline and disappearance of highland cooking banana in western Tanzania (Mbwana and Rukazambuga, 1999). Romero and Sutton (1996), Barekye *et al*. (2011) and Viljoen *et al*. (2016) also reported that black sigatoka disease to be associated with a yield loss of 30 to 50% on bananas and plantains. A production loss of up to 100% in susceptible varieties such as *M. acuminata* Cavendish Grande Naine (*Musa* cv. AAA) and Prata (*Musa* cv. AAB) has been reported due to the disease (Brito *et al*., 2015).

There exist also, a number of minor diseases that affect banana production in Tanzania. These include;speckle/septoria leaf spot, a foliar disease (Ploetz, 2000; Viljoen *et al.,* 2003), Cigar End rot caused by *Verticillium theobromae*, and *Trachsphaera fructigena*) (Maina *et al.,* 2013) and *Armilaria* corm rot disease (Lindqvist, 1980; Ploetz *et al.,* 1992; Otieno, 2002). Similarly, banana can also be attacked seriously by rodents such as mole rat *(Tachyoryetes splendens*) (Makundi and Massawe, 2010) and baboons (Naughton-Treves *et al.,* 1998).

(i) Banana weevil

The banana corm borer, (*Cosmopolites sordidus*) (Germar) (Coleoptera: Dryophthoridae), is the leading insect pests of banana crop in Tanzania (Gold *et al*., 2001; Nkuba *et al*., 2015). The pest is believed to be native in the Indo-Malaysian region (Zimmerman 1968, Clausen 1978). Banana weevil is narrowly oligophagous, adults are nocturnally active and attracted to the host plants by volatiles emanating from fresh and decomposing banana material (Mwaitulo *et al.,* 2011). The pest is commonly associated with crop residues and banana mats since it prefers corm odours (Gold *et al*., 2004). The larvae can infest any stage of development of a plant, feed and develop inside the shoot by forming galleries or tunnels. Symptoms due to *C. sordidus* are yellowing of leaves, pseudostem weakness, reduced bunch formation and development, or presence of defective bunches. The pest is reported to be managed through crop sanitation, i.e. destruction of crop residues, desuckering removal of mulches around the mat area has been reported to lower banana weevil damage by removing adult refuges and breeding sites (Gold *et al*., 2001; Masanza *et al*., 2003; Masanza *et al*., 2005), use of pheromone trap (Budenberg *et al*., 1993a) and local trapping using pseudostem (Tinzaara *et al*., 2005).

(ii) Nematode

Nematodes (parasitic and nonparasitic) are small, worm-like members of the animal kingdom adopted to live in almost every habitat (Coyne *et al*., 2014). Plant-parasitic nematodes spend either all or part of their life in the soil (Mitiku, 2018). *Radopholus similis* (endo-parasite), *Pratylenchus goodeyi* (endo-parasite) and *Pratylenchus coffeae* (endo-parasite) are among the major banana nematode pest reported to cause significant yield losses in Tanzania (Coyne *et al*., 2014; Luambano *et al.*, 2018). Plant-parasitic nematodes have stylets, spear-like mouthparts that pierce cells and allow nematodes to feed on their hosts (Bridge *et al*., 1997). Symptoms due to nematodes infestation are black or purple necrosis of epidermal or cortical tissue of roots, cavities formation, stunted growth, reduced size and number of leaves, yellowing or greenish-yellow bands along the leaf blades and reduced bunch weight (Osei *et al*., 2013). The nematode load in the soil can be reduced with crop rotation, fallowing for six months, exposure of planting material to direct sunlight for a period of two weeks, cover crops that are not susceptible to the nematode, such as *Crotalaria spp*., *Raphanus sativus* and *Tagetes patula* can be sown and the use of disease-free planting materials (Bridge *et al*., 1997; Daneel and De Waele, 2017; Mitiku, 2018).

(iii) Black sigatoka

Black sigatok, is a leaf spot disease of banana plants caused by ascomycete airborne fungus *Mycosphaerella fijiensis* (Morlet), (Anamorph *Pseudocercospora fijiensis*) (Churchill, 2011; Viljoen *et al*., 2016). The fungus is a sexual, heterothallic, haploid and hemibiotrophic ascomycete within the class Dothideomycetes, order Capnodiales and family Mycosphaerellaceae (Churchill, 2011). The pathogen was identified for the first time in Fiji in the year 1963 (Henderson *et al.*, 2006; Churchill, 2011). Over sixty distinct strains with different pathogenetic potentials have been isolated (Bhamare and Kulkarni, 2015). In

Tanzania, the disease was first reported in 1987 along the coastal regions; Tanga, Morogoro, Coast and Pemba-Zanzibar (Mourichon *et al.*, 1997; Frison *et al.*, 1998). The first sign of the disease is the appearance of small, dark brown streaks on the lower surface of leaves (Meena, 2017). These streaks enlarge and coalesce forming necrotic lesions with light grey centres and yellow perimeters, the leaves of banana then drops and collapse (Etebu and Young-Harry, 2011; Meena, 2017). Large areas of leaf can be damaged causing a lowering of photosynthetic ability, premature ripening of the fruit and reduction in yield (Meena, 2017). The pathogen reproduces both sexually (ascospores) and asexually (conidia) and are both important for its dispersal (Henderson *et al*., 2006). Management of the disease is reported to through regular sanitation, nutritional management, irrigation and drainage improvement, use of resistant cultivars, prevention and quarantine (Churchill, 2011; Kilimo Trust, 2012; Kablan *et al*., 2012).

2.3.2 Poor soil fertility

Many agricultural lands in the tropics are succumbed to nutrient loss through many processes which include, soil erosion, nutrient mining, weathering, decrease in organic matter and soil bioactivity, soil acidification, denitrification, volatilization, leaching, salinization, alkalization, poor soil management and pollution (Tisdale and Nelson, 1975; Bosch *et al*., 1996; Baijukya and de Steenhuijsen, 1998; Van Asten *et al*., 2004; Nyombi *et al.,* 2010; Wairegi *et al*., 2010; De Bauw *et al*., 2016). Such nutrient losses lead to nutrient deficiencies in the soil. The more widespread deficiency of plant nutrients in soils has adverse consequences for crop production (Henao and Baanante, 1999, 2006; Pilbeam and Morley, 2007). Nkuba and Mgenzi (2002) reported that, the expansion in cultivated land and intensification of banana productivity are limited by declining soil fertility. The most limiting nutrients in banana production are nitrogen, phosphorus, potassium, magnesium, calcium, zinc and boron (Weinert, 2016). Deficiencies of nutrients in the soil can cause up to 70% yield loss in banana crop (Tisdale *et al*., 1990). The effects due to nutrient deficiencies include reduced leaf growth, thin and profuse roots, lesser number of suckers, reduced photosynthesis, poor quality and fruits development (Nyombi, 2014; Majumdar *et al*., 2016). Other effects of low soil fertility reported by Nyombi *et al*. (2010) and Kablan *et al*. (2012) are increased susceptibility to pests and diseases. Due to the heavy feeder nature of banana plant, large quantities of nutrients have to be replaced in order to maintain soil fertility and to permit the continuous production of high yields (Naandanjain, 2011). Thus applications of nutrients are important for growth and development of plants as well as to beneficial microorganisms (Agrios, 2005). It has been reported that, in many African countries' fertilizer consumption is comparatively very low (Boniphace *et al.*, 2015). The average application rates of fertilizer for arable crops in the East African countries is 30 kg/ha/year, which is far less than the world average of 100 kg/ha/year (Wiggins and Jonathan, 2010). In banana farming regions fertilizer application is not a common practice (Van Asten *et al*., 2006).

