STATUS OF FUSARIUM WILT OF BANANA IN KISII COUNTY AND ITS MANAGEMENT USING SOIL AMENDMENTS

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university

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DEDICATION

This thesis is dedicated to my beloved family, my wife Elimeldah, my daughters Martha, Elizabeth, Risper and sons Joseph, Stephen, Tiberius for the encouragement and support.

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ACRONYMS AND ABBREVIATIONS

AEZ	Agro-ecological Zone
ANOVA	Analysis of variance
AUDPC	Area under Disease Progress Curve
BXW	Banana *Xanthomomas* Wilt
DAP	Di-ammonium phosphate
FOC	*Fusarium oxysporum* f.sp. *cubense*
LH1	Lower Highland 1
LH 2	Lower Highland 2
LSD	Least Significant of Difference
PDA	Potato Dextrose Agar
pH	Hydrogen ion concentration
R 1	*Fusarium oxysporum* f.sp. *cubense* Race 1
R 2	*Fusarium oxysporum* f.sp. *cubense* Race 2
R 3	*Fusarium oxysporum* f.sp. *cubense* Race 3
R 4	*Fusarium oxysporum* f.sp. *cubense* Race 4
UM 1	Upper Midland 1

ABSTRACT

Fusarium wilt is a serious problem in banana growing regions in Kenya. It affects particularly apple bananas but other bananas such as Gros Michel and Bokoboko are also affected to a lesser extent. Improving the conditions of the soils is one of the key control methods as the *Fusarium oxysporum* is widespread in the soils that have high moisture content and poor drainage. The objective of this study was to determine the extent of spread of *Fusarium* wilt of banana in Kisii County and the efficacy of organic and inorganic soil amendments in the management of the disease. A semi structured questionnaire was administered to individual farmers in agro-ecological zones UM1 and LH1 in the form of interviews to establish the spread of *Fusarium* wilt. During the survey, banana cuttings of pseudo stem and roots of four symptomatic and four asymptomatic banana samples from each farm were taken and used in isolation of *Fusarium* wilt pathogen. The soil amendments that were evaluated were wood ash, *Tithonia diversifolia*, poultry manure, diammonium phosphate, urea and sodium hypochlorite. Inoculum was prepared in the laboratory using the collected diseased banana samples and then used to infest soils both in the greenhouse and the field on potted plants. The greenhouse trials evaluated apple bananas only whereas the field trials evaluated susceptible, tolerant and resistant banana varieties.

Majority of the farmers 55% attained an average of eight years education and were in age bracket of 40-50 years. Commonly grown crops by the farmers in the two Agro-ecological zones were bananas, coffee, maize, tea. While many of the farmers grew apple banana as one of the improved banana varieties in both sites, 95% of the respondents in LH1 and 55% in UM1 grew Ng'ombe,atraditional variety. Ng'ombe was the most popular local variety grown in both agro-ecological zones giving 75% of the total respondents' while100% and 90% of the respondents gave apple variety and Uganda green respectively as the main improved/exotic banana varieties

in the two zones. Farmers listed diseases such as *Fusarium* wilt of bananas and Black sigatoka as the main constraints affecting bananas.

The results indicate significant reduction in disease incidence in plots treated with poultry manure and sugarcane ash. The *Fusarium* wilt incidence increased overtime in all the treatments but at different rates with control plots recording the highest incidence every week from the start to the end of sampling time while the least incidence was noted in plots treated with sugarcane ash. The highest *Fusarium* wilt incidence and largest area of disease progress curve (AUDPC) was observed in plots without any soil amendment applied. The experimental results from this study identified poultry manure and sugarcane ash as the most active organic amendments against *Fusarium* wilt, reducing disease incidence by over 30% compared to other amendments. Total suppression is significant in the management of the disease since the pathogen is soil borne and can last for long; however, this was not achieved by any of the amendments**.** In summary, soil amendments can be used to practically manage *Fusarium* wilt and poultry manure and sugarcane ash present good management strategy that should be integrated in *Fusarium* wilt management to reduce the inoculum levels and pathogenicity. Based on the findings of this study, further studies should be done in the field in different soil types, banana cultivars and crop husbandry systems to determine the synergistic effect of integrating poultry manure and wood ash in in management of Fusarium wilt under field conditions.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Fusarium wilt has been known to be a destructive disease all over the world where bananas (*Musa spp*) are grown (Castle, 2009).The very first case of this disease was recorded in 1876 in Australia (Ploetz and Pegg, 2000). The pathogen is a soil borne fungus that induces *Fusarium* wilt in host plants by preventing sap movement in the xylem vessel (Castle, 2009). The fungus also survives in plant debris. It finds its way into the banana plant in most cases through damages on the roots. This means that the disease always starts by attacking the roots of banana plants.

Though the disease has been in existence since 19th Century, its effect was noticed in the 20th Century where it wiped out plantations of the crop in Panama and other parts of the world. The most popular banana variety in Panama: 'Gross Michel' comprised all the export production then. Its susceptibility to *Fusarium* wilt, threatened complete wipe out of banana production (Castle, 2009). Other resistant strains are in use nowadays but the *Fusarium* wilt fungus keeps evolving therefore putting the banana growing regions at risk. Also banana plants are at a disadvantage because they have inability to produce viable pollen hence unable to achieve reproduction by sexual means. Therefore, the crop's asexual reproduction perpetuates in subsequent generations of the crop that are genetically identical and hence susceptible to the same disease (Hand and Koltunow 2014).This disease is present in major banana growing areas of Kenya (Onyango, 2009). Affected varieties in Kenya are the dessert bananas such as Gross Michel 3 and Apple banana where up to 80% of the banana field may show symptoms of the disease (Onyango, 2008).

In Africa *Fusarium* types one, two, three and four exists affecting bananas but in Kenya only types one and two have been confirmed to exist (Onyango, 2008). The severity of *Fusarium* wilt is mainly influenced by the levels of stress for example during the extended periods of floods, imbalance of nutritional contents and limited or low temperatures and increased levels of salinity. In addition, banana plants produced by tissue culture suffer increased susceptibility to the disease when they are planted in the field infected with the fungus (Promusa 2010). *Fusarium* species are believed to be the oldest fungal colonizers on earth (Perez-Vicente *et al*., 2014). Infecting widespread plant species worldwide, *Fusarium oxysporum*, is one of the regular soil saprophyte. It survives in most soils and in both cultivated and non-cultivated fields. The disease development is favoured by the soils of warm, moist and increased high levels of temperatures with optimized soil temperatures for root infection being 30^{0}C or above (Castle, 2009).

1.2 Problem Statement

Fusarium wilt is the most serious constraint to banana production in the former Nyanza, Western, Central, Eastern and Coast provinces in Kenya (Kwach, 2014). *Fusarium oxysporum* f.sp.*cubense*which is a soil borne fungus is the causal pathogen of this disease. Up to 80% of banana field may show the symptoms of the disease. *Fusarium* types one, two, three and four exist in Africa but only types one and two have been confirmed to exist in Kenya (Onyango, 2008). This disease is one of the serious banana diseases and has been causing destruction in banana fields. This has led to abandonment of thousands of hectares of land. *Fusarium* wilt can wipe out the entire field that is infested with the pathogen resulting to zero yields. The emergence of Tropical race four has broken resistance of nearly all the traded international banana varieties such as Cavendish (Poon and Teo, 2019). Infection by FocTR4 is irreversible and untreatable; therefore its economic impact is profound.

Due to the ease with which *Fusarium* wilt spreads, the global industry of banana is under serious threat (Zheng and Siemack, 2018). *Fusarium* wilt is spread to new plantations through infected suckers and rhizomes. The spread may also occur through movement of infested soils adhering to vehicles, footwear, and animal feet over long distances. Over short distances it can be spread through roots' networks and interconnection and in surface presence of run-off water (Daly *et al* 2006). A number of strategies have been developed and tried on banana from the time this disease was reported, however, minimal control mechanisms have succeeded with the resistant cultivars being the alternative control means. The strategies that have been tried included fumigation of soil by use of fungicides, crop rotation, flood-fallowing, and planting of resistant cultivars.

These approaches have not presented an effective solution to control of the disease other than use of resistant cultivars (Daly *et al.,* 2006). Planting resistant cultivars has proved unsustainable because of the preferred taste and flavour of the consumer (Viljoen, 2002). It is against this background that the use of inorganic and organic soil amendments which will protect and promote growth of consumer preferred varieties is considered a suitable in managing the *Fusarium* wilt of banana. In search of methods to control *Fusarium* wilt, scientists around the world have embarked on resistance breeding, chemical control, bio-control, and molecular diagnostic methods. Some of these studies were found to effectively suppress *Fusarium oxysporum* growth in the laboratory and greenhouses but not in the open field (Huang *et al* 2012)

1.3 Justification

Environmental conditions favour banana production making it a key farming business enterprise in Kisii County. However, the presence of *Fusarium* wilt poses a serious challenge to banana production and this call for devising other strategies that can easily be afforded by small scale farmers in controlling the disease. Various control strategies have mostly concentrated on preventing the introduction of the disease into the field, early detection, cultural, biological and chemical control, boosting the vigour of the plant to tolerate the disease. Adoption of crop rotation program and cultural control methods cannot prevent *Fusarium* wilt because chlamydospores remain viable in the soil for a long period of time. Exploring the use of low cost organic amendments that exhibit soil borne disease suppression through improvement of the conditions of the soils is key control method. *Fusarium oxysporum* is has been noted to widespread in the soils that have high moisture content coupled with poor drainage. Methods that can suppress the disease but cost little and ploughing back organic fertility to the soil may highly assist farmers who cannot afford artificial fertilizers. The information generated from this study can be adopted by small scale farmers for subsistence production of banana.

1.4 Objective of the Study

The study sought to contribute towards management of *Fusarium* wilt of bananas using soil amendments.

Specific objectives

The specific objectives were

i. To determine the extent of spread of *Fusarium* wilt of banana in Kisii County.

ii. To determine the efficacy of organic and inorganic soil amendments in the management of *Fusarium* wilt of banana.

1.5 Hypotheses of the Study

The hypotheses were:

i) There is variation in the spread of Fusarium wilt in different agro-ecological zones of Kisii County

ii) Use of inorganic and organic soil amendments is effective in the suppression of *Fusarium* wilt of banana.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of banana Farming

Banana is a key food security crop for third world countries where it is a major source of nutrition and it is ranked fourth after rice, wheat and maize in total global food value production (Njau *et al.,* 2010). Of the total world banana and plantains, Sub-Saharan Africa produces 35% (Tripathi *et al*., 2008). In the East African region, small scale farmers do much of the banana farming where over 90% of the produce is consumed locally. In Kenya, banana crop covers around 82,518 hectares of arable land with production of over 1,058,018 tons per year (Kwach, 2014). Cultivation of banana in Kenya is mostly carried out under rain fed conditions by farmers who are mainly small land holders with a mean of 0.3hectares (Kwach, 2014). Western and Nyanza regions of Kenya are the dominant producers of banana with 641,524 tons of the national output.

