FARMER PERCEPTION AND SOIL FACTORS INFLUENCING TISSUE CULTURE BANANA (*Musa x paradisiaca*) ADOPTION AND PRODUCTION IN SMALLHOLDER FARMS IN UGANDA

MURONGO MARIUS FLARIAN

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DECLARATION

This thesis is my original work and has not been submitted for a degree in any other University.

Signature Date

28th August, 2021

Murongo Marius Flarian

This thesis has been submitted with our approval as University supervisors

Signature

2nd September, 2021

Dr. Frederick. O. Ayuke

Department of Land Resources and Agricultural Technology, Faculty of Agriculture, University of Nairobi.

Signature

18th January, 2021

Prof. Julius T. Mwine (RIP)

African Centre of Excellence in Agroecology and Livelihood Systems, Faculty of Agriculture, Uganda Martyrs University

Signature

1st September, 2021

Prof. John. W. Kimenju

Department of Plant Sciences and Crop Protection, Faculty of Agriculture, University of Nairobi.

DEDICATION

My humble effort, I dedicate to my brothers and sisters along with all firm, hardworking, and memorable teachers whose friendliness, love, encouragement, and prayers of day and night made me able to get such success and honour.

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ACRONYMS

ANOVA	Analysis of Variance
APEP	Agricultural Productivity Enhancement Program
FAOSTAT	Food and Agriculture Organization Statistics
FGD	Focused Group Discussions
HPLC	High Performance Liquid Chromatography
IFAD	International Fund for Agricultural Development
MAAIF	Ministry of Agrculture Animal Industry and Fisheries (Uganda)
MAP	Months after Planting
NARO	National Agriculture Research Organization
PCA	Principle Component Analysis
RCBD	Randomized Complete Block Design
RDA	Redundancy Analysis
TCB	Tissue Culture Banana
UBOS	Uganda Bureau of Statistics
NIST	National Institute of Standards and Technology
NTCB	Non Tissue Culture Banana
GC-MS	Gas Chromatography-Mass Spectrometry
DCA	Detrended Correspondence Analysis

GENERAL ABSTRACT

The rate of adoption of tissue-culture banana at smallholder farmer level in Uganda has been low since the technology was introduced over 20 years ago. This study assessed farmer perception, soil biotic and abiotic factors influencing tissue culture banana (TCB) production, and compared the effect of integrated soil amendments on TCB growth in smallholder farms in Uganda. A cross-sectional survey on 280 smallholder farmers sampled from four districts of western Uganda was conducted among farmers growing both TCB and non-tissue culture banana (NTCB). The responses were subjected to Principal Component Analyses. Nested Case-Control design within smallholder banana orchard farmers was used to establish the interactions between selected biotic and abiotic parameters. Composite root and soil samples were collected from 20 banana orchards, and processed to determine the status of selected nutrients and numbers of plant parasitic nematodes. Banana weevil traps on a total of 1,280 banana mats were used to establish the spatio-temporal and biophysical interactions that exist in banana orchards. Variations in banana weevils trapped, nematodes and soil nutrients extracted were subjected to Redundancy Analysis and nested ANOVA at 5% critical value. Field experiments were carried out to establish the effect of integrated soil amendments on TCB growth. Banana cultivars of Mpologoma and Kibuzi were treated with 0g, 100 g, 300 g, and 500 g of NPK, 0, 5, 10, and 15 litres per plant of both cow manure and banana brew bio-slurries, respectively. Combinations of 100 in 5L, 300 in10L, and 500 in 15L NPK and sole bio-slurries, were applied to the two tissue cultured cultivars. Observations were made on soil and plant banana growth parameters at 3, 6, 9, and 12 months after planting. Composite root samples were analysed for *Helicotylenchus multicintus*, *Radopholus similis Pratylenchus goodeyi*, and *Meloidogyne spp.* Disc-on-stump and split pseudo-stem traps were laid to establish banana weevil variations vis-à-vis the amendments. Phytochemicals were extracted from composite root samples of the banana cultivars by maceration at room temperature with n-hexane (50ml) for 48 hours and sample extracts analyzed by Gas Chromatography-Mass Spectrometry. Demographic and farmer perceived factors influenced ($p \leq 0.05$) the decision to adopt or reject TCB technology. When exposed to weevil and nematode pests in heterogeneous banana orchard conditions, both TCB and NTCB were equally infested with banana weevil and nematodes. Infestation by weevils and nematodes was higher and significant [*Pr (>F)* 0.0343*] in TCB than NTCB during the dry season. Mean banana weevil density was higher for TCB and NTCB orchards in Kiruhura District than any other district. While the highest mean nematode density was recorded for the district of Ibanda, *Helichotelenchus multicinctus* and *Radopholous similis* were found most prevalent in western Uganda. High banana weevil and nematode populations densities independently and negatively influenced TCB adoption ($p<0.001$). Adoption of NTCB was largely influenced by the banana weevil ($P<0.05$) than it was by nematodes in the same farmers' fields ($p>0.05$). Variations in soil pH, and N significantly ($p<0.001$) influenced TCB distribution and adoption. Small amounts of organic and inorganic soil amendments equally caused normal TCB growth up to 12 months after planting and significantly provided nutrients at variable depths. Kibuzi cultivar was more infested with *H. Multicinctus* than Mpologoma cultivar, which was more infested with *P. goodey*i. Generally, Mpologoma was found more prone to nematode infestation by all the four genera under this study. Nematodes and banana weevil populations significantly ($p<0.001$) reduced with application of organic amendments, compared to the control. The study established that there are variations in the occurrence of phytochemicals in the root of banana of different cultivars due to treatment application, which probably acted as a defence against the weevils and nematode attack. Farmers most likely accepted type of banana that co-exists with pest infestation in those management practices that are probably affordable by the smallholder farmers. Critical understanding of seasonal and spatial distribution of banana weevils and nematodes is an essential basis for developing strategic and affordable treatments to manage the pests below the threshold level in smallholder banana farms of Uganda.

Key words:
Tissue culture banana, adoption, banana yield, Banana weevil, nematode, biophysical interactions, bio-slurry, organic amendments, phyto-chemicals.