Therefore, for improved banana yields, regular monitoring of soil macro and micro nutrient status is essential (Van Asten *et al*., 2004; Baijukya *et al*., 2005). Thus, this study also focused on determining the status of nutrient levels in the soil of major banana producing regions in the country. The optimal nutrient levels in the soil for banana production are 2.8-4.0% for total nitrogen, 50-75 mg/kg for phosphorus, 0.4-0.5 cmol(+)/kg for patassium, 1.0-3.0 cmol(+)/kg for magnesium, 4.0-10.0 cmol(+)/kg for calcium, 5-6.5 for soil pH, 2.5-3.5% for OC, 10–20 ppm for boron and 20–35 ppm for zinc (Weinert and Simpson, 2016).

2.3.3 Moisture stress

Water is reported to be the most limiting non-biological factor affecting banana production (Wairegi *et al*., 2010; Surendar *et al*., 2013; Taulya, 2015). There is a direct relation between biomass production and water consumed through transpiration (FAO, 2012). Water is essential for banana crop production; it is important in growth and development as it plays key role in all physiological and biochemical processes in banana plant (Nyombi *et al*., 2010; Surendar *et al*., 2013). Moreover, water is important in mechanical support of the plant by providing rigidity and serves as a carrier in the distribution of mineral nutrients and plant growth (Van Asten *et al*., 2011). According to Nyombi (2013), bananas require approximately 20-30 mm of water per week for satisfactory growth. The banana production system in Tanzania is mostly rain fed (Nkuba and Mgenzi, 2002), which is affected by unpredictable rainfall patterns (Ndamani and Watanabe, 2013). The apparent changes in rainfall patterns are reported to be due to anthropogenic activities and natural processes (Udayashankara *et al.,* 2016).

Due to moisture stress in the soil, there is accelerated poor performance of banana in many areas (Baijukya *et al.*, 2005; Nyombi *et al.*, 2010; Van Asten *et al.*, 2011). Water deficit results in a reduced biomass production that normally reduces yields (FAO, 2012). Application of water has been reported to increase the average bunch weight from 5 to 20 kg (Surendar *et al*., 2013).

Therefore, water conservation practices in banana farms are of prime importance. It was reported that mulch application, fanya juu, fanya chini and trenches are common water conservation techniques (FAO, 2012; Ahamada *et al*., 2018). Wolka *et al*. (2018) and

Adimassu *et al*. (2016) reported increase in yields through water conservation techniques (fanya juu, fanya chini trenches), which reduced runoff by more than 70%. Mulch application is reported to attribute to yield increase of more than 60% of the potential yield of banana in Tanzania (Bananuka and Rubaihayo, 1994b). Mulches have the potential to form an important component in agro-ecosystems and can be a useful tool for weed management in sustainable agricultural systems (Kruidhof *et al*., 2008) including improvement of soil structure (Harris *et al.,* 1966), regulation of soil water content (Hoyt and Hargrove, 1986), enhancement of soil organic matter, carbon dynamics and microbiological function (Steenwerth and Belina, 2008), reducing soil erosion (Malik *et al.,* 2000), soil enrichment by nitrogen fixation (Sainju *et al*., 2001), insectarium for many beneficial arthropod species (Grafton-Cardwell *et al*., 1999), and enhancement of populations of soil macrofauna (Blanchart *et al*., 2006). Mulches also have the potential to suppress weed growth (De Haan *et al*., 1994), increase soil water infiltration (Bruce *et al*., 1992), decrease soil erosion (Cripps and Bates, 1993), contribute N to the crop (Corak *et al*., 1991) and reduce economic risk (Hanson *et al*., 1993). Thus, this study included on assessing the moisture management strategies used by farmers in the farms of the study area.

Tanzania like other countries is struggling to improve its banana production. There is a need to urgently assess the magnitudes of each challenge facing smallholder farmers so as to provide recommendations that can help farmers and other agricultural stakeholders in decision making to enhance in yield improvement.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted between December 2017 and April 2018 in four regions namely Kagera (Latitude: 1^0 54'59.99" S, Longitude: 31^0 17'60.00" E, altitude 793-1874 meter above sea level (m.a.s.l)) (NBS, 2010) and total area of 28 510 km^2 with Tropical savanna, Tropical monsoon and subtropical highland types of climate); Mbeya (Latitude: 8° 29' 59.99" 8 S, Longitude: 33° 00' 0.00" E, altitude from 475- 2981 m above sea level and total area of 62 420 km^2 with a subtropical highland climate, according to the Köppen climate classification); Arusha (Latitude: 3^0 23' 12.9300" S, Longitude: 36^0 40' 58.7820'' E, altitude 1387 m and total area of 37,576 km^2 with subtropical highland climate) and Kilimanjaro (Latitude: 4^0 8' 1.29'' S, Longitude: 37^0 48' 31.57'' E, altitude 2500-5500 m and an area of 13 250 km² with Marine west coast climate. The site selection was based on banana production records and specifically the seven districts namely Bukoba rural, Karagwe, Misenyi, Arumeru, Hai, Rombo and Rungwe (Fig. 2).