Table 2. 1: Area under banana and production in different regions of Kenya

Provinces	Area (Ha)	Yield t/ha)	Production (t)	Value (Ksh (millions)
Nyanza	32,396	16	505,258	3,772
Western	12,645	11	136,266	1,362
Rift Valley	2,870	17	47,613	386
Central	15,540	14	217,175	2,016
Eastern	12,834	6	80,232	892
Nairobi	42	6	253	5
North Eastern	476	12	5,663	45
Coast	5,715	11	65,558	817
Total	82,518	93	1,058,018	9295

Source: Kwach *et al*., 2014

Banana is a basic food for numerous people in developing countries of the tropics where it plays a pivotal role in food security. Nutritionally, bananas are exceptional sources of potassium, vitamins A, B, C and D. Banana fruit can be eaten raw or cooked, its leaves and trunk can be fed on livestock while there are other uses including wrapping food, thatching houses, making ropes and mats (Njau*et al.*,2010). The most common banana cultivars grown widely in Kenya are outlined in a table 2.2 (Onyango, 2009).

Table 2.2: Banana Cultivars Widely Grown in Kenya

Genome Group	Name of Cultivar	Production region	Use
AAA-EA	Ng'ombe	Nyanza, Western,	Cooking
AAA-EA	Ekeganda	Central	Dessert
AAA-EA	Sialamule	Central	Cooking
AAA-EA	Ishighame	Central	Cooking
AAA	Dwarf Cavendish	Taveta Coast	Dessert
AAA	Giant Cavendish	Central	Dessert
AAA	Valery	Central	Dessert
AAA	Israel	Central	Dessert
AAA	Gross Michel	Central	Dessert
AA	Muraru	Central	Dessert
ABB	Bokoboko	Bomet, Nyanza	Dessert
AAB	Apple banana	Central, Western	Dessert
ABB	Apple banana	Nyanza	Dessert

Source: Onyango, (2009)

2.2 Constraints to banana production in Kenya

Diseases constitute the bulk of the limitations facing banana farming in Kenya (Table 2.3). Among these diseases, *Fusarium* wilt is the most destructive disease in the world, affecting mostly the dessert varieties (Njau *et al.*, 2010). In one of the participatory rural appraisal exercises' (PRAs) carried out in Kenya, diseases and pests were found to be the major limiting factors in banana production in most banana growing areas. Among these pests and diseases, the followingfeature predominantly:Banana*Xanthomonas* wilt (BXW), Sigatoka, *Fusarium* wilt, banana weevil, and parasitic nematodes. If the banana crop is to be protected then there must be a strategic plan for control of pests and diseases (Onyango, 2009). Banana farming is closely linked to *Fusarium* disease that has and continues to damage this major crop in the global trade (Onyango, 2009). The industry has experienced a surge in pest and disease in recent years that have lowered yields and plantation lifespan. Due to this a popular variety such as Gross Michel has been replaced by Cavendish as a result of loss in the resistance to race one of panama disease (Njau *et al*., 2010)

Table 2. 3: Pests and diseases affecting banana production in Kenya

Province	Constraints	Cultivars affected most
Coast	Black Sigatoka	Cavendish
Central and Eastern	Panama disease	Gross Michel
	BXW	All cultivars,
	Panama disease	Apple banana
	Sigatoka	All cultivars
	Moles	All cultivars
Nyanza/Western	Weevils and Nematodes	All cultivars

Source: Onyango, (2009). BXW –*Banana xanthomonas wilt*

2.3 *Fusarium* wilt of Banana

2.3.1 Occurrence and Distribution of *Fusarium* wilt

In the history of banana farming, *Fusarium* wilt is regarded as the most damaging disease. This pathogen is soil borne and can stay up to 30 years in the soil as chlamydospores. The disease was first reported in Australia in 1874 but became widely known for the damage it caused in large farms of banana production in Central America at the beginning of 20th century (Ploetz and Pegg, 2000).The *Fusarium* wilt pathogen has spread throughout the globe mainly by use of infected planting material. At present all countries in the world that are growing bananas have the disease with the exception of South Pacific Islands and a few nations that are neighbouring the Mediterranean (Dita *et al*., 2018).The causal agent of *Fusarium* wilt of banana is *Fusarium oxysporum Schlect.* f.sp. *cubense* which exists in the soil as a fungus (Dita *et al*., 2018). This fungus exists as dormant and immobile chlamydospores in decomposing tissues of bananas and also in the soil where it can only sprout if it is stimulated by the roots of the host plant, exudates from non-host roots, or getting into contact with non –colonized fresh plant leftovers (Perez-Vicente *et al.*, 2014).

2.3.2 Causal agent of *Fusarium* Wilt of banana

Fusarium wilt is caused by *Fusarium oxysporum* f. sp. c*ubense* (Foc),which is a fungus that inhabits the soil and remains dormant through chlamydospores until it is stimulated by a susceptible host (Dita *et al*., 2014). The fungus produces macroconidia and chlamydospores for reproduction and dispersal (Perez-Vicente *et al*., 2014). Mycelia and conidia are produced after 6-8 hours of chlamydospores germination and new chlamydospores after 2-3 days (Perez-Vicente, 2014). The pathogen exists as different pathogenic races such as *Foc* races 1, 2, 3 and 4. These are classified based on their ability to cause disease in a set of different banana cultivars. Race 1 causes disease in the Gros Michel (AAA) and Silk (AAB) cultivars. Race 2 attacks Bluggoe (ABB), and race 4 infects Cavendish (AAA) cultivars and all the cultivars that are susceptible to race 1 and 2 (Siamak and Zheng, 2018). Race four is highly virulent on Cavendish and the spores attach first to the banana root tip before the mycelia directly penetrates the cell wall (Zhang *et al*., 2017).

2.3.3 Infection process of *Fusarium* wilt

The dormant and immobile chlamydospores of the *Fusarium* pathogen stay in a dormant state until they are triggered to germinate by host or non-host root discharges or by getting in touch with susceptible root tissues (Ploetz and Pegg, 2000). Conidia and hyphae of the fungus adhere to the surfaces of roots at 1 or 2 days after inoculation (Li *et al*., 2017). Infection of the banana plant occurs directly or through the wounds created by insects or through farm operations on the feeder roots or secondary roots but not through the main root (Guo *et al*., 2014). After germination the pathogen proceeds to enter the plant through the root tips in responding to exudates from the roots, then moves inside the xylem vessels and finally into the rhizome.

The xylem vessels form a series of network with perforated end walls through which sap flows. There is a temporary blockage of both the spores and sap flow, thereby getting trapped at the end walls. This results in the production of both microconidia and macroconidia (Onyango, 2009). The former invades the vessels of xylem of the pseudostem causing plugging of xylem vessels resulting in minimal water flow (Perez-Vicente *et al*., 2014). The spores germinate and hyphae sprout through the perforated adjacent vessels where more spores are produced. The host plant responds by producing gels and tyloses to block infection in the xylem (Perez-Vicente *et al*., 2014). In spite of this defense mechanism, numerous infections take place in the life of the plant resulting to total invasion. Successive spreading of the conidia is blocked by the sieve cells resulting in the spores germinating and growing through them thereby spreading throughout the whole xylem system until it is blocked completely (Perez-Vicente *et al*., 2014).This then leads to death of the plant after which the fungus forms chlamydospores that are released back into the soil (Ploetz and Pegg, 2000). Several nutrients' effects on *Fusarium* wilts from the previous researchers revealed that increase in nitrate ions reduces disease development (Perez-Vicente *et al.*, 2014). Increase in ammonium ions favours disease development; liming and calcium ions increase soil suppressiveness and reduce chlamydospores germination (Perez-Vicente *et al.*, 2014). Neutral pH of 7 is less optimal for *Fusarium* wilt whereas pH below 6.5 favours disease development. Also higher pH in suppressive soils reduces infection (Perez-Vicente *et al.*, 2014).

2.3.4 Spread and Survival of *Fusarium* wilt pathogen

Spread of *Fusarium* wilt is achieved through the pathogen propagules moving passively in both long and short distances either from one agro-ecological zone to another or one farm to another (Dita *et al*., 2018). Longer distance dispersal is however, through anthropogenic-related factors, while dispersal at short distances may be associated to both anthropogenic and natural factors, such as water runoff, animal movement or soils that have the fungus spores (Dita *et al*., 2018). The fungus that causes *Fusarium* wilt of banana is spread to new plantations through infected suckers and rhizome.

The spread may also occur through infected soils adhering to vehicles, footwear and animals feet over long distances. Over short distances it can be spread through the fibrous roots interconnecting resulting to a network of roots and rain water as in surface run-off (Daly *et al.*, 2006). The banana plant is a monocotyledonous large perennial herb that has a rhizome, a terminal with crown of leaves and a pseudostem (Ploetz and Pegg, 2000).Both the root system and the above ground parts arise from a sympodial rhizome. Most species of the *Fusarium oxysporum* complex and more so *Fusarium oxysporum* f. sp. *cubense* survive in the absence of its primary host, by forming thick walls on spores known as chlamydospores (Dita *et al*., 2018).

The *Fusarium* wilt pathogen can survive in the soil as dormant and immobile chlamydospores in decayed banana tissue and soils up to 30 years in the absence of roots of the host or discharges from non-host rootstalk getting in touch with clean fresh plant leftovers (Perez-Vicente *et al.*, 2014). Chlamydospores resist dehydration and therefore can withstand adverse environmental conditions. The chlamydospores are continuously produced once the pathogen colonizes the host and incites the occurrence of symptoms (Li *et al*., 2011). Long period of survival by chlamydospores is enhanced by the pathogen infecting weeds and non- host plants that have no economic value and some of which may not show visible symptoms. For instance *Fusarium oxysporum* f. sp. *cubense* R1 has been reported in *Commelina diffusa* in the Central Americas while *Fusarium oxysporum* f. sp. *cubense* R4 was isolated in the root of *Cyanthillium cinereum* weed that were growing in banana fields (Dita *et al*., 2018).

2.3.5 Symptoms of *Fusarium* wilt of banana

Externally produced symptoms of the disease include; wilting and light yellow colouration on lower older leaves starting from the edge of the leaves (Guo *et al*., 2015). Finally the leaves change to bright yellow colour where the leave margins die. In advanced stages of the disease, additional leaves turn yellow and die. This results to leaves collapsing after dying and thereby hanging around the pseudostem. Affected leaves at times may form a spiky appearance because of the outstanding uprightness of leaves at the apex as opposed to the lower leaves that die forming a skirt. Also the pseudostem may split longitudinally on the outside of the leave bases above the soil level (Perez-Vicente *et al*., 2014). The leaf symptoms of *Fusarium* wilt may be indistinguishable with those of *Xanthomonas* wilt. Plants suffering from *Fusarium* wilt, yellowing and wilting of leaves starts at the older leaves spreading to the young ones. The affected leaves collapse at the base forming a circle round the pseudostem. In plants suffering from *Xanthomonas* wilt, wilting starts from any leaf and the attacked leaves collapses along the leaf blades (Castle, 2009).

Internal symptoms are manifested by discoloured vascular tissue both in the roots and corm. Initially the xylem vessels turn yellowish both in the corm and roots, progressing to a solid yellowish colour, then red and finally brown vessels in the pseudostem (Daly *et al.,* 2006;

Wardlaw 1961).Bananas that are prone to the disease once attacked by it they rarely overcome it. Finally symptoms of the disease have never been seen in or on the fruit (Daly *et al*., 2006). It is hard at times to distinguish between *Fusarium* wilt and Moko disease, whose causal agent is race two of *Ralstonia solanacearum* bacterium, because of the similarities in the symptoms. That notwithstanding it attacks plants that are of less than four months old causing wilting and yellowish coloration and the inner parts of a fruit is changed in colour by fading, streaking or staining it whereas *Fusarium* wilt attacks plants that are four months old and above(Ploetz, 2000; Perez-Vicente *et al*., 2014).