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Background

Banana is one of the most important, but usually undervalued food crop in the world (Surendar *et al*., 2013). It is a staple food crop for millions of people of diverse cultural orientations in Africa. According to Thomas (2010) and Kamira *et al*. (2016), bananas are part of ancient crops domesticated in the subtropical climatic conditions. Banana is consumed in various forms and cooking methods have evolved over time (Infomusa 2004; Thakur *et al*., 2012). They are eaten raw, cooked, baked, steamed or fermented (Ravi *et al*., 2013). In many places, the whole plant is exploited with uses drawn from leaves, pseudo-stem, medicinally rich plant sap or fibre Asten (2011). Thus, bananas are grown for multiple uses apart from the edible fruit and have become interwoven with the culture and livelihoods of human society Ravi *et al*., (2013). Whereas it is quite true that bananas provide the services alluded to by Ravi *et al*. (2013), the present discussions fall short of addressing the adoption of TCB by smallholder farmers through use of the new technologies that come along with the development of the crop. Further still, the soil factors affecting banana growth require extensive study.

Smallholder farmers are the major targets of the developed banana production technologies and are co-experimenters in the development of agricultural technology (Bongers *et al*. 2012). The farmers live by the results of research, although they do not look into banana-related microbes, nematodes, weed seeds or even nutrients, their knowledge allows them to develop farming systems, farming procedures and accept cultivars that work, especially those that are adapted to the circumstances within which the smallholders live and operate (Van Asten *et al*., 2011). The implication is that, where smallholder farmers hesitate to adopt a new technology, probably pertinent issues exist with that particular technology. Further participatory research into factors that limit the adoption of such new technologies becomes necessary.

Banana is considered a semi-subsistence women's crop, which has provided steady incomes under a low input regime among East African countries (Tushemereirwe *et al*., 2003; Nguthi, 2007). As a result of increased urbanization and a significant drop in the incomes from traditional cash crops, notably cotton and coffee, banana has become highly commercialized (FAOSTAT, 2018). According to Nguthi (2007), tissue-culture banana technology was introduced as a package that included the provision of disease-free planting materials, information on crop husbandry, and post-harvest handling practices. During the adoption process, labour availability, gender of the household head and land size seem not to have a significant relationship and appear not significantly related to the adoption of TCB (Nguthi, 2007, and Mbaka *et al*., 2008). On the other hand, land tenure has positively influenced the adoption of tissue culture technology in addition to farm households' savings (Nguthi, 2007).

1.2. Banana production in Uganda

Banana is the staple food crop in Uganda with per capita consumption of 14.6kg by 2013, but the peak per capita banana consumption was 31.4kg in 1968, and the lowest (14.0 kg) in 2011, (FAOSTAT, 2015). Uganda was ranked the 21st in 2003 and 32nd in 2013, respectively as the highest consumer of banana out of the 149 banana consuming countries of the world (FAOSTAT, 2018). In Uganda, banana consumption is high in the central region but its production is increasing in the western part of the country. According to Tushemereirwe *et al*. (2003), the annual production for bananas in the country was estimated at 9.8 metric tons per annum by 2001. Regardless of the introduction of tissue culture technology, banana production has significantly continued to decline (Wandui *et al*., 2013). A report by

FAOSTAT indicates that banana production in Uganda declined from 10.5 metric tonnes in 2002 to a low of 5.8 metric tonnes in 2016. Subsequently, the land areas under banana production declined by 56% from 1.8 hectares to less than 1 hectare (FAOSTAT 2018).

More than 85% of the banana grown in Uganda is the East African Highland banana type (AAA genomes) with Matooke and Mbidde being the commonest landraces (Van Asten *et al*., 2011). The tree crop is an important source of income and has a high industrial potential for the production of juice, wine, and assorted post-harvest foodstuffs. However, continuous production of bananas is threatened by several pests, such as banana parasitic nematodes, banana weevils, and diseases such as black leaf streak/black Sigatoka, banana bacterial wilts, causing yield losses of 50 to 90 percent in banana and plantain production at household level. In Uganda, production has nearly halved, and the trends are similar in Kenya, Tanzania, Rwanda and Burundi; countries where the banana is a major source of calories. The rapid decline in banana production over the last 20 years, has been mostly due to pests and diseases, declining soil fertility, moisture stress, completion from weeds and slow acceptance of technologies developed to enhance banana and plantain production by smallholder farmers (Eden-green, *et al*., 2007; Nyombi, 2013; Dimelu, 2015). According to Wandui *et al*. (2013), attempts made to subside the causes of low banana productivity included the development of TCB planting materials. Other attempts to alleviate the imminent challenges of pests, diseases, and declining soil fertility, according to Tushemereirwe *et al*. (2003), have been through the introduction of improved varieties derived from conventional breeding through soma-clonal/hybridization and tissue culture approaches. Research indicates that improved varieties such as FHIA17, FHIA 23, SH3436-9 and those developed by soma-clonal hybridization using tissue culture (cell culture) techniques out-yielded the local genotypes by 40% on average under different agronomic practices (MAAIF, 2011). Nevertheless, the adoption by smallholder farmers and the adoption of plantlets produced through tissue culture has remained a challenge in Uganda. Farmers have chosen to use conventional planting materials other than tissue culture plantlets claiming that plantations established using TCB plantlets have a shorter lifespan compared to those established with the conventional planting materials (suckers). Therefore, research aimed at abating the rate at which plantations established with tissue culture materials deteriorate need to be developed to give smallholder banana farmers hope in the use of tissue culture technologies for productivity, sustainability and profitability of smallholder banana production in Uganda.

The review by Nyombi (2013), showed that the spatial and temporal variability creates nutritional differences for banana, thus, research on mineral fertilizer recommendations for the major banana producing areas should be done. The review highlighted two major challenges; first, the nutritional requirements for TCB, that may vary in both space and time, and second, the appropriate source of the nutrients for sustainable TCB growth. It is, therefore, not sufficient to suggest that only mineral fertilizer alleviates the growth differences. In the production of landraces, substantial amounts of nutrients are recycled to the soil through shredded leaves and pseudo stems. Depending on the number of banana plants per unit area, differences in nutrient recycling between agro-ecological sites are expected to occur (Ndabamenye 2013). Strategies that combine both organic and mineral sources of fertilizers and their effect on soil biophysical and TCB plant behaviour needed to be studied in totality to provide solutions to degenerating TCB orchards.