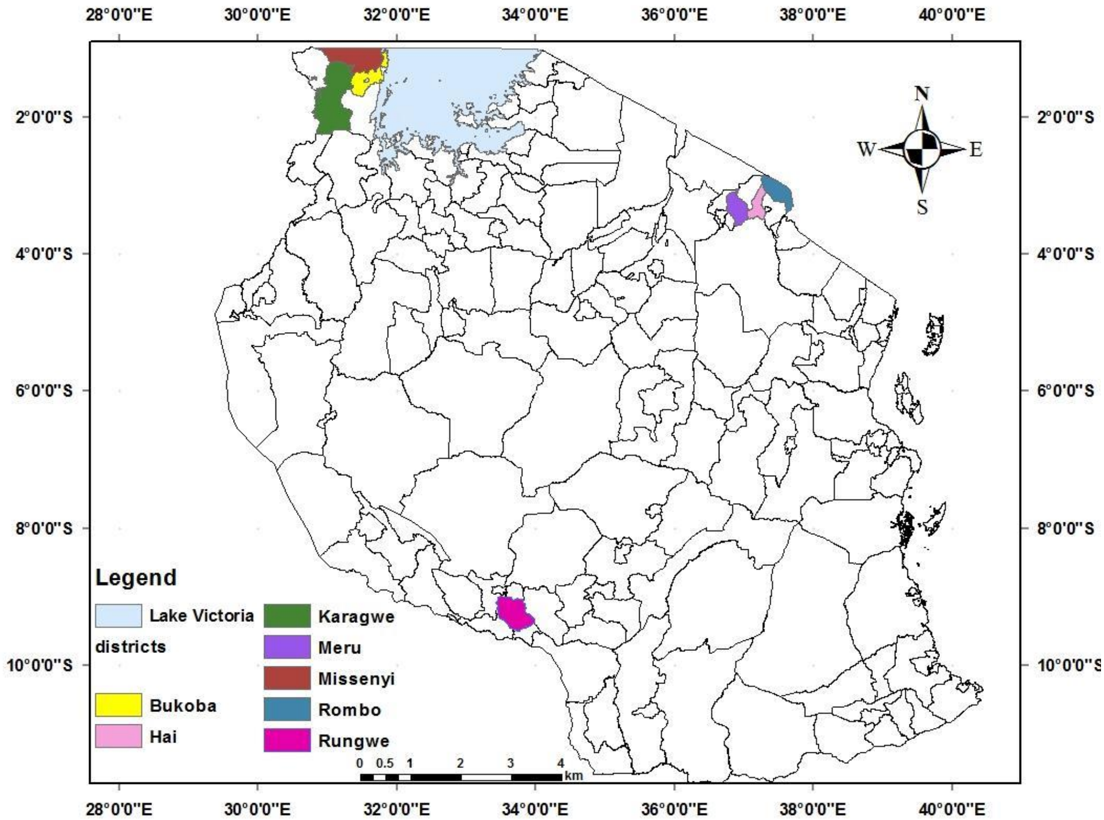

Figure 2: A map showing districts of the study area

3.2 Experimental Design and experiments

The experiment was arranged in a randomized complete block design with four replications. In each location, four villages representing four replications were randomly selected for collecting information of insect pests and diseases and soil sample. In total, 56 locations covering 560 farms with 560 corresponding number of farmers.

3.3.1 Nematodes Damage Assessment

On each farm, six mats with at least one flowered plant (plant in their first 14 days of flower emergence) were randomly selected for nematodes assessment. On every selected mat, a 20 cm squared hole was dug on the ground close to the flowered plant, using a spade to obtain sample roots for nematodes assessment. The number of functional and dead roots were counted and recorded. Root cortical necrosis (percentage) in banana roots was evaluated on five functional roots randomly selected per sample as described by Speijer and De Waele (1997). Root necrosis index (RNI) was estimated on a scale of 0 (no damage) to 20 (complete damage) for each root, by scoring each longitudinally split half root (Fig. 3A) and results were recorded in percentages as described by Speijer and De Waele (1997).

3.3.2 Banana weevil damage assessment

Banana weevil damage was assessed from the corm of harvested plants (not more than three weeks after harvesting). The corm was cut into a transverse cross section at the collar of the upper cross section inner diameter and outer diameter based on the protocol (Gold *et al*., 2004; Viljoen *et al*., 2016). The scores for weevil damage were recorded in percentage for the inner cylinder and outer cortex of the upper cross section. The corms were cut again into a transverse cross section at 5cm below the collar and the diameter of the inner and outer cylinder on the lower cross-section, damage were scored and recorded in percentage for both. The total weevil percent damage per corm was obtained by calculating the average of cross section percent damage of the inner cylinder and outer cortex using a formula (XT= (UXI+UXO+LXI+LXO)/4)) as described by Gold *et al*. (2004) and Viljoen *et al*. (2016). Whereas UXI = Upper cross section inner cylinder damage, UXO = Upper cross section outer cortex damage, LXI = Lower cross section inner damage and LXO = Lower cross section outer damage. Then the percentage average damage per village was calculated from the average percentage damage per corm. Interpretation of the percentage damage was done using a scale of 0 - 100 described by Oliveira *et al*. (2017), the following damage scale (score): 0 (no galleries present), 5 (traces of galleries observed), 10 (between 5 and 20 galleries present), 20 (galleries in approximately 25% of the rhizome), 30 (galleries in approximately 20% - 40% of the rhizome), 40 (galleries in approximately 50% of the rhizome), 50 (galleries in approximately 75% of the rhizome), and 100 (galleries in the entire rhizome) (Fig. 3B).

Figure 3: Roots prepared for nematodes assessment (A), and corm prepared for weevil assessment (B).

3.3.3 Assessment of black sigatoka leaf spot

The flowering plant selected for nematodes assessment was also used for black sigatoka disease assessment. The position of the youngest leaf spotted (YLS) with necrotic lesion was used for assessment of sigatoka leaf spot disease (Stover and Dickson, 1970). This parameter was monitored by counting from the first fully furl leaf down, to the youngest with at least 10 or more mature necrotic lesion (youngest leaf spotted (YLS)) (Viljoen *et al.*, 2016). For the plant with no symptoms, the total number of standing leaves on the plant were added with one (NSL+1) (Jones, 1993). The effect of the disease was indirectly evaluated using Index of non spotted leaves (INSL) based on the formula, INSL = (YLS-1)/NSL*100%.

3.3.4 Assessing pests control practices (PCP) used by farmers

For each farm, a common structured questionnaire was administered through face to face interview with the farm owner/family member. The questionnaire was designed to gather general information on pests and diseases management practices currently in use by the farmer. The questions on the control practices were open to allow selection of responses according to current practices used by farmers.

3.3.5 Weed cover assessment

To obtain data on weed cover, banana plots were divided into three strata. The first stratum was close to the homestead (up to 20 m) the second stratum was the intermediate distance from the homestead (between 20 and 40 m) and lastly, far from the homestead (over 40 m). On each stratum, 3 mats were taken making a total of 9 mats on each field. Weed cover assessment was done due to the reason that weeds are alternative hosts for pests; compete with crops for nutrients and harbors pests (Kropff, 1988). Percentage weed cover was estimated around the mat area (Fig. 4). The same procedure was repeated in all farms of the surveyed districts. Finally, weed cover were estimated and recorded in percentage (%).