2.4 Factors affecting the development of *Fusarium* wilt of banana

Factors such as temperature, pH, moisture, organic matter and source of nutrients affect development of *Fusarium* wilt (Orr and Nelson, 2018). Multiplication and growth of this fungus depends on the presence of the above listed factors. *Fusarium* wilt problems can occur when temperatures are high for prolonged periods during the day (Li *et al*., 2017). Moisture stress either from the soil or internal plant is critical for disease development and symptoms expression. For instance moisture stress in the soil enhances the growth of the *Fusarium* fungus in the soil and suppresses bacterial antagonists (Gang *et al.*, 2013). Research on the effects of several nutrients on *Fusarium*wilt*s* revealed that high levels of nitrate ions reduce disease development. However, other researchers reported that nitrogen fertilizer enhances development of vigorous plant, which results in accentuated water extraction and greatly increased water stress both within the plant and in the soil (Wang and Xing, 2016). Increase in ammonium ions favours disease development, liming and calcium ions increase soil suppressive capability and reduce chlamydospores germination, pH of 7 is not optimal for *Fusarium* wilt whereas pH below

6.5 favours disease development. Also higher pH of above 7 in suppressive soils reduces infections (Perez-Vicente *et al* 2014).

2.5 Strategies of managing *Fusarium* wilt of Banana

Various strategies have been put into use in an effort to control *Foc* infection, such as crop rotation, flood fallowing (Ghag *et al*., 2015) and organic soil amendments; however none has been able to manage the disease. The planting of resistant banana cultivars is the only sure known method of managing this disease in banana growing regions across the globe. More measures have been recommended to block spread of the disease pathogen to areas not yet infested with it include observing quarantine procedures with extreme monitoring (Dita *et al*., 2010). Planting resistant cultivars has proved to be unsustainable because of the preferred taste and flavour of the consumers (Viljoen, 2004). Preventive measures such as inspection to exclude infected plant materials, cleaning of farm tools and observing quarantine measures can help in minimizing the dispersal of the pathogen. Due to this, it is hoped in this study that use of organic and inorganic soil amendments which will protect and improve growth of consumer preferred varieties may be effective solutions in managing *Fusarium* wilt of banana.

2.5.1 Use of chemicals

Limited success has been achieved against *Fusarium* wilt disease with chemical fungicide belonging to the group of benzimidazole group including benomyl, carbendazim, and thiabendazole (Nel *et al*., 2007). An experiment conducted using cyproconazole, propiconazole and prochloraz fungicides recorded a decrease of around 80% (Ghag *et al*., 2015). Soil fumigation has also been employed to eradicate *Fusarium oxysporum* f.sp. *cubense* from infested banana field but without much success(Kidane *et al*., 2008; Kidane and Laing, 2010). In South Africa, application of the now banned methyl bromide suppressed the disease for two years only and then the spread resumed. This practice is however, very expensive and may only be used as a short term management options.

2.5.2 Use of cultural methods

Rotations and inter-cropping decrease the buildup of specific *Foc* host pathogens in the soil (Ghag *et al*., 2015). Rotation of about 3 to 4 years can be achieved through the use of crops such as paddy, sugarcane, cassava and cereals (Buddenhagen, 2009). According to Huang *et al*. (2012) rotation of Chinese leek-banana is effective in managing this disease in banana, due to the reduction in the disease incidence from 97% to 88%. Rotation impact on the disease is minimal when *Foc* accumulation is high. Sound weed management approaches and exclusion of asymptomatic alternate hosts in the fields of bananas that are infected with the disease can stop and block the spread of this disease (Ploetz, 2015). The commonly intercropped crops include banana- bean, banana-coffee, where the derived benefits include improvement of soil fertility, suppression of pests and diseases, increased yield through nitrogen fixation from the atmosphere, decreased water loss through evapo-transpiration, weed smothering and/orboost of nutrient availability to plants in the soil through soil pH regulation (Zhang *et al*., 2013). Planting of infected plant materials is a primary means of introducing *Foc* into new banana production areas. The use of tissue cultured bananas is a milestone in checking *Fusarium* wilt from spreading into fields that are free of the disease. Tissue cultured bananas are clean and therefore devoid of disease causing pathogens and once planted their growth is vigorous, with reduced production cycle that is uniform, and finally the fruits produced have a higher quality than the fruits obtained from suckers (Nel, 2004).

2.5.3 Use of resistant cultivars

When *Fusarium* wilt establishes in an area, fruits may be affected seriously, therefore it is advisable to use varieties that are resistant as a way of managing the disease (Dita *et al*., 2015). Approaches towards disease control have embraced crop diversification as one of the key methods where banana cultivars are grown in a mixture to ensure sustained production in the banana field. Resistance occurs in three levels, complete resistance is shown by Cavendish variety where *Fusarium oxysporum* f.sp.*cubense* R1 interaction cannot cause disturbance in the physiological processes, maintains yields and blocks levels of inoculum from increasing, while in resistance that is intermediate, cultivars show lesser severe symptoms in the same environmental conditions and inoculum buildup while in susceptible varieties, such as Gross Michel for *Fusarium oxysporum* f.sp.*cubense* R1, Cavendish *Foc* R4 and Silk *Fusarium oxysporum* f.sp.*cubense* R1 serious physiological disturbances and yield losses are experienced. Therefore, varieties with complete resistance accompanied by cultural practices that enhance yield should be employed.

2.5.4 Use of organic and inorganic soil amendments

Manipulations of soil pH, use of fertilizers and soil amendments are key approaches in the control of *Fusarium* wilt (Nel, 2004). Fertilization with the right fertilizer and the recommended amounts enhances plant vigour which in return increases plant resistance to diseases. At the same time, depending on the type of fertilizer applied, it can have significant effect on the population of pathogenic fungi in the soil (Alabouvette, 2009). Application of ammonium fertilizers increases *Fusarium* wilt severity while increase in nitrate ions reduces disease development, liming and calcium ions increases soil suppressive capabilityand reduces chlamydospores germination. The pH of 7 is less optimal for *Fusarium* wilt whereas pH below 6.5 favours disease development. Also higher pH in suppressive soils reduces infections (Perez-Vicente *et al.*, 2014). Decomposed organic remains are linked to an increase in activity of the microbial biomass that generally enhances the suppression of the disease. Adding of organic amendments has effectively boosted the suppressiveness of the soil to the disease. Application of fresh organic manure has been reported to control soil borne pathogens (Alabouvette, 2009).

CHAPTER THREE

OCCURRENCE OF *FUSARIUM* WILT OF BANANA IN KISII COUNTY

3.1 Abstract

Farmers growing bananas in Kisii County face several challenges including depletion of soil fertility, low yields and diseases especially *Fusarium* wilt caused by *Fusarium oxysporum* f. sp. *cubense*. A study was conducted to determine the extent of the spread of *Fusarium wilt* of banana in Kisii County. Twenty farms were sampled in each of the Agro-ecological zone where four symptomatic and four non-symptomatic mats were sampled. Incidence was determined by relating banana suckers affected and the total number of banana suckers planted while severity was determined by measuring the extent of the damage/brown discoloration of the stem in length. Banana roots and pseudostem cuttings that were infected with the disease were used for isolation of the *Fusarium oxysporum* f.sp. *cubense*. Majority of the farmers 55% attained an average of eight years education and were in age bracket of 40-50 years. Many of the farmers grew apple banana as one of the improved banana varieties in both sites while Ng'ombe was the most popular local variety. Farmers listed diseases such as *Fusarium* wilt of bananas and Black sigatoka as the main constraints affecting bananas. *Fusarium* wilt was common in in both Agro-ecological Zones (UM 1 and LH 1) and the management practices used by farmers are poor and ineffective. Therefore an understanding of the distribution and diversity of *Fusarium oxysporum* f. sp. *cubense* can have important and positive implications on management.

Key Words: Agro-ecological Zone, Banana, Incidence, *Fusarium oxysporum* f. sp. *cubense,*

3.2 Introduction

Banana is classified as third among the world's key starch crops after cassava and sweet potatoes and it is the fourth most widely grown crop after rice, wheat and maize (Kwach, 2014). In Kenya banana is a key crop that is grown for both subsistence and commercial use covering 82,518 ha (Kwach, 2014). Counties in the west of the Rift Valley where bananas are grown account for 30 % of the total production in Kenya, while those in mount Kenya region account for 26 % (Njuguna *et al*., 2008). Bananas are grown in a wide range of altitudes and are largely carried out under rain fed conditions and in Kenya it is grown by small scale farmers who own approximately 0.3 hectares (Kwach, 2014). According to Dijsksra and Magori (1994) banana yield gives over 70 % of earnings to farmers in Kisii. Banana produces bunches throughout the year thereby providing a steady supply of food and earnings to the farmers. Continuous availability of harvestable bunch from a banana stool is especially important for farmer's economic stability.

Banana farmers face several challenges including low soil fertility, low yields and diseases especially *Fusarium* wilt caused by *Fusarium oxysporum* f. sp. *cubense* (Rutherford and Kangire, 1998; Ploetz, 2016). *Fusarium oxysporum f.* sp. *cubense* is a soil borne pathogen that has a long survival period in the soil even in adverse conditions. The disease causes severe damage and losses all over Africa where bananas are grown. In a survey that was done in Kenya, the incidence of *Fusarium* wilt was 80% in parts where Gross Michel, which is susceptible, is widely grown (Rutherford &Kangire, 1998). The spread of the disease is extensive; found in all regions where bananas are gown except in some parts of the Mediterranean and Pacific islands and its causal pathogen is therefore the most extensively disseminated (Ploetz, 2016). Planting material, water, soil particles, footwear and tools can efficiently disseminate the pathogen

(Perez-Vicente *et al*., 2014). The fungus can survive as chlamydospores in the soil for a long time and has a long latent period. Because of the effect of the disease and lack of a control strategy, it's important to understand its occurrence and distribution, as well as the available methods of managing it in Kisii County.

3.3 Materials and Methods

3.3.1 Description of the study area

Kisii County is located to the South-Western part of Kenya It neighbours Narok County to the South, Nyamira County to North East, and both Migori and Homabay Counties to the West. It lies between latitude 0^0 30' and 10^0 South and longitude 34^0 38' and 35^0 East (Ojowi *et al.*, 2001).The County has nine constituencies and forty five electoral wards. The survey was done in agro-ecological zones of lower midland one (LM1) and lower Highland (LH2)

The County has the following agro-ecological zones: lower Highland (LH1 and LH2) and lower upper midland (UM1). It has been determined that seventy five per cent of Kisii County is in the Upper midland whereas the remaining twenty five per cent is in the lower highland (Ojowi *et al.*, 2001). Bimodal rainfall pattern is received annually with an average of 1500mm. Thelong rains come between March and June, whereas the short rains are experienced between September and November. The temperatures range from 15^0C-20^0C minimum and 21^0C-30^0C maximum (Soft Kenya, 2014; Ojowi *et al.*, 2001)

Seventy five per cent of the county has red volcanic soils (nitosols) that have a lot of organic matter to greater depths. The rest, which comprises of twenty five percent has red loams, sandy soils and Clay soils (Phaezems) that have poor drainage ((Soft Kenya, 2014; Ojowi *et al.*, 2001).

Kisii County is agriculturally able to support both livestock and growth of all crops because of the reliable rainfall. The common crops grown include maize, bananas, coffee and tea.