1.3. Statement of the Problem

The TCB technology adoption is one of the ways projected to draw smallholder farmers out of poverty and enhance food security across the East African countries (Kalyebara *et al.*, 2007; IFAD, 2009; MAAIF, 2011; Bwogi *et al*., 2014; Alex *et al*., 2016). Banana production has nearly replaced most traditional cash crops as an income-generating crop. TCB technology was introduced in Uganda mainly to answer the “Pest and Disease” question in banana production, so as to enhance productivity, fill income gaps, and improve food security at the smallholding level (Mbaka *et al*. 2008). However, the farmers tend to stick to the conventional banana suckers, even when results have shown that the TCB gives higher yield. It is not clear though, whether the discontinuance is due to factors that smallholder farmers are directly responsible for, or it is due to soil, and field related factors. Hence, the need to concretize the reasons for non-adoption and discontinuance after the adoption of BTCB by smallholder farmers by this study was important. Some studies suggest deterioration of the Banana orchards to be due to the action of banana weevils, nematodes, biophysical factors, and soil exhaustion (Alou *et al*., 2014), However, appropriate simple and affordable solutions to curb banana plantation deterioration appear elusive to the smallholder farmers. Additionally, the response of banana plantations to weevils, nematodes and other soil chemical properties when smallholder farmers apply local soil amendments is not clearly known to these farmers (Gaidashova *et al*., 2009). Assessments that capture the factors prompting the production dynamics of banana especially the TCB among smallholders in Uganda, and designed approaches to enable sustainable production TCB at smallholder production while providing a solution to biotic and abiotic factors associated with TCB orchard degeneration were justified.

1.4. Objectives

1.4.1. Broad Objective

Assess farmer perception and soil factors influencing banana **(***Musa x paradisiaca***)** adoption and design soil amendments to increase production, productivity, sustainability and profitability of smallholder TCB production by at least 30% in Uganda.

1.4.2. Specific Objectives

1. Assess factors that influence TCB technology adoption at smallholder farm level.
2. To establish the biotic and abiotic factors that affect the production of TCB orchards at smallholder farm level.
3. To compare the effect of selected integrated soil amendments on selected biotic and abiotic factors in TCB growth and production.

1.4.3. Hypotheses

1. Adoption of TCB technology is not influenced by farmer perceptions at the smallholder farm level.
2. Selected biotic and abiotic combined or individual interactions in smallholder farmer fields have no significant effect on the production of TCB orchards at the smallholder farm level.
3. Integrated soil amendments in TCB production have no effect on the biotic and abiotic factors that are significant to TCB orchard growth, and productivity.

1.5. Justification of the study

Most African governments are investing in agricultural innovations and technologies aimed at improving peoples' incomes and livelihoods (MAAIF, 2011). This is a constitutional obligation to achieving prosperity for their citizens using agriculture as a locus (IFAD, 2009; IFAD, 2012). The Uganda government's policy vision is to see progressive annual improvement in incomes of households that are dependent on agriculture as well as food and nutrition security. Although an institutional legal framework exists, there is a deficiency of specific policy for the banana sub-sector (Alex *et al.*, 2016). Gaps exist in areas of land proprietorship and access with regard to women. Women form a large part of the labour force in the banana production process. The use of banana derivatives such as alcohol residues and recycling of spin-offs are issues of policy concern. On the basis of unstable productivity, financial institutions are watchful in extending financial assistance to banana farmers. Working strategies developed for smallholder farmers were meant boost national and regional food security, and enhance policy formulation to address the identified policy gaps. Studies that provide information on the behaviour of the developed technology and establish the means for perpetuation of the technology are justified. It is in this spirit that, this study was suggested. Furthermore, smallholder farmers continue to observe the effects of declining soil fertility, pests, diseases and climate change challenges and therefore, the methods suggested will develop strategies that are friendly and affordable at the smallholder farm level in solving TCB production and provide production resilience to climatic change challenges.

1.6. Conceptual framework

This section explains both narratively and graphically, the main concerns of the current study. The key factors, concepts, and variables involved in the study, as well as the foreseeable relationships among the variables, are described. This study considered the adoption of the tissue culture plantlets by smallholder farmers as a dependent factor upon the dispositions and interests of the farmers themselves. Farmers' motivation, perception, and interest are enkindled by the productivity of the plantlets from tissue culture (Abdullah and Samah, 2017). Where farmers have a negative attitude, it may affect the productivity of a given technology. Several factors affect farmers' attitudes towards a given technology (Sjakir *et al*., 2015), hence, the type of attitude influences the management practices accorded to the technology in question.

The adoption rate of tissue culture plantlets by farmers is not only affected by farmer attitude but also by other factors stemming from the biophysical interactions between TCB plantlets and the ecosystem where the plantations are established. For example, nutrient distributions within the farmers' fields may not be supportive of the performance of the technology in question (IFAD, 2012; Abdullah and Samah, 2017). Location of the plantations, land use and tenure affects the productivity of TCB because they form the general environment within which the crop is produced. Several soil factors including, pH, organic matter, and nitrogen, phosphorus and potassium nutrients strongly affect the performance of TCB plantations. Commercial banana producers and the small-scale banana farmer's sale raw matooke in major towns. The trade process generally limits the return of the residues such as banana peelings and fibres back to the field to provide manure, therefore, the nutrient recycling processes involved in technology management need consideration. The interaction of the biological components is an important factor as indicated by (Ayuke, 2010). The prevalence of destructive weeds, weevils, nematodes, and other pests has to be clearly implicit in the TCB production system as these significantly affect the survival and longevity of a banana plantation.

Figure 1.1 below shows the major concepts and their relationship to the variables and methods of the study.