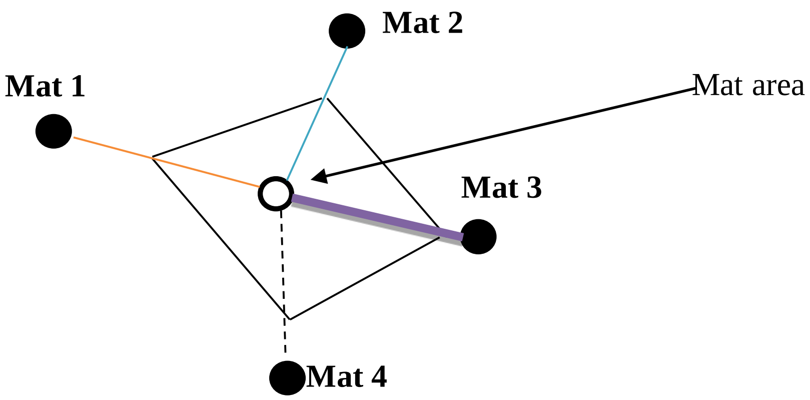

Figure 4: Assessment of weed and mulch cover within the mat area of the reference mat at each of the four points selected to be representative of the mat area.

3.3.6 Soil sampling

The representative composite soil sample was obtained from three locations at 2.82 m, 3.99 m and 5.64 m in different directions from the mat as described by AfSIS (2016) using tied ropes. The reason for using this particular sampling pattern is to obtain composite samples that are good representative of a 100 m^2 area, for both top and sub soils (Fig. 5).

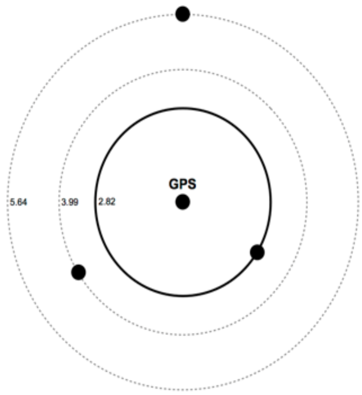

Figure 5: Field soil sampling layout AfSIS, (2016)

Marked soil auger was used to collect two separate soil samples at the depth of 0-20 cm (topsoil) and 20-50 cm (subsoil) on the same site. Three soil samples obtained from each mat area at the same depth were thoroughly mixed on clean plastic sheet to obtain a composite soil sample. A composite soil sample was obtained by mixing and quartering the soil samples leaving three-quarters till an estimated amount of 500 g was attained. Then, the 500 g of composite soil samples from each mat obtained at different depths were kept into separate plastic bags and properly labeled. A total of 1168 composite soil samples were collected from 560 farms during the survey with additional information such as latitude, longitude and altitude of each surveyed farm. From the field the samples were brought in the screen-house, removed from their bags and spread for air-drying. A 500 g of each composite soil sample were ground and sieved for laboratory analysis. The composite soil samples were sent for analysis of soil Organic carbon (OC), pH, available P, total N as well as extractable Mg, Ca, K, Zn and B at the Tanzania Research Institute, Selian Centre.

The collected soil samples were analyzed using Alpha Spectrometer method which utilizes Mid-Infrared (Aynekulu *et al.*, 2016; Gourlay *et al.*, 2017). The computation was corrected using reference soil samples that were analyzed using Mehlich 3 wet-chemistry method (Gourlay *et al.*, 2017). Levels of nutrients in the soil were recorded in different units (mg/kg, cm/kg and ppm).

3.3.7 Assessing soil and water conservation practices used by farmers

To obtain data on mulch cover and mulch depth, banana plots were divided into three strata. The first stratum was close to the homestead (up to 20 m), the second stratum was the intermediate distance from the homestead (between 20 and 40 m) and lastly, far from the homestead (over 40 m). On each stratum, 3 mats were taken making a total of 9 mats on each field. Mulch cover assessment was done due to the reason that mulches are among water conservation techniques (Bananuka and Rubaihayo, 1994b). Percentage mulch cover was estimated around the mat area (Fig. 4), whereas mulch depths were measure by using ruler. The same procedure was repeated in all farms of the surveyed districts. Finally, mulch cover were estimated and recorded in percentage (%).

Another method was questionnaire, where respondents were asked to say whether they use mulches, trenches, contour ploughing, grass and soil bunds, minimum tillage, cover crops and fallowing for soil and water conservation or not whereby the number of responses were counted.

3.4 Data analysis

All data were organized using Microsoft Excel. For nematodes, percentage dead roots were calculated by dividing average number of dead roots over total number of roots. Furthermore, nematode necrosis damage observations were normalized using arcsin ($\sqrt{x}/100$) prior to analysis of variance in order to reduce data variability. Then all data were subjected to Analysis of variance and mean separation test using Duncan Multiple Range Test to observe significance. For weevil damages, the percentage average damage per village was subjected to analysis of variance using GenStat version 14 (VSN International LTD, 2012).

The numbers of respondents from questionnaires were used to calculate the average percentage control practice and the average percentage soil and water conservation practice per district. Spearman correlation was used to show relationships between pests and disease damages against weed and mulch cover. Nutrients in the soil (mg/kg, cm/kg and ppm), the average % weed covers were subjected to Analysis of variance and mean separation test using Duncan multiple range test for ascertaining the significant difference among the surveyed districts.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Nematode damage levels

The results showed that, the number of dead roots differed significantly ($P<0.001$) among the surveyed banana production areas of Tanzania (Table 1). Karagwe and Misenyi had the highest number of dead roots and they differed significantly ($P<0.001$) with other districts. However, there were no significant difference ($P<0.05$) in dead roots among Arumeru, Hai, Rombo and Rungwe districts which had the lowest percent dead roots. Bukoba rural recorded 4 numbers of dead roots out of 10 which differed significantly with other districts.

Root necrosis due to nematode pest ranged between 3% and 16% which indicates a moderate level of infestation (Speijer and De Waele, 1997). The analysis of variance showed significant difference ($P<0.001$) in root necrosis between the surveyed districts. The highest necrotic ration was observed in Rungwe district with (16.0 de) followed by Misenyi, Bukoba rural and Karagwe districts which differed significantly (P<O.001) among all districts (Table 1).

Comparison on total root necrosis on the plant grown close to the homesteads (13.4%), on the middle of the farm (12.5%) and far end of the farm (9.2%) indicated to be significantly different ($P<0.001$) (Table 3). The observed decrease in Total Root Necrosis (TRN) from the household towards the far end of the farm could be due to high mulch application near the household. The results also showed that there was positive correlation on root necrosis which mulch cover ($r = 0.14$, $P<0.001$), mulch depth ($r = 0.05$, $P\leq0.05$) and weed cover ($r = 0.13$, $P\leq0.02$) (Table 2).