3.3.2 Determination of the status, incidence and severity of *Fusarium* wilt

The survey to determine the status of *Fusarium* wilt in Kisii County was carried out in the month of June 2015. The survey was carried out using a structured questionnaire and personal observations. Sampling was confined to cover upper midland (UM1) Suneka and Mosocho divisions and lower highland (LHI) in Keumbu and Nyamache divisions (Ojowi *et al* 2001). Twenty farms were sampled in each Agro-ecological zone and in each farm four symptomatic and four non-symptomatic mats were sampled. Incidence of *Fusarium* wilt was determined by randomly selecting twenty farms in each Agro-ecological zone and in each farm. The symptoms that were used to identify the samples included light yellow coloration and wilting starting with aged leaves at the base, longitudinal splitting at the base just above the ground level, collapsing of leaves forming a skirt round the pseoudostem, spiky young leaves, among others. Incidence of *Fusarium* wilt was determined by counting infected banana plants then divided by the total number of the bananas in that mat times 100 to get percentage incidence. A total of eight banana samples were selected from each farm. This comprised of four samples that were symptomatic and four that were asymptomatic.

3.3.3 Isolation and identification of *Fusarium oxysporum* f.sp *cubense*

Samples roots of banana were washed under tap water to remove soils and cut into pieces of two millimeters length. The pieces were then surface sterilized in 1% sodium hypochlorite solution for five minutes, followed by rinsing in three changes in sterilized water (Perez-Vicente., *et al* 2014). Five pieces were then plated on molten potato dextrose agar (PDA) amended with antibiotics (streptomycin and tetracycline). The plates were then incubated for seven days when observations were made. *Fusarium oxysporum* f.sp. *cubense* was identified based on microconidia, macroconidia, chlamydospores as morphological characteristics and through their cultural appearances (Perez-Vicente *et al.*, 2014).

3.3.4 Data analysis

Data was subjected to analysis using SPSS Version 20 for analysis of software. Descriptive statistics analysis used included percentages, means, and frequencies of variables to describe the characteristics of respondents, their current knowledge and practices regarding general banana production. Laboratory data was statistically analyzed using Genstat Software version 15. The means were separated using Fisher's protected variance by determining the least significant difference at 5% probability levels.

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3.4 Results

3.4.1 Socio-economic characteristics of the banana growing farmers

Majority of the farmers (55%) attained Kenya Certificate of Primary Education (KCPE) while 40% of them had attained secondary education and only 5% of the respondents had tertiary education. The majority of the farmers (60%) in LH1 had slightly higher score on education than farmers in UM1. (Table 3.1). Majority (55%) of the respondents in both sites were in the age bracket of 40-50 years, followed by those in the age bracket of above 50 years. The farmers interviewed were on average 46 years of age, ranging from 30 - 60 years old.

Table 3.1: Socio-economic characteristics of banana farmers in different agro-ecological zones

Variable	Description	Agro-ecological zones		Mean
		LH1 (%)	UM1 (%)	
Education level	Primary	60.0	50.0	55.0
	Secondary	35.0	45.0	40.0
	Tertiary	5.0	5.0	5.0
Age	30-39	5.0	15.0	10.0
	40-50	20.0	15.0	17.5
	above 50	15.0	14.0	14.5

3.4.2 Banana production

All the farmers used suckers as banana planting materials and obtained them from various sources including own farm and from neighbours. Also farmers in LH1 (65%) obtained suckers from Jomo Kenyatta University of Agriculture and Technology. However, other farmers (35%) obtained the suckers from, KALRO Kisii Research Centre, situated in the County (Figure 3.1).

Crops grown alongside banana in the two agro-ecological zones included; coffee, maize and tea (Table 3.2). Majority of the respondents in both zones planted maize (87%), vegetables (67%), sugarcane (48%) and fodder (43%) for cattle. All the farmers grew apple banana as one of the improved banana varieties (Table 3.3) in both agro-ecological zones while 95% of the respondents in LH1 and 55% in UM1 grew Ng’ombe a traditional banana variety. Ng’ombe (75%) was the most popular local variety grown in the two agro-ecological zones while apple variety (100%) and Uganda green (90%) were the main improved banana varieties in the both zones respectively (Table 3.4).

Other improved varieties grown included: Valery, Gross Michel, Chinese Cavendish, and Grand Nain, Nusu ng’ombe, Bokoboko, Gross Michel 3, Fhia 17, Gross Michel 2, and hybrid apple banana. In agro-ecological zone LH1, Uganda green (100%) and apple (100%) variety were the most preferred varieties while in agro-ecological zone UM1, the most popular variety was apple (100%). Gross Michel variety was not planted by any farmer in agro-ecological zone LH1 while Nusu Ng'ombe variety was not planted by any farmer in UM1 (Table 3.2).

Farmers reported various biotic and abiotic constraints to increased productivity of banana in Kisii County (Table 3.6). The biotic constraints were diseases (80%), and insect pests (73%). The other constraints included lack of market and low prices, high labour costs (63%), and high transport costs (70%). Majority of the farmers interviewed in agro-ecological zone UM1 reported banana diseases as the major constraint affecting banana production, followed closely by low banana prices and insect pests while in LH1 many farmers (90%) reported low market prices, followed by high transport costs, while insect pests comprised of 65% in LH1 and 80% in UM1 and diseases 65% in LH1 and 95% in UM1 as the major biotic constraints affecting banana production in the County.

Table 3.2: Proportion of farmers growing different crops in different agro-ecological zones in Kisii County

Crops grown	Agro-ecological Zones		Mean (%)
	LH1 (%)	UM1 (%)	
Banana	100.0	100.0	100.0
Coffee	55.0	20.0	37.5
Maize	85.0	90.0	87.5
Fodder	50.0	35.0	42.5
Vegetables	45.0	90.0	67.5
Tea	55.0	10.0	32.5
Sugarcane	40.0	55.0	47.5
Millet	15.0	25.0	20.0
Mean	55.6	53.1	54.4
LSD (p≤0.05)	22.1	29.7	23.4

LSD- least significant difference, LH1- lower highland 1, UM1- upper midland 1

Table 3. 3: Local and improved/exotic banana varieties planted by farmers in different AEZs in Kisii County

Local cultivars			Improved cultivars		
Local Varieties	LH1 (n=20)	UM1 (n=20)	Improved varieties	LH 1 (n=20)	UM1 (n=20)
Ng'ombe	95.0	55.0	Apple banana	100.0	100.0
Nusung'ombe	25.0	0.0	Giant apple	25.0	65.0
Bokoboko	15.0	25.0	Varaley	0.0	15.0
Gross Michel 3	0.0	10.0	Gross Michel	0.0	35.0
Fhia 17	10.0	70.0	Uganda green	100.0	80.0
Hybrid apple banana	0.0	40.0	Chinese Cavendish	30.0	15.0
Gross Michel 2	0.0	55.0	Grand Naine	15.0	25.0
Mean	20.7	36.4		38.6	47.9
LSD (P≤0.05)	31.5	23.8		40.2	31.3

LH1- lower highland 1, UM1- upper midland 1

Table 3. 4: Proportion of farmers growing different banana varieties in the two AEZs

Banana varieties	Agro-ecological zones		Mean (%)
	LH1 (%)	UM1 (%)	
Uganda green	100.0	80.0	90.0
Apple banana	100.0	100.0	100.0
Ng'ombe	95.0	55.0	75.0
Chinese cavendish	30.0	15.0	22.5
Giant apple	25.0	65.0	45.0
Nusu ng'ombe	25.0	0.0	12.5
Grand naine	15.0	25.0	20.0
Bokoboko	15.0	25.0	20.0
Fhia 17	10.0	70.0	40.0
Varaley	0.0	15.0	7.5
Hybrid apple banana	0.0	40.0	20.0
Gross Michel 2	0.0	55.0	27.5
Gross Michel 3	0.0	10.0	5.0
Mean	31.9	42.1	35.9
LSD ($P \leq 0.05$)	22.3	17	19.7

LSD- least significant difference, LH1- lower highland 1, UM1- upper midland 1

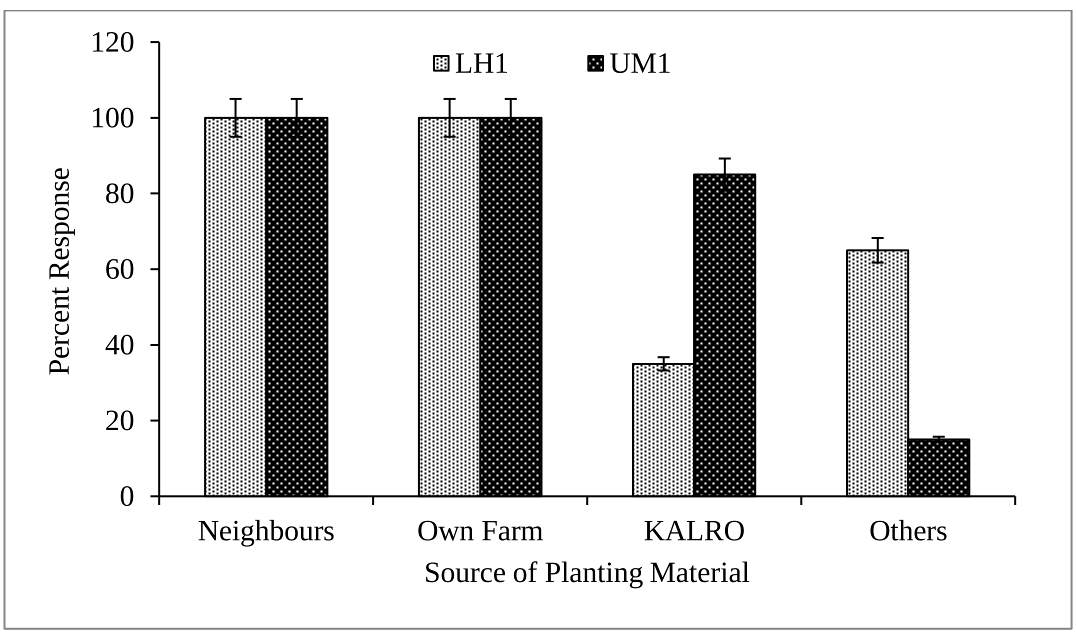

Figure 3. 1: Sources of banana suckers used by farmers in Kisii County

3.4.3 Diseases and Pests Affecting Banana

The major diseases reported by the farmers in both AEZs (Table 3.6) were: *Fusarium* wilt of bananas (73%), black sigatoka (60%) while the major pests were; moles (34%), banana weevils (20%), nematodes (20%) and thrips(13%). Majority of the farmers in AEZ UM1 reported *Fusarium* wilt (85%) as the most devastating banana disease followed by black sigatoka (55%). Major pests were; moles (41%) followed by nematodes (40.1%). In agro-ecological zone LH1, majority of the farmers reported black sigatoka (65%) as the main disease affecting bananas followed closely by *Fusarium* wilt (60%) while the major pests were; moles (30%) and banana weevils (30%).Majority of the interviewed farmers in ago-ecological zone LH1 (95%) and UM1 (85%) did not manage the banana diseases with any management strategy (Figure 2). However, only a few (10%) in UM1 and (5%) in LH1 applied manure as a method of managing banana diseases. A few other farmers (5%) in UM1 used wood ash to manage the diseases.