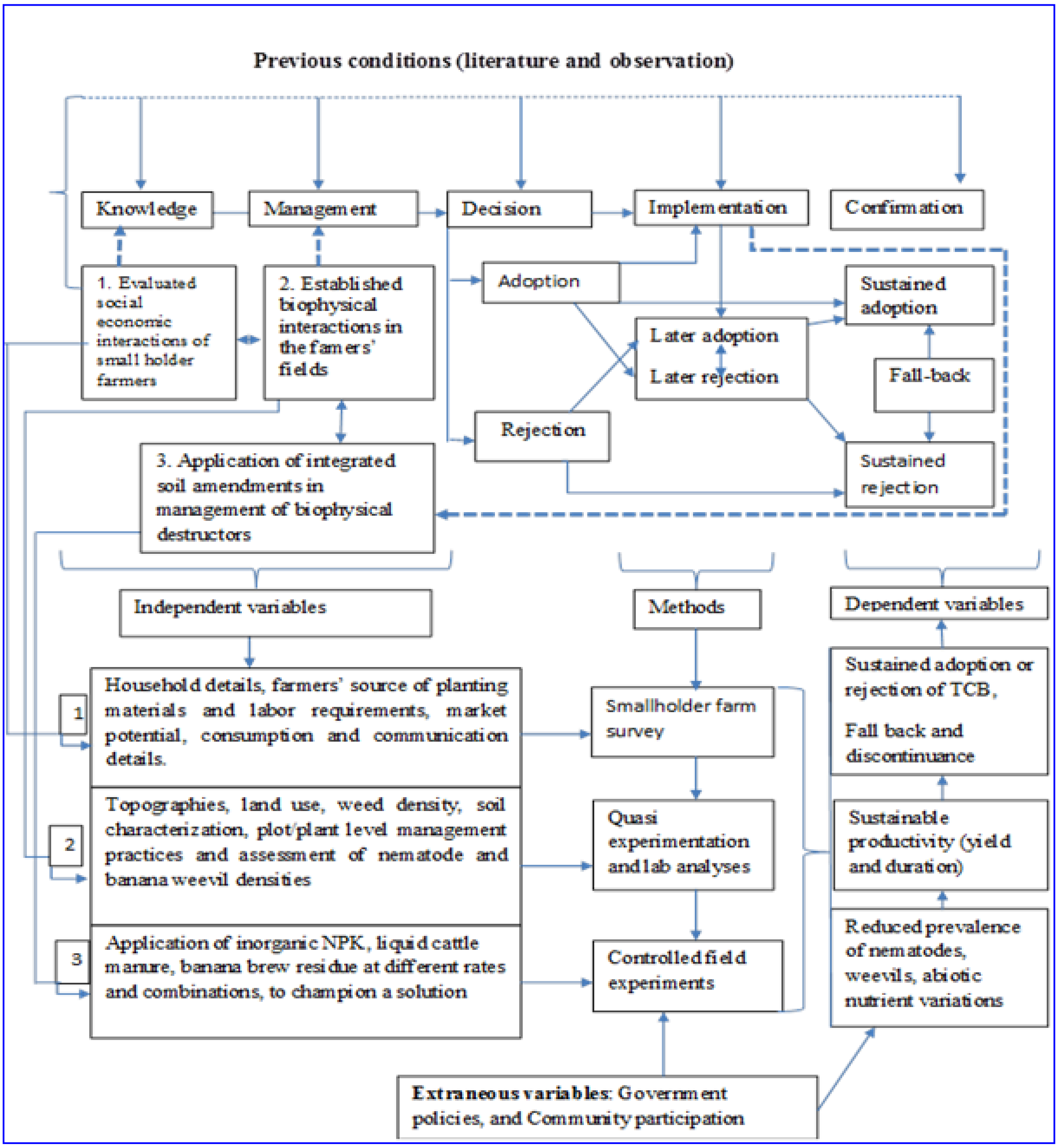

Figure 1.1: Conceptual framework of the factors, concepts, and variables of the study

The study acknowledged the fact that smallholder farmers possess knowledge from observations and literature on the previous conditions of banana production technologies. The acquired knowledge provided the management options in banana production and subsequently informs the decisions for implantation of the model of production. Comparisons of the farmers' knowledge, management, and decision and implementation aspects facilitate confirmation by the farmer, whether to sustain or reject the technologies. The study put the factors influencing TCB technology adoption in the perspective of Farmer perceptions and evaluated them under the knowledge aspects of the conceptual model. The framework assumed that knowledge aspects translate into management options, hence, the smallholder farmers put into practice what they concretely understand, and therefore, biophysical interactions of the study were assessed under the management auspices of the conceptual model. At implementation, farmers put to experimentation the knowledge and management practices they decide upon. The current study placed the experimental application of soil amendments under the implementation section of the model. At implementation, farmers may adopt or reject the technology. Those who earlier had rejected the technology may later adopt it and those who had to reject the technology may adopt it. The present study based on the confirmation stage to select smallholder farmers. The study considered smallholder farmers who were engaged in banana production for a period of not less than fifteen years. This period was considered long enough for the farmers to go through the knowledge management decision implementation and confirmation process to defend their sustained adoption and or sustained rejection of the technology and study.

The resolve of the study was to contribute to the solutions towards increasing the adoption of TCB technology. The environment within which the farmer operates and management of the biophysical environment within the TCB plantations inform any solution of this nature. The major hindrance to the adoption of TCB technology lies in the fast degeneration of the banana plantations in the field resulting mainly from damage due to banana weevils, nematodes, and variations in soil abiotic components (Alou *et al.,* 2014). The study framework suggested management options deemed affordable to the smallholder farmers and expected to ameliorate biophysical soil factors that hinder the productivity of TCB plantlets and longevity of plantations from TCB planting materials hence increase the technology adoption.

The current study focused on the factors surrounding the smallholder farmers in the production of bananas in general, with special interest on TCB. The factors of particular interest included household details, farmers' source of planting materials and labour requirements, market potential, consumption and communication details. The study hypothesized that these factors are generally not responsible for the rejection of TCB or fall back and the discontinuance of TCB for the farmers that already adopted the technology. The study also focused on factors that affect the performance of the banana crop (regardless of whether TCB or not), including, land use/tenure, soil fertility, management practices, nematode, and banana weevil populations. The hypothesis based on these factors was that these factors are not significant to the degeneration of TCB plantations, but their interaction results in sustainable productivity of the crop. The study framework was further limited to the application of inorganic fertilizers (NPK), liquid cattle manure and banana bio-slurry at different rates and combinations to champion a solution to the prevalent nematodes, banana weevils and give an affordable source of plant nutrients for the smallholder TCB farmer. The study hypothesized that integrated soil amendments in plantations established with tissue culture plantlets have no effect on the factors that affect the growth and productivity of banana.