Table 1: Damage levels of nematode, weevil and black sigatoka disease on banana in different districts

Districts	Dead Roots out of 10	Total Root Necrosis	Weevil Damage (%)	Index of non-spotted leaves (%)

Bukoba Rural	4.0b	13.2bcd	11.3c	35.9a
Karagwe	5.0c	12.5bc	5.7b	44.0ab
Misenyi	4.9c	14.5cde	10.3c	43.4ab
Arumeru	2.1a	3.0a	1.1a	84.0cd
Hai	2.2a	9.3b	1.3a	83.0cd
Rombo	2.1a	13.2e	0.8a	89.0d
Rungwe	2.2a	16.0de	5.9b	32.0a
Grand mean	3.2	11.7	5.2	58.8
CV %	17.5	28.6	25.1	14
P $_{(\alpha<5\%)}$	<0.001***	<0.001***	<0.001***	<0.001***

- Mean values with same letters in a column are not significantly different based on the DMRT (p=0.05). INSL=index of non spotted leaves due to black, *** indicates very highly significant (P <0.001).

4.1.2 Weevil damage

Banana weevil damages were found all over the surveyed districts. The damage levels were between 0 and 11 galleries which represent 25% of pseudostem damage according to scale. Analysis of variance on percentage pseudostem damage showed significantly difference (P<0.001) between the surveyed districts (Table 1). Weevil damages in Bukoba rural and Misenyi were significantly higher (P<0.001) compared to other districts. Damages in Karagwe and Rungwe were at moderate levels and statistically different (P<0.001) with Rombo, Arumeru and Hai.

Analysis of variance on weevil damages indicated no significant difference (P≤0.1) between the three sub-plots of the farm in all surveyed districts (Table 3). Correlation analysis showed that weevil damages correlated positively and significantly with mulch cover (r = 0.89, P<0.001), mulch depth (r = 0.67, P≤0.003) and weed cover (r = 0.32, P<0.001).

4.1.3 Sigatoka leaf spot disease

Results on the index of non spotted leaves (INSL) showed significant difference (P<0.001) among the surveyed districts (Table 1). The highest INSL was observed in Rombo, followed by Arumeru and Hai whereby Rombo differed significantly with the later districts, though both the later had no significant difference between them. On the other hand, there were no significant difference between Karagwe and Misenyi, though they differed significantly with Bukoba Rural and Rungwe with all these districts having lower INSL (Table 1).

There was no significant difference (P≤0.2) between the three sub-plots of the farm in terms of mean INSL, though the INSL seemed to decrease from the household towards the far end of the farm implying increased in disease incidence (Table 3).

Table 2: Influence of mulch, mulch depth and weed cover on weevil and nematodes

	Weevil damages		**Nematode damage (TRN)**	
	Spearman correlation	**P value**	**Spearman correlation**	**P value**
Mulch cover	0.89	0.001***	0.14	0.001***
Mulch depth	0.67	0.003**	0.05	0.05
Weed cover	0.32	0.001***	0.13	0.02*

- Spearman correlation of weevil damages and Total root necrosis against mulch cover, mulch depth and weed cover among surveyed districts. (P>0.1 indicates no significant different, * indicate significant difference (P≤0.05), ** indicates highly significant different (P<0.01) and *** indicates very highly significant (P <0.001).

Table 3: Pest and disease damage levels from the household to the far end of the farm

Farm plot	**Mean Weevil damages**	**Mean Nematode damages**	**INSL**
Sub-plot 1	6.5	13.4	58.4
Sub-plot 2	6.1	12.5	53.0
Sub-plot 3	5.9	9.2	52.7
Grand mean	6.2	11.7	54.7
F-probability	0.1	0.001***	0.2

- Mean comparison among weevil damages, Nematode damages and INSL against farm sub plots among surveyed districts (P >0.1 indicates no significant different and *** indicates highly significant (P <0.001).

4.1.4 Pests control practices (PCP) used by farmers

Farmers use a number of practices to manage pests and diseases in banana farms. This study identified that most common practice was uprooting. More than 70% of farmers in surveyed districts are using uprooting method to control pests and diseases (Table 4). Although it is widely used practice across all districts, uprooting was most mentioned by farmers in Misenyi, Karagwe and Bukoba districts in Kagera region (Table 4). Intercropping was the second most used pests and diseases management practice. Overall 20% of the respondents reported using the intercropping method to control pests and diseases. A total of 17% of farmers mentioned to use trapping method for pests and diseases management, and 16% of the farmers reported to use resistance varieties as the method for pests and diseases management. Only 13% of the farmers mentioned using inorganic pesticides as the pests and diseases control practices. In general the percentage of farmers using other pests and diseases management practice was very low, less than 10%.

Table 4: Mean percentage of farmers using different pests and diseases management practices

Districts	Pests and Diseases Management practices (%)										
	Traps	Uprooting	Inorganic pesticides	Local pesticides	Pest repellant	Fertilizer application	Natural enemies	Resistant cultivars	Burning	Intercropping	Crop rotation
Karagwe	2	96	11	2	0	11	0	15	21	36	0
Misenyi	9	97	0	1	0	7	0	15	18	40	3
Bukoba rural	36	86	3	0	0	0	3	19	7	36	13
Arumeru	24	49	21	5	2	14	5	11	2	2	0
Rombo	16	56	27	3	0	0	0	19	0	6	0
Rungwe	23	73	10	0	4	7	2	13	1	17	11
Grand mean	17	74	13	2	1	6	1	16	6	20	5

4.1.5 The soil nutrient status

The results from this study indicated that the soils of major banana growing regions in Tanzania are deficient in many macro and micro nutrients, low organic carbon and optimal soil pH (Table 5 and Table 6).

(i) Soil pH

The pH values for soils in the study areas ranged from 5.6 to 6.2 (Table 6) which is medium acidic to slightly acidic (Landon, 1991). The mean separation test on soil pH using Duncan Multiple Range Test showed significant ($P<0.001$) difference among the surveyed districts. The highest pH of 6.2 was found in Hai district while the lowest pH of 5.6 was recorded in Misenyi district.

(ii) Organic Carbon (% OC)

The soils of the study area had % OC which were below the optimal level (> 2.5) for banana production. Statistics indicated that soil % OC contents differed significantly ($P<0.001$) among the surveyed districts (Table 6). There were no significance difference between Misenyi and Bukoba Rural districts, which recorded the highest % OC (1.9-2%), though differed significantly and were at medium level. Mean separation on % OC for Rungwe, Arumeru, Hai and Karagwe districts showed no significant different among them with % OC higher than Rombo, which differed significantly with these districts with the lowest % OC. According to Landon (1991) these values imply low levels of percentage Organic Carbon in the soils of the study area.

(iii) Total Nitrogen (%TN)

The levels of % Total Nitrogen in the soils of the study area were below the optimal levels (2.8-4.0 %) for banana production. Statistics showed that, percentage total nitrogen content in the soil differed significantly ($P<0.001$) among the surveyed districts (Table 5). Percentage total N ranged between 0.03% and 0.14%. Highest N percent was recorded in Hai district (0.14%) whereas Rombo and Rungwe recorded the lowest percent N (0.03%). There was no significant difference in percentage total nitrogen among Arumeru, Karagwe, Rombo Rural and Rungwe districts though they differed significantly with other districts. Furthermore, Bukoba rural and Misenyi had no significant difference between them.