Table 3. 5: Constraints affecting banana production in agro-ecological zone LH1 and UM1

Production constraint	Agro-ecological zones		
	LH1 (%)	UM1 (%)	Mean (%)
Diseases	65.0	95.0	80.0
High labour cost	65.0	60.0	62.5
Lack of market	60.0	65.0	62.5
Low market prices	90.0	85.0	87.5
Lodging	5.0	5.0	5.0
Pests	65.0	80.0	72.5
High transport cost	75.0	65.0	70.0
Mean	26.5	29.3	27.9
LSD ($P \leq 0.05$)	24.5	27.1	25.0
CV (%)	33.4	36.4	28.9

LSD- least significant difference, LH1- lower highland 1, UM1- upper midland 1

Table 3. 6: Major pests and diseases associated with bananas in agro-ecological zones LH1 and UM1 as reported by the respondents

Pests / diseases	Agro-ecological zones		
	LH1 (%)	UM1 (%)	Mean (%)
Black sigatoka	65.0	55.0	60.0
Fusarium wilt	60.0	85.0	72.5
weevils	30.0	10.0	20.0
Moles	30.0	40.9	35.5
Thrips	15.0	10.0	12.5
Cigar-end rot	5.0	10.1	7.5
Nematodes	0.0	40.1	20.1
Mean	29.3	35.7	32.5
LSD ($P \leq 0.05$)	23.5	26.2	23.0
CV (%)	16.3	18.4	26.6

LSD- least significant difference, LH1- lower highland 1, UM1- upper midland 1

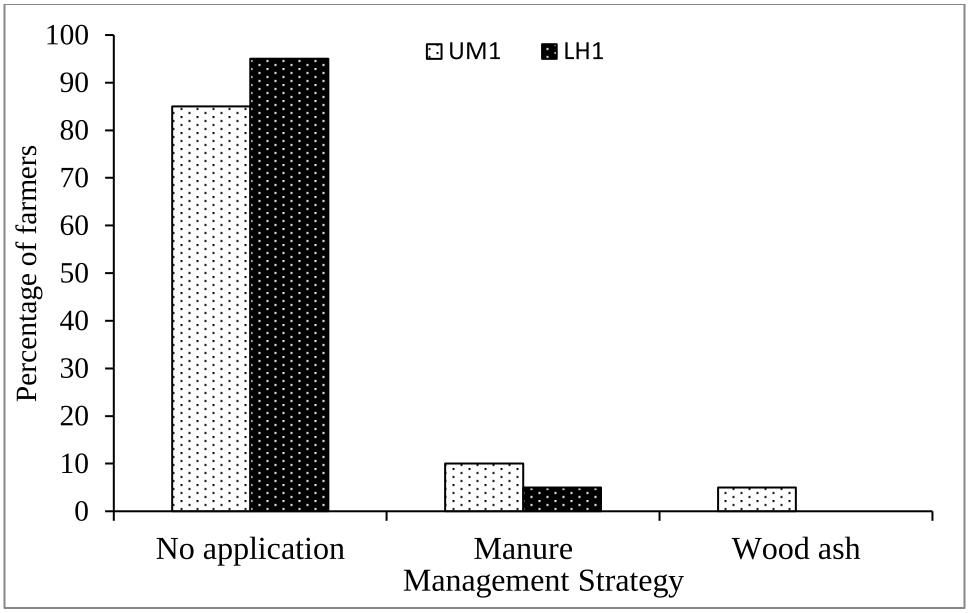

Figure 3. 2: Percentage of farmers using different methods to manage *Fusarium* wilt in the two Agro-ecological zones

3.4.4 Incidence of *Fusarium* wilt

There were significant differences ($p \leq 0.05$) in asymptomatic banana samples collected from the two agro-ecological zones. Higher incidences of *Fusarium* wilt disease was found in agro-ecological zones UM1 compared to LH1 (Table 3.6). There was consistency in disease incidence in each agro-ecologicalzone, however high disease incidence of 78% was observed in UM1 in Mosocho and the lowest disease incidence was observed in Suneka (60%). The incidence of *Fusarium* wilt of bananas in symptomatic samples varied between the agro-ecological zones at $p \leq 0.05$ with Agro-ecological zone UM1 having high incidences of the disease(78%) at Mosocho compared to agro-ecological zone LH1at Keumbu (22%). However, there were no significant differences in sites in each agro-ecological zone.

Table 3. 7: Incidence (%), of *Fusarium* wilt on banana samples infected with *Fusarium oxysporum* in Kisii County

	AEZs		
Sub County	LH1	UM1	Mean
Suneka	26.0b	60.0a	43.0a
Mosocho	26.0b	78.0a	52.0a
Keumbu	22.0b	74.0a	48.0a
Nyamache	32.0b	74.0a	53.0a
Mean	26.5	71.5	49.0
LSD (P≤0.05)	11.5	11.5	7.2
CV (%)	65.8	65.8	65.8

Means followed by same letter(s) within each column are not significantly different at P ≤ 0.05
LSD: least significant difference; CV: coefficient of variation

Table 3. 8: Severity (%), of *Fusarium* wilt disease on banana samples infected with *Fusarium oxysporum* wilt in Kisii County

Sub County	LH1	UM1	Mean
Suneka	42.3b	79.0a	60.7
Mosocho	42.0b	82.7a	62.3
Keumbu	39.3b	81.0a	60.2
Nyamache	44.7b	79.7a	62.2
Mean	42.1	80.6	61.4
LSD (P≤0.05)	12.2	12.2	12.2
CV (%)	55.2	55.2	55.2

Means followed by same letter(s) within each column are not significantly different at P ≤ 0.05
LSD: least significant difference; CV: coefficient of variation

3.5 Discussion

3.5.1 Socio-economic characteristics of the farmers and banana production practices

Majority of the farmers in the study areas were of 40-50 years old with up to primary school level of education. The results concur with those of Tsafack *et al*., (2015) in Ethiopia where they stated that most farmers had an average of primary education. According to Mwangi and Kariuki (2015) education increases the uptake of new agricultural technologies including the use of newly released and improved banana varieties. Educated farmers look for suitable agricultural knowledge to boost their production. Education improves productivity of the human factor and makes people more aware of opportunities to earn a living (Okurut *et al.*, 2002).

Apart from banana, the farmers also planted maize, vegetables, sugarcane and fodder crops which are mainly used as cattle feed. Other crops grown include tea, millet, and coffee. These crops were seen as complimenting the major crops and are planted between the major crops for intercropping and for crop rotation. According to Karangwa *et al*. (2018), intercropping systems have suppressive ability on plant diseases by creating an environment that is not conducive to diseases such as Fusarium wilt through change of vector dispersal, changing the morphology of the host, physiology and moisture, as well as preventing the pathogen entry (Ouma, 2009; Boudreau, 2013). Intercropping has also been reported to improve soil fertility thus increasing yield through processes such as atmospheric nitrogen fixation, smothering weeds and boosting the available nutrients in the soil through regulation of soil pH (Ouma, 2009). Other findings indicate that crop rotation affects severity and disease development in the field. For instance rotations with non-cereal crops reduce severity of crop diseases but this is dependent on crop type. This result agrees with those reported by Karangwa *et al*, (2018).

The small-scale farmers in Kisii County mostly plant both local and improved banana varieties sourced mainly through the informal seed systems. Farmers preferred to grow the improved banana varieties because they are high yielding, palatable, easy to cook, and are able to tolerate disease compared to the local cultivars. All the farmers used banana suckers as planting material which they obtained mostly from their own farms and neighboring farmers as was observed by Lwandas *et al.*, (2013) where majority of banana famers obtained their suckers from neighbouring farmers. However, the level of reliance on KALRO Kisii, as source of planting material varied significantly within the two Agro-ecological zones due to season variability, household characteristics such as wealth status and the level of production (Birachi *et al*., 2011). The planting material or suckers were not certified and probably were the main source of dissemination of *Fusarium* wilt pathogens among the farmers (Li *et al*., 2013). Planting improved and certified cultivars result in increased yield and reduced incidences of diseases. According to Birachi *et al*. (2011) many farmers benefit from planting these improved varieties, however, access is still a challenge.

The study highlighted the dominance of banana variety Ng'ombe and apple in LH1, while Uganda green dominated in UM1. This aspect confirms the relative importance of banana in the Kisii culture (Nsabimana *et al*., 2008). The reason for the dominance of the three varieties could be due to their sweet taste, their ability to yield highly and disease tolerance ability. Several studies have identified high yielding capability of banana as one of the reasons for massive uptake. Due to current surge in *Fusarium* wilt, farmers have embraced the use of improved varieties so as to manage the disease (Nsabimana *et al*., 2008).

3.5.2 Constraints to banana production in Kisii County

Farmers reported various biotic and abiotic constraints affecting banana production in Kisii County, chief among them being diseases followed by insect pests. Other mentioned constraints include high labour and transport costs, and fluctuations in market prices. The same results were reported by Ouma and Jagwe, (2010). Banana producers prioritized these constraints as key to low yield realized by the majority of farmers interviewed. These results agree with the report by Njau *et al*. (2010) who in his findings noted plant diseases as the major constraint to banana production. Other reported constraints include, and high transport costs. From the survey it was found that,*Fusarium oxysporum* f.sp. *cubense* was present in the two agro-ecological zones and the presence of more than one symptom was noted on a single plant. The pathogen causing the disease was confirmed through isolation from wilting symptomatic plant parts. Notably, the pathogen *Fusarium oxysporum* f. sp. *cubense* was found to be common throughout the banana growing regions.

Other noted symptoms included yellowing of older leaves progressing from the base to the top where younger leaves are up to the unfolded central leaf which remains erect and green, the same symptoms were reported by Ploetz and Pegg, (2000), Ploetz *et al*. (2015). Splitting of the base of the pseudostem was also observed, particularly on young, rapidly growing plants (Ghag *et al.*, 2015). The results concur with those reported by Ploetz (2006) and Li *et al*. (2013) where symptomatic pseudostems had various contaminations with *Fusarium oxysporum* f. sp. *cubense.* This disease is regarded as one of the most damaging diseases of banana (Tushemerirwe *et al*., 2004) and can wipe out an entire farm of susceptible banana varieties. According to Tushemerirwe *et al*. (2004) FHIA clones were considered resistant while Gross Michel appeared susceptible; however, they were only adopted by few farmers. The failure by farmers to adopt the resistant banana varieties calls for increase in extension service delivery to teach farmers the benefits of technology uptake.

Interestingly, the symptoms of *Fusarium oxysporum* wilt were common in Agro-ecological zone UM1 when compared to Agro-ecological LH1. The high presence and incidence of this disease in bananas in UM1 zone is because of the environmental conditions that allows *Fusarium* spp. pathogens to thrive best. Therefore the conditions of the soil coupled with the cropping systems and the environment may also influence the severity of *Fusarium* wilt. According to Li *et al*. (2011), limited knowledge of banana *Fusarium* wilt by the small scale farmers, use of suckers obtained from neighbouring farmers for replanting instead of certified banana suckers promotes rapid spread of the disease. Once the disease is introduced within the farm, the pathogen being soil borne will survive in the fields for longer periods and therefore will affect subsequent banana crops (Li *et al*., 2017). Apart from *Fusarium* wilt, farmers also reported black sigatoka as another common banana disease while the major pests included moles, weevils and nematodes. Majority of the interviewed farmers did not manage the disease, however, only a few in both agro-ecological zones applied manure as a method of managing *Fusarium* wilt of banana while a few others in UM1 (5%) used wood ash to manage the diseases.

The study confirmed that *Fusarium* wilt is prevalent in the two Agro-ecological Zones in Kisii County; however, management practices applied do not meet the required strategies for the management of the disease. An understanding of distribution and diversity of *Fusarium oxysporum* in banana producing regions of Kisii County can have an important and positive management implication.