Figure 1.1 indicates that the participation of the community, the government, and other stakeholders, were external variables that had a bearing on this study. Individual farmers have a stronger voice to reject or accept the technology when they act as a community. Equally, the policies by government, Universities, and local communities may not favour some practices in TCB production, hence affecting adoption. It is upon this background that the study recommended various policy directions and research viewpoints

CHAPTER TWO

LITERATURE REVIEW

2.1. General banana production dynamics

Banana (*Musa accuminata* L.) is a perennial herb, in the family *Musaceae*, which provides staple food to millions of people in tropical and subtropical regions of about 150 countries all over the world (FAOSTAT, 2015). The family is further classified as cooking, dessert, roasting and beer bananas. A study by Muazu *et al*. (2014) indicated that the world-wide acreage under banana production was 4.84 million hectares, translating into a minimum production of about 95.6 million tons per year. The banana is planted for its versatile functions including but not limited to fresh fruit for food, beverage, alcohol and spirits' production, and animals feed, art crafts, and vegetable production (Ali *et al*., 2011). According to Erima *et al.* (2016), banana is a source of important raw materials in banana production processes. Propagation of banana is mainly by vegetative suckers which grow from lateral buds originating from corms (Ngomuo *et al*. 2014). However, propagation of banana using suckers is very slow (Hussein, 2012). Suckers result into pest and disease transmission, although the use of suckers is one way of conserving the genetic makeup of the mother plant (Tinzaara *et al.*, 2006). TCB production technologies were introduced as superior technology with respect to optimal yield (Tropentag *et al.* 1999), growth uniformity (Tinzaara *et al*. 2006), rapid multiplication of planting material (Njau *et al.*, 2011), but most importantly, production of pest and disease-free propagation material (Erima *et al.*, 2016) Speijer, 2017).

Banana production generally declines with time due to poor orchard management practices coupled with declining soil fertility (Mbaka *et al.*, 2008). This is rather a generalized postulation that falls short of the specific attributes that exacerbate soil fertility decline. Andersson and Andersson (2014) found out that yields for cooking banana were significantly higher in smallholder farms that use organic manure compared to inorganic fertilizers. Organic manure is, therefore, a factor useful in banana production. According to Ndabamenye *et al.* (2012), plant density management is one of the key management practices that offer the prospect of increasing banana productivity. A report by Andersson and Andersson (2014) recommended that plant density should have an agroforestry approach instead of monoculture. Van Asten *et al.* (2011), found that banana yields, regardless of the type, are significantly higher in coffee-banana intercrops compared, to mono-crops. According to Bongers *et al.* (2012), and UBOS (2016), the reason for intercropping coffee and banana on the same plot of land stems from issues of land scarcity. Most studies are, however, not explicit on the longevity of plantations established with Tissue Culture plantlets and the smallholder farmer perception management recommendations to arrest challenges of declining soil fertility, destruction by pests and faster orchard degeneration; the consequence of which has kept adoption of the TCB technology staggering.

In Uganda, banana production is higher in the western part of the country; especially in districts that were predominantly pastoralists. According to Lysenko (2004), a production trend of this nature is attributed to edaphic factors drawing from a history of enrichment with farmyard manure from the pastoral animals. Figures 2 and 3 show the production potential of the major regions involved in banana production in Uganda for the period 2014-2016 for both the area under banana production and productivity of banana in tons per annum. The review indicated that the cardinal reasons for banana production in Uganda is for food and liquor brewing (Kalyebara *et al*., 2007). An increase in acreage of production (Ha), as shown in figure (2.1) resulted in increased production of all types of banana regardless of the reasons advanced for production (Figure 2.2). An increase in total acreage to approximately 501000 ha in western Uganda, enhanced production of banana to approximately 2.8 million tons in the same region.

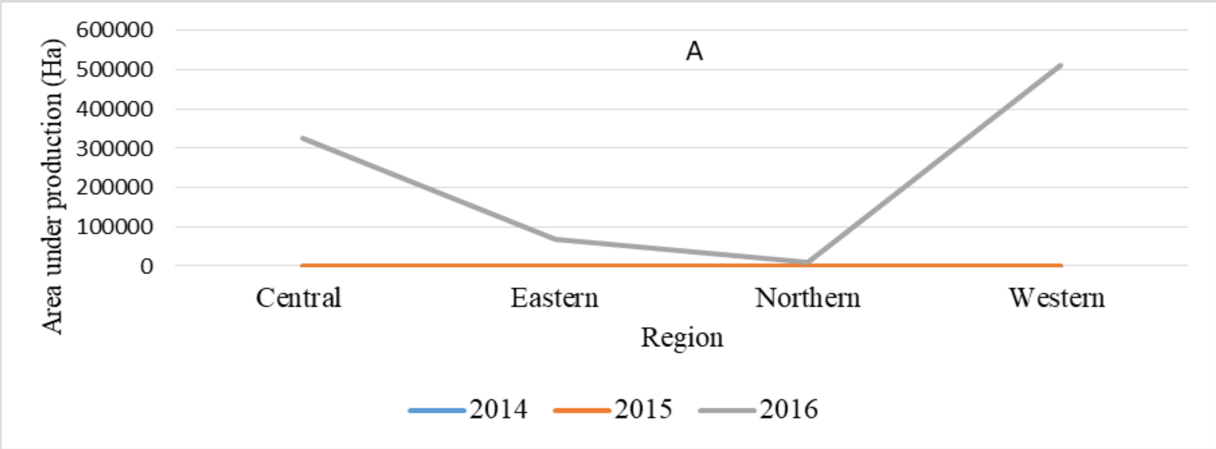

Figure 2.1: Banana production by region in Uganda; Area under production (ha)