(iv) Available phosphorus (P)

There was low available P in the soils of the study area which was below the optimal requirement (50-75 mg/kg). Statistical analysis indicated that, available P differed significantly ($P<0.001$) among the surveyed districts (Table 5). Rombo district had the highest level of available P and differed significantly from other districts. Bukoba rural, Karagwe, Hai and Rungwe had no significant difference among them though they differed significantly ($P<0.001$) from other districts. These districts had medium levels of available P (Landon, 1991). On the other hand Arumeru and Misenyi had no significant difference between them, though they differed significantly with other districts. According to Landon, (1991) these districts had low levels of available P.

(v) Potassium (K)

The observed levels of exchangeable K were below the optimal requirement (0.4-0.5 cmol(+)/kg) for banana production. There were no significant difference ($P<0.1$) on exchangeable K among districts of the study area (Table 5). The amount of Potassium (K) in the soils ranged from 0.02 to 0.28 cm (+)/kg. According to Landon (1991), the level of K in the soils is low in all districts of the study area. The highest K levels were recorded in Rombo district with 0.28 cmol (+)/kg and Hai district with 0.26 cmol (+)/kg. Lowest level of exchangeable K was recorded in Arumeru and Rungwe districts both having 0.02 cmol (+)/kg. The observed levels of potassium in all districts are below the recommended K levels for banana production which range between 0.4 and 0.5 cmol (+)/kg (Weinert and Simpson, 2016).

(vi) Calcium (Ca)

There were low Calcium levels in the soils of the study area which were below optimal requirement (4.0-10.0 cmol(+)/kg) for banana production. Analysis of variance showed that, Calcium levels in the soil differed significantly ($P<0.001$) among the districts of the study area (Table 5). The highest Ca content was in Misenyi district followed by Bukoba Rural which differed significantly between them and with other districts. Karagwe and Rombo did not defer significantly to each other inspite of their difference with the rest of districts. The lowest Ca content was recorded in Hai, Arumeru and Rungwe districts with no significant difference among them. Earlier study by Landon (1991) reported that the soil Ca content levels in the study area ranged from very low to low.

(vii) Magnesium (Mg)

The soils of the study area had low levels of Magnesium which are below the optimal requirement (1.0-3.0 cmol(+)/kg) for banana production. Statistics indicated that Magnesium content in the soil of the study area differed significantly ($P<0.001$) in all surveyed districts (Table 5). Misenyi, Bukoba rural and Karagwe had the highest recorded levels of soil Mg, though they had no significant difference among them; they also differed significantly with other districts. Arumeru, Hai and Rungwe had no significant difference among them with the lowest levels of soil Magnesium. Similarly, Rombo had lowest Mg but differed significantly with all other surveyed districts. According to Landon (1991) the results indicated that, all the soils of the study areas had very low exchangeable magnesium.

(viii) Boron (B)

There were low Boron levels in the soils of the study area which are below optimal requirement (10-20 ppm) for banana production. Analysis results on Boron levels in the soil indicated a significant difference ($P<0.002$) among the soils of the study area (Table 6). Bukoba rural, Misenyi, Karagwe and Rungwe had no significant difference among them but they differed significantly with other districts. However, Rombo, Arumeru and Hai differed significantly among them and with all other districts. Statistics showed that, there were significant differences ($P<0.05$) in levels of Boron in soils of the study area though according to Landon (1991), these levels were very low.

(ix) Zinc (Zn)

The observed levels of Zinc in the soils of the study area were below optimal requirement (20-35 ppm) for banana production. Statistical analysis on the levels of Zn in the soil showed a significant difference ($P\leq0.002$) among the soils of the study area (Table 6). Bukoba rural and Misenyi had no significant difference between them with highest recorded levels of Zn and they differed significantly with other districts. Similarly, Hai and Rungwe had no significant difference among them but they differed significantly with other districts. On the other hand Arumeru, Karagwe and Rombo differed significantly among them and with other districts. According to Landon (1991) the levels of Zn in all soils of the study areas were medium.

Table 5: Macro nutrient status for top and sub soils in the surveyed districts

Districts	**TN (%)**		**P (mg/kg)**		**K (cmol(+)/kg)**		**Mg (Cm(+)/kg)**		**Ca (cm(+)/kg)**	
	Top Soil (0-20cm)	**Sub Soil (20-40)**	**Top Soil (0-20cm)**	**Sub Soil (20-40)**	**Top Soil (0-20cm)**	**Sub Soil (20-40)**	**Top Soil (0-20cm)**	**Sub Soil (20-40)**	**Top Soil (0-20cm)**	**Sub Soil (20-40)**
Arumeru	0.04a	0.04ab	5.5a	5.3a	0.02a	0.02a	0.03ab	0.01a	0.21ab	0.2a
Bukoba rural	0.08b	0.08bc	6.7ab	6.4ab	0.07a	0.06a	0.12c	0.12e	1.6c	1.6c
Misenyi	0.09b	0.09c	4.9a	5.0a	0.06a	0.06a	0.13c	0.10d	2.01d	2.0d
Hai	0.14c	0.17d	7.0ab	6.8ab	0.25b	0.26b	0.04ab	0.04b	0.32ab	0.3a
Karagwe	0.04a	0.04ab	6.7ab	6.4ab	0.04a	0.04a	0.10c	0.10d	1.02b	1.0b
Rombo	0.03a	0.03a	8.0b	7.5b	0.28b	0.28b	0.06b	0.06c	0.71b	0.7b
Rungwe	0.03a	0.03a	6.5ab	6.3ab	0.02a	0.02a	0.03ab	0.03b	0.22ab	0.2a
C.v%	27.4	0.05	21.7	1.85	167.4	0.02	33.2	0.02	29.4	29.4
F.pr	<0.001***	<0.001***	<0.001***	0.146	0.102	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***

- Mean values with same letters in a column are not significantly different based on the DMRT (p=0.05). The comparison is along the column and *** indicates highly significant (P <0.001), C.v% = coefficient of variation, F.pr = Fishers probability.