CHAPTER FOUR

EFFECTIVENESS OF ORGANIC AND INORGANIC AMENDMENTS IN THE MANAGEMENT OF *FUSARIUM* WILT OF BANANA

4.1 Abstract

Fusarium wilt caused by *Fusarium oxysporum* f.sp. *cubense* is the most devastating disease of banana. Despite rigorous research efforts focused on managing this disease, no effective long-term strategy either chemical or cultural has been identified for combating the disease. This is because *Fusarium* wilt pathogen can survive in the soil as dormant and immobile chlamydospores in decayed banana tissue and soils resting dehydration up to 30 years. The pathogen can infect weeds and non- host plants that have no economic value and some of which may not show visible symptoms (Li, C., *et al*., 2011).This study was therefore carried out to determine the efficacy of various organic and inorganic soil amendments in managing this disease. Soil amendments evaluated were wood ash, *Tithonia diversifolia,* poultry manure, diammonium phosphate, urea and sodium hypochlorite. Spore suspension of *Fusarium oxysporum* f. sp.*cubense* was used to infest the soils in the green house. Clean tissue-cultured banana cultivar apple banana plantlets were planted into infested soils and left for three weeks. Apple banana was evaluated in the greenhouse. A significant reduction of about 58% in disease incidence was observed in plants treated with poultry manure and sugarcane ash. The largest area under disease progress curve (AUDPC) and the highest incidence of this disease were recorded in pots without any soil amendment. The study showed that in terms of effectiveness, sugarcane ash and poultry manure were the most effective organic amendments when compared to the control.

Key Words: Banana, Manures, Organic soil amendments, *Panama* disease, *Tithonia diversifolia*.

4.2 Introduction

Banana is a major food security crop in third world countries where it plays a great role as a source of nutrients (Kwach, 2014). The crop supplies 75 % of the carbohydrates to 20 million people in these countries (Tripathi *et al*., 2009). The production of banana is however, threatened by a host of pests and diseases which are gradually driving the popular varieties out of production (Tushemereirwe *et al*., 2004). Among these pests and diseases, *Fusarium* wilt, banana *Xanthomonas* wilt (BXW), sigatoka, banana weevil, and parasitic nematodes are the most limiting. If the banana crop is to be protected and high yields experienced then there must be a strategic plan for control of pests and diseases (Onyango, 2009).

Fusarium wilt is a destructive disease of banana all over the world and it is caused by *Fusarium oxysporum* f. sp. *cubense*. *Fusarium oxysporum* f. sp *cubense* attacks nearly all commercial cultivars of banana. Hermanto *et al*. (2011) reported that farmers suffered losses due to *Fusarium* wilt reaching a monetary value of Kshs. 2.8 billion during the 1993-1994 harvesting period. Another report by Soerkino (2009) reported that an average of 2.11 million banana mats have been damaged yearly from 2003 to 2007. This disease is present in major banana growing areas of Kisii, Homabay, Meru, Murang'a, Kakamega, Busia, Kisumu, Migori, TaitaTaveta and Coast region. Affected varieties in Kenya are the dessert bananas such as Bokoboko, Gross Michel, Apple banana and Muraru where up to 80% of the banana field may show symptoms of the disease (Onyango, 2005).

Several nutrients such as an increase in nitrate ions may reduce disease development, ammonium ions increment favors disease development, liming and calcium ions increase suppressive capability of soil thereby reducing chlamydospores germination and pH of close to seven is less optimal for *Fusarium* wilt whereas pH below 6.5 five favour disease development. Higher pH in suppressive soils reduces infections (Perez-Vicente *et al.*, 2014).

Various methods that have been tried include fumigation (Shen *et al*., 2015), application of fungicides (Nel, 2007) and fallow-flooding. Planting resistant cultivars has proved to be unsustainable because they lack the taste and flavour preferred by consumers (Viljoen, 2002). Resistant varieties include Uganda green and Cavendish for R1.The development of appropriate strategies in *Fusarium* management in banana requires knowledge on the *Fusarium* pathogen evolution and diversity (Li *et al*., 2013). This study determined the effectiveness of organic and inorganic soil amendments in the management of *Fusarium* wilt of banana

4.3 Materials and Methods

4.3.1 Preparation of soil amendments, design and layout

The soil amendments used include *Tithonia diversifolia*, wood ash from sugarcane jaggery, poultry manure, DAP, and sodium hypochlorite. The pot diameter was 14 cm whose area was determined to be $0.0154m^2$.The fresh leaves and tender stems of *Tithonia diversifolia* were chopped into small pieces and mixed with soils in the pots at the rate of 30.8gper pot (20 tons/ha), 30.8g of wood ash from sugar cane jaggery, poultry manure from poultry farm in a cage was weighed and then mixed with soils in each pots at the rate of 20 tons/ha, five grams of both urea and di-ammonium phosphate (DAP) were mixed with soils at the rate of 5 grams per pot in each respective container (3200Kg/ha) and 4.6ml of sodium hypochlorite was measured and applied per pot ($300ml/M^2$) was poured to each respective polythene bags before transferring the tissue cultured banana plantlets into each. The experimental design was a completely randomized design. Ten seedlings were subjected to seven treatments and then replicated four times.

4.3.2 Isolation of *Fusarium* wilt pathogen from plants

The apple banana samples from the farmer's farms that had the symptoms of *Fusarium* wilt were taken from the vascular bundles in the inner part of the pseudostem that showed brownish colouration (Perez-Vicente *et al.*, 2014). The cut sections of three millimeters long from the vascular bundles of the pseudostem were then put in 1% of sodium hypochlorite solution for five minutes and then rinsed in three changes of sterile water. Five pieces plated in potato dextrose agar (PDA), which had been treated with streptomycin and tetracycline antibiotics. The isolates of *Fusarium oxysporum* f. sp. *cubense* were identified using a microscope according to their shape,microconidia, macroconidia, chlamydospores as morphological characteristics and through their cultural appearances such as colour (Perez-Vicente *et al*., 2014). Similarly samples of soil from the wilted plantlets in the pots were taken and used for isolation in potato dextrose agar.

4.3.3 Preparation of inoculum and inoculation

Samples of infected apple bananas were cut into three millimeters cubes and sterilized as described in section 4.3.2. The samples were then placed in an absorbent paper to remove excess water. Using sterile fine forceps, five pieces were placed in a PDA media in Petri-dishes and incubated for seven days. Then single spores isolates of *Fusarium* wilt pathogen were inoculated on Petri plates with potato dextrose agar (PDA) half strength (18gms of PDA dissolved in one liter of sterile water) which was pre-treated with 10mls of both streptomycin prepared by dissolving 200mg in one liter of sterile water and 0.5g of tetracycline antibiotics in 100ml of water (Perez-Vicente *et al.*, 2014).

The inoculum of *Fusarium oxysporum* f. sp. *cubense* was prepared by soaking 200gm of sorghum grain in 400ml distilled water in 1-litre Erlenmeyer flask overnight. Excess water was decanted and the grains were then sterilized in an autoclave for 15 minutes at 121^{o}C. The sorghum grains were then allowed to cool in the flasks before being inoculated with five mycelia plugs of 5mm diameter of isolates of *Fusarium oxysporum* f. sp. *cubense* that had been incubated for 15 days in complete darkness (Juber, *et al*., 2014). The soils were infested by placing three grams of colonized sorghum grains below the banana roots which had been previously washed using tap water and excess roots trimmed. The pathogen was spread in each pot as a layer before covering them with two centimeter of a soil layer. The banana suckers were then placed on top of it in the pots and then covered with soil (Juber, *et al*., 2014).

4.3.4 Assessment of *Fusarium* wilt incidence and severity

This constituted a visual observation of typical symptoms of *Fusarium* wilt for disease incidence. The number of infected plants in each pot was recorded out of the total number of plants to evaluate incidence. Based on infection counts and disease symptoms assessment, incidence was calculated (%) = $\frac{\text{number of infected plantlets}}{\text{Total number of plantlets}} \times 100$.

The severity of the disease was evaluated longitudinal sections of the pseudo stem of the infected banana suckers. The length of the discolored part was measured and related to the total length of the banana plant multiplied by 100 to get percentage length of the discoloration.

In addition, the area under the disease progress curve (AUDPC) was calculated, as proposed byMadden *et al*. (2007)

$$AUDPC - \sum_{i=1}^{n} \frac{(y_i + y_{i+1})}{2} (t_{i+1} - t_i)$$

Where:

y_i is the disease severity observed i;

y_{i+1} is the severity of the disease at the time of the subsequent evaluation i + 1;

t_i is the time (days) at the time of observation i;

t_{i+1} is time (days) at the time of the subsequent evaluation i + 1;

n is total number of evaluations.

4.3.6 Re-isolation of *Fusarium* wilt pathogen from plants and soils

The re-isolation of the pathogen was done as outlined in section 4.3.2. The isolates of *Fusarium oxysporum* f.sp.*cubense* were identified according to the shape and colour of microconidia, macroconidia, chlamydospores as morphological characteristics and through their cultural appearances (Perez-Vicente *et al*., 2014). Colony morphology and coloration was used for identification of *Fusarium* wilt pathogen on the Petri-dishes.

4.3.7 Statistical data Analysis

Data analyses were conducted using Genstat (15^{th} Edition, VSN International Ltd, UK, 2012). The percentages of severity of symptoms were transformed prior to conducting the analysis of variance (ANOVA).The data was subjected to analysis of variance to determine the significant difference among the treatment means. The means were separated using Fisher's protected variance to determine the least significant difference (LSD) at 0.05.

4.4 Results

4.4.1 Effect of different soil amendments on the incidence and severity of *Fusarium* wilt

All treatments had significant ($P \leq 0.05$) reduced severity and incidence of *Fusarium* wilt, however, at different levels. There was significant reduction (58%) in disease incidence in plants plots amended with poultry manure and sugarcane ash while the highest incidence was observed in plants in control plots followed by plots amended with sodium hypochlorite (75%). However, there was no significant difference in severity in both symptomatic and asymptomatic plant samples among the treatments applied. *Fusarium* wilt symptoms of banana were observed in the third weeks after inoculation (Table 4.1). However, the incidence of *Fusarium* wilt varied between the treatments and across the sampling times ($p \leq 0.05$).

Inplots with no amendment applied, the highest incidence was observed every week from the start to the end of sampling time while the least was observed in plots treated with sugarcane ash. Sugarcane ash and poultry manure can be grouped as the best treatments with regard to low incidence (Figure 4.2). Plants in plots amended with sodium hypochlorite at the initial weeks had the lowest incidence compared with other treatments. High incidence of *Fusarium* wilt on bananas and largest area under disease progress curve (AUDPC) were recorded in plots with no amendment applied.. However, there was no significant difference between the different treatments applied.