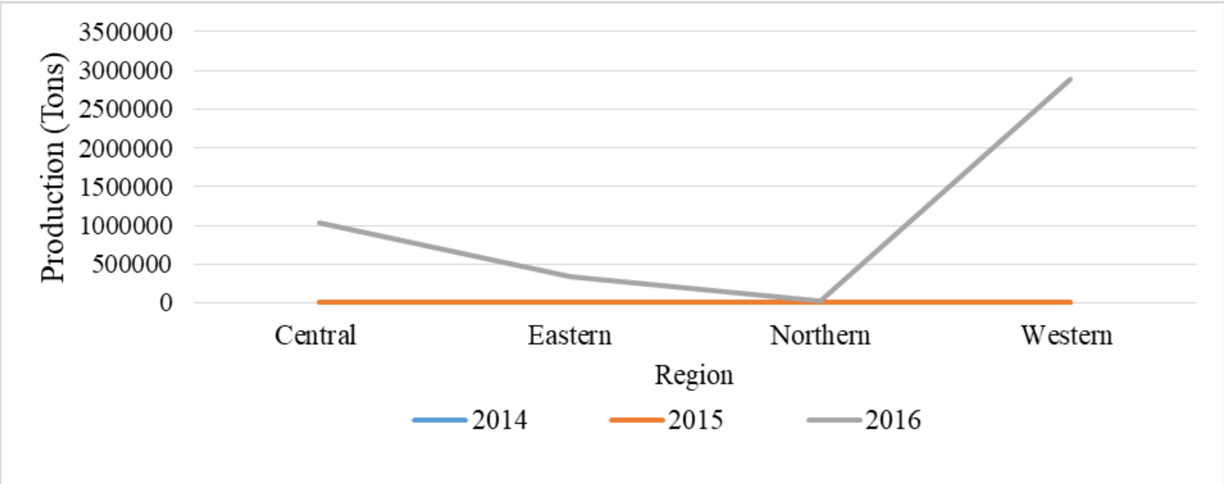

Figure 2.2 Banana production by region in Uganda (Tons)

Figure 2.1 and 2.2 were developed from UBOS report of 2016. The data breakdown for individual regions for 2014 (colour green on the legend) was not available in the 2016 UBOS report.

The Uganda census for agriculture of 2009 identified Isingiro district in western Uganda as the highest banana producing district with an average production of 601,363 tons per year (UBOS, 2016). Districts taking the lead in Central, Eastern, and Northern regions were

Mubende (204,109 tons), Mbale (99,011 tons) and Arua (17,106 tons), respectively (UCA, 2009). Uganda Bureau of Statistics (UBOS) further reported that the production of banana increased by 1% from 4,574,471 million tons in 2014, to 4,623,367 million tons in 2015 and later dropped to 4,297,375 million tons in 2016. Time and again, such declines have been attributed to banana weevil, often overestimating the weevil damage, since they are also blamed for the damage caused by nematodes. Currently, soil fertility decline and nutrient mining are major reasons for yield decline in banana production.

Cooking banana covers the largest area under production (2.9 million ha.), with 61% of the total hectare under mixed stands (UCA, 2009). The Northern region had the largest area (62%) under a pure stand of cooking banana (UBOS, 2016), followed by Western and Eastern with 41.4% and 34.1%, respectively. It is evident from the review that regions that grow banana in pure stands have low yield returns. The total acreage under the beer type is estimated at 208,000 ha, taking into consideration both banana pure stands and intercrops (UCA, 2009; UBOS, 2016). Beer banana pure stands occupied 55% (114,000 ha) against 45% (94,000 ha) mixed stands of the total production area. While the Northern region cultivated beer banana in pure stands, other regions, intercropped beer banana with cooking banana and other crops, national statistics (UBOS, 2015) showed that 61.2% and 32.2% of the area under beer banana production was under mixed stands in the Western and Eastern regions, respectively.

2.2. Tissue culture banana technology and adoption

Tissue culture is the technique through which an appropriate plant part (other than storage organs) is cultured on a nutrient medium under sterile conditions with the purpose of obtaining growth and rapid multiplication of planting material, faster growth rate and increased productivity (Nguthi, 2007). The whole idea has its origin in the cell theory that was formulated by Schleiden and Schwann in 1839. Tissue Culture planting materials are widely adopted by farmers in Asia and have been encouraged for smallholder farmers in Uganda (Ogenga-Latigo and Bakyalire, 1993). In support of the technology Abdullah and Shamah (2017), and IFAD (2012), have indicated that farmers found TCB technology important since it encourages the planting of disease-free and high-quality planting materials. In Uganda, the technology was introduced in the late 1990s (Wandui *et al*., 2013), and has spread to both the public and private domains although the spread is slow amongst the smallholder farmers (Murongo, *et al.*, 2018).

In Uganda, the puzzle remains as to why a technology that evidently brings forth advantages is not rapidly taken up by smallholder farmers. In a study by Murongo *et al.* (2018), it was established that 83% of the banana farmers in Uganda use conventional suckers obtained from their own farms, and from the neighbourhoods of similar plantations. The study further indicated that 75% of the farmers engaged in banana production go for conventional plantations even when they are cognisant of the advantages brought forth by TCB technologies. The behaviour expressed by smallholder farmers largely contravene Baffoe-asare and Danquah (2013) conclusion that embracing advancements in agricultural technology (including tissue culture), increases agricultural production.

Baltaci-goktalay and Ocak (2006) defined adoption in terms of integrating the new technology into the existing one. For fear that the technology adopted may become irrelevant in the future, farmers normally start by trying new technology in small plots so as not to waste time, energy and resources. The trials in the small plots over time later transform into adaptations that lead to adoption. The study is, however, not explicit on the duration of time that farmers may take to adapt to the technology under trials. According to Mercer (2004), it is difficult to predict the rate in case where adoption is a mental process that requires practice after an innovation to allow the cognitive domain decide on utilization that later leads to adoption. This means that if the farmer has enough time to discern and integrate TCB technology into their knowledge domain, then, adoption may occur faster. Indimuli (2013) argue that the adoption of improved technology in agriculture requires certain expertise that is scarcely attained by the local farmers. According to Berg (2013), the financial challenges involved in acquiring the planting materials are a great hindering factor. The likelihood of the smallholder farmer to revert to conventional banana production technologies are largely influenced by the lifespan and yield potential of the technology (Nakato *et al.,* 2017), environmental and soil conditions (Ali *et al.,* 2011), unsustainable tillage practices (Huang and Yeung, 2015). However, pest and disease epidemics drastically affect the yield and quality of the crop and negatively affect the adoption as well. Sucker propagated plants are easily affected by diseases and once infected, the pathogens are transferred from cycle to cycle and the entire population may be wiped out within few years (Huang and Yeung, 2015), yet smallholder farmers remain attached to these banana propagules.

2.3. The farmer perceptions influencing the tissue culture adoption

Studies have identified social networks, learning categories, and human capital as important factors compelling farmers to adopt new technology (Dawson, 2008). These social networks, learning categories, and human capital enshrine gender perspectives, age strata, occupational and religious networks (Katungi *et al.,* 2006). For example, the social networks among farmers of the same living standards can easily influence adopt of the new technology or not. Male farmers are highly networked and can easily access information about any new technology as compared to females. Besides, women can fail to adopt a new technology because of limited input land ownership (Doss *et al.,* 2011).