Table 6: Soil pH, percentage organic carbon (% OC) and micro nutrient status for top and sub soils in the surveyed districts

Districts	**Soil pH**		**OC (%)**		**B (ppm)**		**Zn (ppm)**	
	Top Soil (0-20cm)	**Sub Soil (20-40)**	**Top Soil (0-20cm)**	**Sub Soil (20-40)**	**Top Soil (0-20cm)**	**Sub Soil (20-40)**	**Top Soil (0-20cm)**	**Sub Soil (20-40)**
Arumeru	5.7a	5.7ab	1.2b	1.2b	0.50a	0.5a	1^-8a	1^-8ab
Bukoba rural	5.8ab	5.8b	1.9c	1.9c	0.73c	0.8b	0.01bc	0.01b
Misenyi	5.7a	5.6a	2.0c	2.0c	0.73c	0.6ab	0.01bc	0.01b
Hai	6.2d	6.2d	1.2b	1.2b	0.53ab	0.5a	0.00001ab	1^-8ab
Karagwe	6.1cd	5.9bc	1.0b	1.0ab	0.6abc	0.6ab	0.01bc	0.01b
Rombo	6.0bc	6.0cd	0.7a	1.0ab	0.7bc	0.7ab	0.03c	0.03c
Rungwe	6.0bc	6.0cd	1.0b	1.1a	0.55ab	0.6ab	0.01bc	0.01b
C.v%	2.1	0.18	16.2	0.19	13.5	0.20	49.3	0.01
F.pr	<0.001***	<0.001***	<0.001***	<0.001***	0.002***	0.153	<0.001***	<0.001***

- Mean values with same letters in a column are not significantly different based on the DMRT (p=0.05). The comparison is along the column, *** indicates highly significant (P <0.001), C.v% = coefficient of variation, F.pr = Fishers probability.

Comparison between top and sub soils showed that, there were no significant differences (P>0.05) between top and sub soil for TN (%), K (cmol(+)/kg), Mg (cmol(+)/kg), soil pH, OC (%), B (ppm) and Z (ppm) (Fig. 6). However, there was a significant difference (P<0.05) between top and sub soil for available P and Ca.

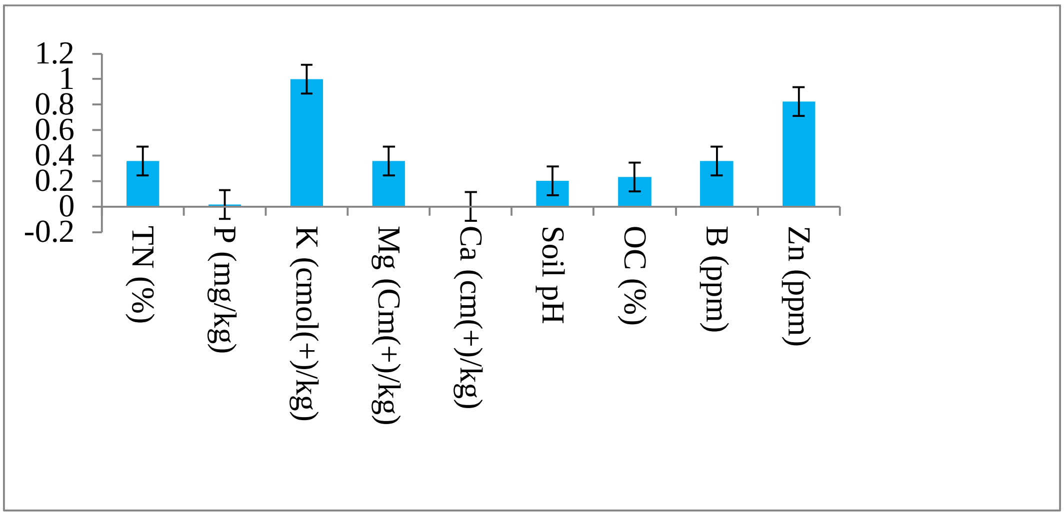

Figure 6: T-test showing nutrient relationship between top and sub soils of the study area

4.1.6 Soil and water conservation practices used by farmers

Mulching was the mostly used soil and water conservation practices across all the surveyed districts. Rungwe district is the leading in terms of mulching application on their fields followed by Rombo and Bukoba districts. The observed differences in levels of mulch application might be contributed by different uses of banana leaves, difference in water management skills and shortage of labor. Other major water conservation practices were rarely used across all surveyed district (Table 7).

Table 7: Major soil and water conservation practices (SWCP) used by farmers

Management practice (%)	Arumeru	Bukoba Rural	Hai	Karagwe	Misenyi	Rombo	Rungwe
Mulching	24	72	49	49	61	75	95
Trenching	11	1	3	1	1	0	0
Contour ploughing	1	0	1	0	0	0	0
Grass and Soil bands	2	0	0	0	0	0	0
Minimum tillage	7	0	5	0	0	0	0
Cover crops	5	0	1	0	0	0	0
Fallowing	0	9	0	5	3	0	0
Grand mean	7	11	8	8	9	11	14

- Mean percentage of the major soil and water conservation practices used by farmers in the districts of the study area

4.2 Discussion

In this study, variations were observed on nematode damage levels in the study area, though the damage levels were low according to scale (Speijer and De-Waele, 1997). The difference infestation levels based on counts of dead roots could be due to biotic and abiotic factors. For instance, Speijer and De-Waele (1997) and Gauggel *et al*. (2003) reported the abiotic factors such as climatic conditions, nutrient imbalance, loss of porosity, soil erosion, poor drainage, and biotic factors such as increase in nematode population and decrease in soil micro and microorganisms to have a negative effect to banana roots and yield. The results on necrotic rations showed that there are differences in damages due to nematodes; this might be due to the ability of different banana cultivar to react to the pests, soil type, insect species diversity and climate. Price (1994) and Gaidashova *et al*. (2008) reported that there are susceptibility differences on nematode among different banana cultivars whereas some nematode species are aggressive than other species. Kumar *et al*. (2014) and Coyne *et al*. (2014) reported that, soil types and climatic factors significantly affect nematode performance. On the other hand Moens *et al*. (2001) reported that crop residue and mulch application favor infestation of pests such as nematodes.

The differences on damages due to banana weevil could be due to mulch covers, weed cover, crop residues, knowledge difference on phytosanitary measures and banana cultivar susceptibility. This result agrees with what was reported by Gold (1999) that weevil pest is mostly found in crop residues and mulches which provides hatching sites for the pest. Moreover, weevil attack various banana cultivars based on susceptibility (Ortiz *et al*., 1995; Kiggundu *et al*., 2007). However, damages observed between the farms' sub plots might be due to uniformity of banana cultivar grown in the farms. Same cultivars respond similarly in terms of infestation and damage (Kiggundu *et al*., 2003). The positive correlation of weevil damage against mulch application and weed cover observed indicate that presence of mulches, weeds and their improper management favors infestation of weevils by providing hatching sites (Gold, 1999).

The observed differences in Index of Non Spotted Leaves among the surveyed districts could be attributed to weather conditions, susceptibility of cultivars, difference in isolate aggressiveness, geographical location, differences in disease management skills and soil silicon nutrient content. This agrees with Chuang and Jeger (1987) and Churchill (2011) who reported that black sigatoka disease is strongly related to weather conditions and plant susceptibility.