Table 4.1: Incidence and severity of *Fusarium* wilt of bananas treated with different organic and inorganic amendments

Amendments	Incidence (%)	Severity (%)	AUDPC
No amendment	100.0	50.6	4172.0
Sodium hypochlorite	75.0	46.2	3243.0
Urea	70.8	55.4	3372.0
Diamonium phosphate	66.7	54.7	3337.0
Tithonia	66.7	42.4	3173.0
Poultry manure	58.3	34.7	3115.0
Sugarcane ash	58.3	37.9	2753.0
Mean	70.8	46.0	3309.3
LSD ($P \leq 0.05$)	16.2	16.4	399.4
CV (%)	12.9	20.1	18.6

Means followed by same letter(s) within each column are not significantly different at $P \leq 0.05$
LSD: least significant difference; CV: coefficient of variation

Table 4. 2: Incidence of *Fusarium* wilt of banana following different soil amendments after different weeks of assessment

Amendments	weeks after treatment applications								
	3	4	5	6	7	8	9	10	Mean
No amendment	13.3	23.3	40.0	56.7	66.7	76.7	86.7	90.0	56.7
Urea	6.7	13.3	36.7	43.3	53.3	63.3	76.7	76.7	46.3
DAP	6.7	13.3	33.3	50.0	53.3	66.7	73.3	73.3	46.2
Sodium hypochlorite	0.0	16.7	26.7	40.0	46.7	63.3	73.3	76.7	42.9
Tithonia	3.3	20.0	33.3	36.7	50.0	66.7	70.0	70.0	43.8
Poultry Manure	6.7	16.7	36.7	46.7	53.3	60.0	63.3	66.7	43.8
Sugarcane ash	6.7	6.7	20.0	36.7	43.3	56.7	60.0	66.7	37.1
Mean	6.2	15.7	32.4	44.3	52.4	64.8	71.9	74.3	45.2
LSD ($P \leq 0.05$)	3.7	4.9	6.3	6.8	6.8	5.8	8.1	7.4	5.5

Least significant difference; CV: coefficient of variation

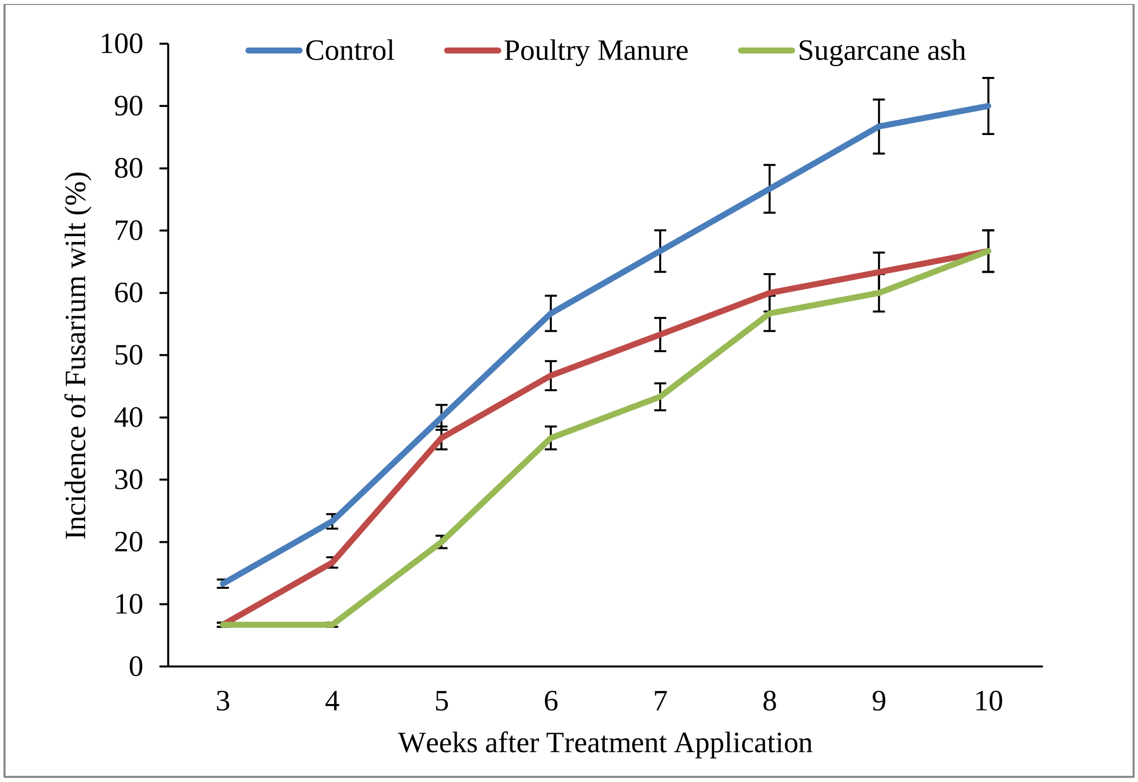

Figure 4. 1: Disease progress curves of *Fusarium* wilt of banana following different soil amendments

4.4.3 Effect of different soil amendments on re-isolation frequency of *Fusarium oxysporum* f. sp. *cubense*

There were significant differences in the treatments in the re-isolation frequency of *Fusarium oxysporum* f. sp. *cubense. Fusarium oxysporum* f. sp. *cubense* was re-isolated from all the banana samples (Figure 4.4). The pathogen was re-isolated in high incidences from banana samples that were amended with urea, DAP and sodium hypochlorite and in control plots. Samples of banana amended with either sugarcane ash or poultry manure had low re-isolation frequency of *Fusarium oxysporum* f. sp. *cubense.*

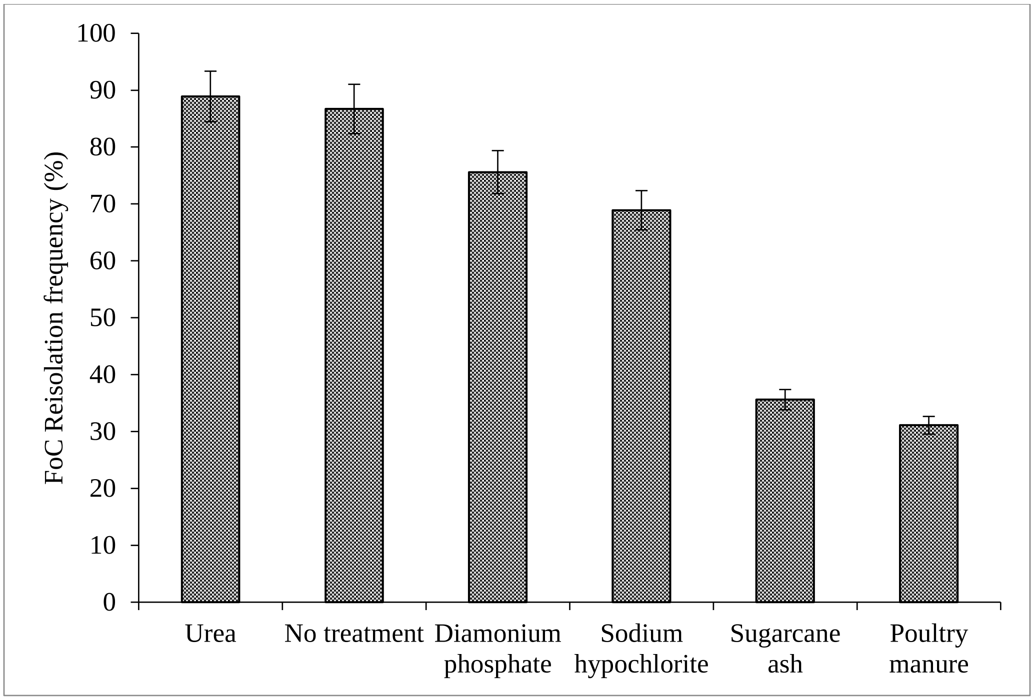

Figure 4. 2: Percentage *Fusarium oxysporum* re-isolation frequency as affected by different soil amendments in Kisii County

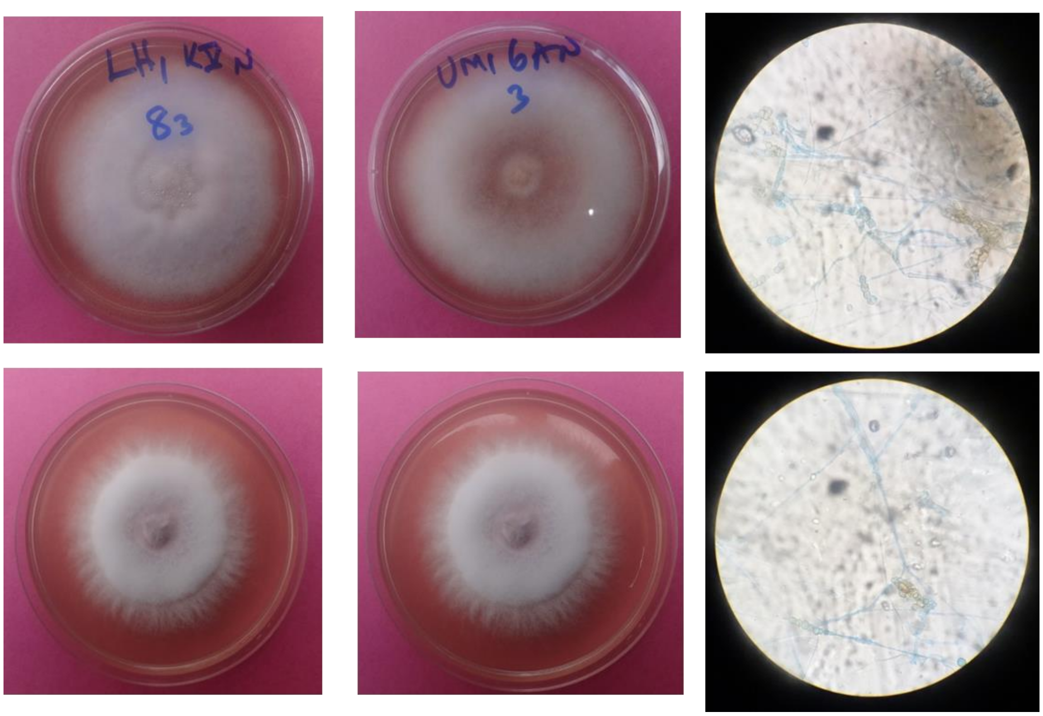

Figure 4. 3: *Fusarium oxysporum* f. sp. *cubense* cultures and conidia

4.5 Discussion

4.5.1 Effect of different soil amendments on the incidence and severity of *Fusarium* wilt

The results show that wilt incidence was significantly reduced when organic and inorganic amendments were applied into the soil. Significant reduction in disease incidence was observed in plots treated with poultry manure and sugarcane ash. These results agree with the findings of Dita *et al*. (2018) and Zhao *et al*. (2016) who reported that organic amendment greatly reduce incidence of *Fusarium* wilt. Organic amendments are very important in maintaining soil health and soil suppressive capability (Larkin, 2015). Organic matter affects plant health, the chemical, physical and biological characteristics of soil, and disease suppression and that is attributed to biotic and abiotic factors (Bonanomi *et al*., 2010; Baum *et al*., 2015). The pathogens' survival is reduced both in the plant remains and in the soil. The results also showed that wilt severity was significantly reduced with both sugarcane ash and poultry manure. Sugarcane ash and poultry manure were the most effective organic amendments of all the tested organic manures.

Application of sugarcane ash resulted in an increase in soil pH, which concurs with findings of Dita *et al*. (2018). According to Dita *et al*. (2018) lower pH values are consistently associated with higher levels of *Fusarium* wilt in banana. Application of urea and ammonium fertilizers have been associated with increased incidences of *Fusarium* wilt (Nasir *et al*., 2008; Dita *et al*., 2018). This is because increased acidity in the soil interferes with plant resistance, and may enhance pathogenicity (Dita *et al*., 2018). The other two organic amendments also showed positive influence towards management of this disease, however, the effect was less compared to poultry manure and sugarcane ash. The incidence and severity increased overtime in all the treatments but at different rates. In plots with no treatment applied, highest incidence was recorded every week from the start to the end of sampling time while plots treated with sugarcane ash gave the least incidence. Progression of disease depends on host susceptibility, environmental factors, and management practices. However, incubation periods depends on the inoculation method, infection route, environmental conditions and the infected plant's maturity level (Blomme *et al*., 2017)

The results, however, contradicts the findings by Nasir *et al*. (2003) who found out that amending soil with chicken manure had no significant effect on the activity of *Foc* but amendments with sawdust had significant effect reducing the activity of *Foc*. In fact, chicken manure increased the incidence of the disease with all the plants showing *Fusarium* wilt disease symptoms. According to Nasir *et al*. (2003) this phenomenon may occur in instances where chicken manures are not fully or are only partially decomposed. The adverse effect of poultry manure has been associated with increase in root damage, N source and soil pH reduction which acts as predisposing factors (Nasir *et al*., 2003). However, other researchers have attributed the increase in incidence and severity of *Fusarium* wilt following poultry manure application to toxicity levels of ammonia. However, in this study no evidence of banana leaf tip showing burning symptoms were noticed (Ploetz, 2015). The activity of *Foc* in the un-amended soils was high compared to other treatments. Accordingly there was pathogen suppression associated with sugarcane ash as organic amendment, with activity reduced by about 40%. High incidence of *Fusarium* wilt on bananas and largest area under disease progress curve (AUDPC) were recorded in plots without any soil amendment applied.