The decision to adopt an agricultural technology by farmers may depend on the new technology Studi *et al.* (2003), the natural conditions surrounding the farmer (Eleni *et al.,* 2003; Amugune *et al.*, 2007; Boadi and Bokanga, 2007; NARO, 2017). The nature of dissemination of the new technology Tessema *et al.* (2016),and also influence farmers to adopt some technologies. The level of adoption depends on the farmers' judgment of the benefits arising from the new technology vis-à-vis the existing one Baffoe-asare and Danquah (2013), and Abdullah and Samah (2017), agree that any new agricultural technology is acceptable as far as it contributes to the solution of the problem at hand. In fact, people easily adopt a technology that is relevant to their needs than the technology whose relevance is not geared to meeting peoples' needs. In Uganda, farmers have been planting bananas for a long period but the orientation has been towards use of conventional suckers Karamura (1998); and NARO (2017), and the reasons for which they have been slow on the uptake of new approaches is a matter for debate.

As Dawson (2008) and Katungi *et al.* (2006), identified social networks and religious aspects as factors that sway farmers from one technology to a more advantageous one, the ability of the smallholder farmers to try out an improved agriculture technology before is important in influencing the adoption of the technology (Baffoe-asare and Danquah, 2013). Smallholder farmers come to understand the comportment of the new technology, its productivity in relation to the already existing one. Titus (2016) found that the characteristics of the technology as identified prior to application play a significant role in adoption and uptake decision. Smallholder farmers reluctantly adopt technologies with features similar to the traditional technologies that have been productive. Mrica *et al.* (1995), adds that this sentiment goes with the stereotype and attitude of the farmers to improved technology, the basis upon which Wandji *et al.* (2012), and Peter and Susan (2014), concluded that perception is important in determining the adoption of a new technology among traditional farmers. Perception is often linked with the people's situation and need for the food or cash crop to be used under that technology. Peter and Susan (2014) are explicit on perception as an influential factor determining technology adoption among the smallholder farmers as it is linked to the people's situation and need.

Human capital has an imperative influence on the adoption of new technology in agriculture. Studies on banana assessed human capital in terms of education, age, gender and the size of the household among various farmers (Meiguran and Basweti, 2016). Education intertwines with human capital to help individual farmers assess the capability to use the adopted technology. Education increases the ability of the farmers to adopt, process and use the obtained information through training (Kansiime *et al.,* 2014) and is instrumental in the use of inputs by smallholder farmers (Ajewole, 2010). The fact that education is associated with improved technology, uneducated individuals would not use the technology but, may hire the educated personnel to aid in the application of the technology on their farms. There are, however, some instances, where education does not influence farmers to adopt an improved agriculture technology. Oyekale and Idjesa (2009), found that more farmers with no formal and/or limited formal education levels adopted new technologies faster in comparison to farmers with formal and tertiary and post-graduate education. In Uganda, most banana farmers are educated to the level of primary and secondary school category (IFAD,2009; IFAD,2012; UBOS, 2016). In conclusion, while education is significant in information access and understating, it may not be a prerequisite in some cases of adoption.

Gender is an important dynamic in the process of adoption of agro-technology with some studies expressing mixed results about male versus female attitudes to the adoption of new technology. Asiedu-darko (2014) argued that women would be the fast adopters of any agricultural technology if they were not limited by their vulnerability. This argument corroborated with Beloved *et al*. (2012), Bwogi *et al.* (2014), and Mwangi and Kariuki (2015), whose studies indicated that women do not have control over land, neither do they control the labour of the households.

Gender is often nested with age in making comparisons for the adoption of the technologies. While nesting gender with age (Edoge, 2014) noted that age distribution is strongly associated with the labour force to be used in the introduced technology. The old people do adopt new technology than the youth, but this depends on gender. Most female youth do not consider learning of new agricultural technologies as being beneficial (Sarwar, 2011). However, eversion and decreased long-term investment occur with the increase in age of male farmers. Despite this, supposing old men have access to improved technology and thus accept it, its impact is often less felt than agricultural technology adopted by young women (Bwogi *et al.*, 2014). This is because young women are committed to what they adopt and can be easily found on the farms, plantations and in the kitchen compared to their counterpart young males. Gender remains a focus of argument in the adoption of tissue culture technology in Uganda since heads of households are the final decision-makers. In such a situation, men have control of labour and land; they are more favoured by culture and tradition compared to females.

Household size as identified by Farid *et al.* (2015, and Yan and Moiwo (2015), is a significant factor in influencing the adoption of certain agriculture technology. Household size determines labour availability as well as the size of the farm or plantation. In Uganda, farmers with large families are likely to have large banana farms due to available labour (Alex *et al.*, 2016), and in turn, large farms are more likely to adopt the new or the improved technology than the farmers with small families and small farms. It is expected that if small households with small farms can provide incentives to the adoption of improved technology than the large farms, the rate increases. For example, farmers with small farms can easily adopt zero-grazing farming and greenhouse technology that allows small-scale production of TCB.

The factors that link the social and economic issues in the adoption of the technology include the cost of the technology and the income of the farmer. The cost (in terms of farm inputs, labour, transport and mechanization) of adopting any agricultural technology if high, is a major hindrance to adoption, labour (Mrica *et al*., 1995; Sulo, 2012; IFAD, 2012). The cost of the technology has a direct relationship with the farmers' income as a major determinant for the adoption of the technology involved. According to Derpsch *et al.* (2010), low-income farmers may not adopt high-cost technology, but there is no clear likelihood that farmers with substantially high incomes may reject low-cost technologies. Other economic factors influencing the adoption of agriculture technology include off-farm activities (Mwangi and Kariuki 2015). Hence, strategies that assist smallholder farmers with cheap and sustainable inputs enhance the uptake of the technology associated with those inputs.