Kablan *et al*. (2012) and Wang *et al*. (2017) reported a reduced black sigatoka disease due to silicon application in banana. Low levels of youngest leaf spots reported in form of INSL might be due to frequent pruning of leaves near homestead for animals feed, mulches and cooking that reduces inoculums near homestead.

The variability observed in soil pH might be contributed by differences in parent rock materials, climate and human activities (USDA-NRCS, 2014). These soils had pH values which are within adequate levels of 5.5–6.5 for banana production (Weinert and Simpson, 2016). This pH is both optimal for nutrient availability and soil microbial activities (Dotaniya and Meena, 2014). This also agrees with UMass Extension (2011) which reported that pH below 5.2 render nutrients in the soil unavailable for plants.

The observed low and differences in levels of percent Organic Carbon might be attributed to differences in mulch application, use of banana leaves as animal feeds, use for cooking and thatching materials. Baijukya and de Steenhuijsen (1998) reported that % OC is contributed by mulch application. Removal of banana pseudostem, leaves and male buds have contributed to lowering percent OC. This is in line with what Kamira *et al*. (2015) reported that pseudostem and male bud are used as animal feeds due to their high nutritive value. Use of the male bud as a vegetable was also reported and could be promoted among communities in the region. The nutrient value of the pseudostem is high and could be promoted as animal feed in this highly populated region to enable zero grazing of small ruminants. For all the soils in the study areas, application of organic manures, incorporation of crop residues and mulch should be encourage increasing the carbon content and microorganisms in the soils so as to improve crop growth and yields.

The low and differences observed in total nitrogen levels could be due to leaching, nutrient mining, volatilization and denitrification. This agrees with Taulya (2015) who reported that 10 to 20 kg of Nitrogen ha^{-1} yr^{-1} are exported off banana farms through bunches harvest. Other studies have reported that, nitrogen (N) get lost through leaching in form of nitrate due to high rainfall, poor intercropping and low fertilizer application (Henao and Baamate, 2006; Nyombi, 2014; Majumdar *et al*., 2016). Furthermore, N losses are due to denitrification and ammonia volatilization from soils and plants (Jones *et al*., 2013). Therefore, farmers in the study areas should aim to increase N through split application of farm yard manure and mineral fertilizers to replace nutrients losses.

The reason for low and the differences observed in the available P could be due to nature of the parent rock materials and application of P releasing fertilizers. According to Moreira and Fageria (2009), low inherent P in the parent rock material and phosphate fixation by aluminal-silcate and iron minerals present in the soils contribute to the variation in the levels of available P. Therefore, application of P releasing fertilizers such as rock phosphate e.g. Minjingu rock phosphate is highly recommended.

The reason to low and differences in levels of exchangeable K in the soil might be due to nutrient mining through harvest, animal feeding, cooking and thatching materials. Taulya (2015) reported that 20 to 80 kg K ha^{-1} yr^{-1} are exported off banana farms through bunches harvest. Other processes reported to cause low exchangeable K in the soils are leaching, fixation, biological activities and inherently low K in the parent rock material. Potassium containing parental material like feldspar and mica has influence in levels of exchangeable K in the soil (Nahon, 1991). Akbas *et al*. (2017) reported that low levels of K in the soils is a consequence of interactions between parent materials, biology, climate, time and topography and human factors such as fertilization, tillage and cropping systems.

The low and differences in levels of calcium in the soil agrees with a report by Weinert and Simpson (2016), who reported that, Calcium deficiency is a widespread problem in banana growing areas. The deficiency in soil Ca might have been contributed by several factors, these include; inadequacy calcium in the inherent rock material and moisture stress (Tisdale and Nelson, 1975; Jakovljevic *et al*., 2003), intensive production practice (Olle and Bender, 2009) and leaching (Upadhyay *et al*., 2013). The most obvious measure of correcting this deficiency is by the application of calcium carbonate or dolomitic limestone and other calcium containing fertilizers like Minjingu Nafaka and Yalamila winner.

The low levels of Mg content in the soils might be caused by low Mg in the inherent parent rock material, leaching and low application of Mg containing fertilizers. It is reported by Van Asten *et al*. (2004) that, Magnesium deficiency is one of the major constraints of East Africa highland banana production. Van der Pol and Traore (1993) and Grzebisz (2011) reported that, Mg losses from the soil are attributed by mobilization, subsequent leaching, long-term unbalanced crop fertilization practice and through crop Mg removal. It is also reported further that magnesium in the soils is influenced by nature of bedrock and minerals (Tisdale and Nelson, 1975).

The differences and low levels of boron in the soils of the study area agree with a report by Singh *et al*. (2005) that, Boron deficiency is one of the major constraints to crop production. The possible reasons for low levels of boron in the soil might be due to leaching, drought, intensive cultivation, low of B releasing fertilizers, liming and low organic matter in the soil (Ahmad *et al*., 2012). Thus, application of boron containing fertilizers like Minjingu nafaka and Yaramila winner in the soils of the study area is of great important to alleviate the problem of very low boron in these soils.

Low levels of zinc in the soils of the study area correlate with other studies that, Zinc deficiency is a common problem (Singh *et al*., 2005). Zinc is one of the important micronutrients required for growth and development of banana plant, although it is required in small quantity nevertheless, it is critical important in increasing banana bunch yield (Moreira and Fageria, 2009; Weinert and Simpson, 2016). The content of Zn in soil is connected to the chemical composition of the parent rock and the extent of weathering processes (Chesworth, 1991).

There was less use of water conservation practices except mulch in all surveyed districts. This might be due to knowledge differences among smallholder farmers, economic status and age of the farmer (Winter, 1992).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this study has demonstrated that parasitic nematodes, banana weevils, together and black sigatoka disease are of great economic importance due to the loss they cause. Improper weeds and mulch management favor high and rapid infestation of banana weevils and parasitic nematodes. Moreover, both macro and micro nutrients in the soils of the study area were low for banana production except phosphorus which was in medium levels in all districts except Arumeru and Misenyi. There was low percentage Organic Carbon in all districts except in Misenyi and Bukoba rural which had medium levels. Soil pH was optimal for banana production in all soils of the study area. There were minimum efforts and practices for water conservation except mulch in all surveyed districts. The observed infestation levels of pests and disease together with low nutrient levels in the soil have great chances of decreasing banana productions in the country.

5.2 Recommendations

In the current situation we recommend banana farmers in the study areas to apply natural organic manure e.g farmyard manure and fertilizers like Yalamila winner and Minjingu nafaka, in order to increase nutrient levels in the soils. More research is needed to find out suitable methods to be used to manage the emerging banana pests and diseases for sustainable banana production. This result also recommends that there is a need for developing quick interventions with regards to soil fertility management so as to improve banana production in Tanzania. The results on the levels of nutrients in the soils suggests that, in order to increase banana crop productivity in the country, maintenance of soil fertility status is important for sustainable banana production and increased banana yields.

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