The intensity of *Fusarium* wilt was diagnosed visually by analyzing both internal and external symptoms. *Fusarium* wilt pathogen populations were suppressed following use of poultry manure, sugarcane ash and *Tithonia diversifolia* both in the field and in the greenhouse. Viability of inoculum of *Fusarium oxysporum* f. sp. *cubense* has been reported to be reduced in soils amended with poultry manure and sugarcane ash. The most effective amendment that resulted in reduced viability of *Fusarium oxysporum* f. sp. *cubense* was poultry manure. This suggests that a higher application rate may be more effective in managing the disease. Similar results were reported by Borrego-Benjumea *et al*.(2014). In their findings they indicated an increase in the amount of poultry manure applied in field infested with *Fusarium oxysporum* f. sp. *cubense* would completely manage *Fusarium* wilt disease.

Application of these organic amendments modify soil environment biologically thus providing microorganisms with nutrients which then through their increased activities, improve the quality of the soil thereby suppressing *Fusarium* wilt pathogens (Fu *et al*., 2016). According to Hammerstein *et al*., (2016) green manure and residues of cover crops together with a low level of C: N ratio boosts the germination of chlamydospores and show low disease suppression levels. Thus it is important to allow green manure residues to decompose before utilizing them as composts. The samples collected from banana in plots amended with urea, sodium hypochlorite, and untreated plots showed high fungal infection as shown by a high frequency of re-isolation of the *Fusarium oxysporum* f.sp. *cubense.* The inoculation by *Fusarium oxysporum* f. sp. *cubense* has been reported as causing greater visual symptoms and yield loss to banana, an observation supported by this study. However, high significant reduction in disease severity was observed in plots treated with poultry manure and sugarcane ash.

The study showed that sugarcane ash and poultry manure were the most effective organic amendments of all the tested organic manures compared with the control. As a result, the study suggests strategies that if employed may reduce the activity of *Fusarium oxysporum* f. sp. *cubense* in the soil and are therefore likely to prevent the occurrence of the disease.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSSION AND RECOMMENDATION

5.1 General Discussion

The study revealed that majority of the farmers in both agro-ecological zones were on average aged 46 years of age with many attaining an average of primary school education. The results concur with those of Kangire *et al*. (2000) who reported majority of farmers as having an average of primary school education. Education enhances the uptake of newly released and improved banana varieties. Farmers with formal education easily look for suitable agricultural knowledge in order to improve their production.

Coffee, maize, tea vegetables, sugarcane, tea, millet, and fodder were some of the crops that were planted by the interviewed farmers. These crops were planted between the major crops for intercropping and for crop rotation. According to Zhang *et al*., (2013) systems of crop intercropping improves soil fertility thus contributes to yield improvement. Intercropping suppresses plant diseases through modification of the plant environment making it unsuitable to diseases (Karangwa *et al*., 2016). The farmers also rotated bananas with other crops which have various benefits including an effect on severity and development of diseases (Mugo, 2013).

The farmers mostly plant both local and improved banana varieties accessed mainly through the informal seed systems. Varieties Ng'ombe, Uganda green and apple were the most popular varieties grown in both agro-ecological zones. The three varieties dominated because of their sweet taste, and their ability to yield highly. High yielding capability of banana is one of the reasons for massive uptake by the farmers. According to Birachi *et al*. (2011) many farmers benefit from planting these improved varieties since they increased yield and reduce incidences of the diseases.

Majority of the farmers reported pests and diseases as the main constraint facing banana production. The results obtained agree with those reported by Birachi *et al*., (2011) that plant diseases are the major constraint to banana production. The high prevalence and incidence of this disease of banana in UM1 zone was as a result of the suitable environment conditions that favour the growth of *Fusarium* spp. According to Birachi *et al*., (2011) the conditions in the environmental, the cropping systems and soil may also influence the common bean root rots severity across the agro ecological zones. Many of the interviewed farmers did not manage this disease, only a few farmers applied manure for controlling *Fusarium* wilt. Application of organic amendment manipulates the soil environments which greatly reduce the incidence and severity of *Fusarium* wilt in bananas. Organic manure reduces the aggressiveness and infection ability of the pathogen while improving the plant vigour as a result of increased soil nutrient status (Fang *et al*., 2012; Ghorbhani *et al*., 2008).

Results show application of organic amendments such as poultry manure and sugarcane ash had significant effect on both incidence and severity of this disease in banana crop. The study showed that both sugarcane ash and poultry manure were the most effective organic amendments. The other two organic amendments also showed positive influence towards management of this disease. According to Larkin, (2015) organic amendments are essential for soil health and soil suppressive capability on disease pathogens. The use of organic soil amendments reduces the survival of the pathogens of *Fusarium* wilt both in the remains of plants and in the soil. The results, however, contradicts findings by Nasir *et al*. (2003) who reported chicken manure as having no effect on the activity of *Fusarium oxysporum* f. sp. *cubense.* In his findings, he reported chicken manure as having increased the incidence of *Fusarium* wilt.

However, this scenario mostly occurs when chicken manures are not properly or are partially decomposed. *Fusarium* wilt disease was suppressed following use of poultry manure and sugarcane ash both in the field and in the greenhouse. These organic amendments act by biologically modifying soil environment thus provides nutrients to the microorganisms which in their biomass activity boosts the quality of the soil thereby suppressing the disease pathogen (Fu *et al*., 2016)

5.2 Conclusions

This study document and establish the distribution of *Foc* in Kisii County and to evaluate the use of organic amendments in the management of *Fusarium* wilt disease. This disease of banana was found in all the agro-ecological zones in Kisii County that was covered during the survey. However, agro-ecological zone UM1 had higher incidences of the disease compared to LH1. Nearly all the farmers who took part in the study did not manage the disease, a few who did, only use manure. *Fusarium oxysporum* was readily isolated from vascular tissues with wilt symptoms. Farmers planted various crops in between the bananas primarily to improve soil fertility especially beans and suppress plant diseases through change of the environment of the plant by rendering it unsuitable to diseases.

The study identified poultry manure and sugarcane ash as the most effective organic amendment against *Fusarium* wilt, reducing disease incidence by over 30% compared to other amendments. Total suppression is desirable in the management of the disease since the pathogen is soil borne and can last for long years; however, this was not achieved by any of the amendments. From the study we hypothesize that management may be maximized by raising the soil pH to the highest value possible without negatively interfering with the growth of the plant and sustaining high organic level in the soil. Addition of fully decomposed poultry manure reduces disease severity.

To assess the effectiveness of either sugarcane ash and poultry manure, there is need for tests to be done in the field individually and in combination, in different agro-ecological zones, soil types, banana cultivars and systems of management. For bananas, due to the semi-perennial nature of production, trials must be long term to examine possible accumulation or dissipation of effects over time. Understanding the significance of organic manure among farmers can create new avenues for *Fusarium* wilt disease management. In conclusion, the potential exists for the practical use of soil amendments in the management of *Fusarium* wilt. Poultry manure and sugarcane ash present a good management strategy to integrate in *Fusarium* wilt management, reducing the inoculum levels and pathogenicity.

5.3 Recommendations

i. Organic amendments especially poultry manure and sugarcane ash should be integrated in order to get synergistic effect on the pathogenic *Fusarium* spp

ii. The farmers should be encouraged to use disease free and certified planting materials sourced from organization such as KALRO to reduce the occurrence of the disease.

iii. Banana varieties grown in these agro-ecological zones are susceptible to *Fusarium* wilt. Therefore there is need for introduction of new resistant banana varieties as a way of stemming out the threat caused by the disease.

iv. There is need for awareness creation of the threat of *Fusarium* wilt among the farmers in order to manage and control the spread of the disease.

v. Further research should be done in the field individually and in combination, in different regions, soil types, cultivars and management systems to assess the effectiveness of sugarcane ash or poultry manure.

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APPENDIXES

Appendix (I): Survey Questionnaire:

A) Background Information:

1) Gps-------------Altitude-------------Longitude-----------------Latitude---------------------

Village------------Sub-Location------------------Sub County ----------------------County--------------

Agro-Ecological Zone---

2) Name----------------------Age----------------------------Educational Level-----------------------

Farm Size------------------area under banana---

3) State the crops grown in your farm:

i) ---ii) ---

iii) ---iv) --

v) ---

4)a)List the banana varieties you grow:

i)---------------------------------------

ii) --------------------------------------

iii) -------------------------------------

iv) ------------------------------------

v)---------------------------------------

vi) --------------------------------------

b)list the most popular by order:

i)---------------------------------------

ii) --------------------------------------

iii) -------------------------------------

iv) ------------------------------------

v) ---------------------------------------

vi) --------------------------------------

5) State the type of planting materials you use---

-

6)Where do you get the planting materials from?--

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7)a) State the constraints/problems you encounter in banana production:

b) list the constraints/problems in order of importance:

i)--- i)---

ii) --- ii) ---

iii) --- iii) ---

iv) --- iv) ---

v) --- vi) ---

8) State the diseases/pests affecting banana in your farm:

i) ---ii) ---

iii) ---iv) --

9) Is *Fusarium*wilt a problem in your farm? Yes-----------No---------------

10) Which varieties are affected by *Fusarium* wilt?

i) --ii) --

iii) --iv) --

11) What is the level of damage of the varieties stated in (10)?

i) --ii) --

iii) --iv) --

12) How do you manage the disease?

i) --ii) --

iii) ---iv) --

13) When did you start seeing the disease? --

14) How many bunches have you been harvesting?

i) Current year--ii) Last year------------------------------

iii) Previous year--

B) Personal Observation:

15) Total number of mats in the farm-------------------------------Number of mats affected----------

16) a) Mat 1Total pants-------Number showing wilts----presence(+)/absence(-) of browning----

b) Mat 2 Total pants-------Number showing wilts----presence (+)/absence (-) of browning----

c) Mat 3 Total pants-------Number showing wilts----presence (+)/absence (-) of browning----

d) Mat 4 Total pants-------Number showing wilts----presence (+)/absence (-) of browning----

e) Mat 5 Total pants-------Number showing wilts----presence (+)/absence (-) of browning----

f) Mat 6 Total pants-------Number showing wilts----presence (+)/absence (-) of browning----

g) Mat 7 Total pants-------Number showing wilts----presence (+)/absence (-) of browning----

h) Mat 8 Total pants-------Number showing wilts----presence (+)/absence (-) of browning----

i) Mat 9 Total pants-------Number showing wilts----presence (+)/absence (-) of browning----

j) Mat 10 Total pants------Number showing wilts----presence (+)/absence (-) of browning----