2.4. Biophysical constraints in banana production

For this review, the study adopted the definition of Mahajan and Tuteja (2005), that biophysical constraints are the biotic and abiotic environmental factors surrounding an organism. They either influence the survival, development, and evolution (Ayuke, 2010) or lead to total destruction of interacting organisms (Speijer, 2017). East African countries have a higher potential for banana production compared to Latin America and other sub-Saharan countries, although, the level of banana production among smallholder farmers in East African countries still remains low (Salami *et al.,* 2010). This could be attributed to seasonal variability in temperature, rainfall, mineral nutrients, and organic matter. The variations throughout the year may reduce the level of production, lead to difficulties in estimating plant densities of crop generations, and disorient simple technologies to sustain soil health and fertility. According to Brooker *et al.* (2013), deterioration of adopted technologies may start with human migrations, where energetic persons that would have provided enough labour to a rural-based TCB production move to urban areas in "rural-urban" migration waves. The banana weevil, *Cosmopolites sordidus* (Germar) of the order *Coleoptera*, family *Curculionidae* according to and the parasitic nematodes (Gowen, 2005) are the major biotic constraints for banana production in the world.

The severity and occurrence of biotic risk factors [the banana weevil and nematodes] and plant damage depends on the prevailing environmental conditions such as light, wind, temperature, water supply, erraticism of the soil physical and chemical composition, which have great influence on the growth of banana plants in many ways. Changes in these factors cause irreversible damage to plant tissues (Wahid *et al*., 2007) , lead to high salinity (Huang and Yeung, 2015), cause soil acidity (Lysenko, 2004), and enhance pathological reactions that inhibit growth and development of the banana plant (Ochola *et al*., 2015). High prevalence rates of the banana weevil and the parasitic nematodes, influence the survival, development, and evolution of the crop under production (Ayuke 2010; Speijer, 2017). Banana varieties planted in Uganda are prone to detrimental biological interactions with the banana weevil and the parasitic nematode (Alou *et al.,* 2014). The interactions lead to the collapse of the orchards (Ocan *et al.*, 2008), damage the roots rapidly provide space for the infection by pathogens, destroy the banana plant stability (Arinaitwe *et al.*, 2014), and result in serious yield losses. For tropical crops such as banana, nematode parasitism in roots is characterized by simultaneous infestations by several species (Gowen, 2005). Most widespread parasitic nematodes of Musa cropping systems in African lowlands arise from four genera; *Radopholus similis, Pratylenchus goodeyi, Helicotylenchus multicinctus,* and *Meloidogyne* spp. According to Gaidashova, *et al.* (2009), these are the most common nematodes found in banana plantations at different altitudes in Africa. The species of nematodes found to be most detrimental to banana are those, which are involved in the destruction of the primary roots, disrupting the anchorage system and resulting in the toppling of the plants. Symptoms of environmental stress on banana can sometimes appear similar to those caused by biotic stress, but a combination of both factors leads to faster degeneration of the orchards in Uganda.

Banana growth requirements include a sustainable supply of organic matter, phosphorus, potassium and amended soil to allow pH range 5.5-6.5 for proper nutrition and resistance against biotic and environmental vagaries. Besides its value as a source of plant nutrients, organic matter has a favourable effect on soil physical properties (Pawar and Shah, 2009). The organic matter content of a typically well-drained mineral soil is low varying from 1 to 6% by weight in the topsoil and even less in the subsoil (Pawar and Shah, 2009). The influence of organic matter (OM) on soil properties and consequently on plant growth is far greater even though the percentage of organic matter (OM) may be less in the soil. Smallholder banana farmers in Uganda do not quantify the percentage of organic matter content due to the expensive cost involved.

2.5. Soil amendments and their effect on biotic and abiotic factors in banana production

This section examined how the application of different integrated soil amendments affect the nematode and banana weevil factors in the growth and productivity of banana in an abiotic environment. Integrated soil amendments referred to in this review are a set of agricultural soil management practices adapted to local conditions not only to supply and maximize the adeptness of nutrient and water use in TCB production but also contribute to and improve agricultural productivity. The amendments centered on the combined use of mineral fertilizers and locally available materials such as lime, crop residues, compost, and green manure to replenish lost soil nutrients. According to Thangavelu and Mustaffa (2012), the ability of the nematode to thrive in the field is often impeded by application of organic concoctions into the soil. However, Sumbul *et al.* (2015), related the survival of the nematode in the roots of the banana to the nutrition of the banana itself. Nematodes depend on the nutrient reserves in the banana roots. According to Galadima *et al.* (2015), a banana genet well supplied with nutrients presupposes a well-fed nematode inside the banana root. However, the consequences of feeding the nematode are often detrimental to banana growth and productivity. A study by Nelson *et al.* (2006), further confirms that the decline in banana growth and productivity across the globe is largely attributed to banana weevils and nematodes. The occurrence of nematodes depends mostly on the temperature, type of the crop, type of soil and management options by the farmers (Hussein, 2012). Soil organic content, soil structure, soil aeration, soil moisture content, and host plant roots all determine the survival of nematodes in the soil (Rizvi *et al.*, 2012). Besides, the population of the nematodes is higher in warmer areas than cold areas Galadima *et al.* (2015) and when nematode damages banana roots, it becomes difficult for the plant to absorb water and mineral nutrients from the soil. Soil amendments that increase organic matter, improve the texture and moisture content, and regulate the temperature of the soil would control the pest in question.

Regular application of organic matter into the soil is important in maintaining a fertile soil for banana plant growth and production (Mmbaga *et al.,* 2014) and improves the soil water holding capacity (Jansa, 2014). Dupont *et al.* (2009), showed that the application of compost boosts plant immunity to resist against weevils and nematodes, but most importantly, it introduces some nematode hostile agents in the soil. Kalele *et al.* (2010) indicate that antagonistic fungi in the soil organic amendments may attack, compete for food, or produce substances that may kill nematodes. Other approaches that are normally associated with decreasing nematodes and weevils as well as sustaining the nutrient status of the soils in banana orchards include but are not limited to; crop rotation, minimum tillage, use of animal manure and using cover practices on the plantation of the banana.

Farmers in developing countries normally apply synthetic nematicides in order to control nematodes (Benard *et al.,* 2017; Agbenin, 2011). Despite their role against such parasites, scientists have found that chemicals have adverse effects on human life, animals and the environment at large (Kumar *et al.,* 2012; Mahmood *et al.,* 2015). Whereas this has been a fact among scientists, there is yet another assertion that the use of synthetic pesticides has a greater effect in controlling pests and this, in turn, increases productivity and crop yields. Due to misuse among farmers, the use of chemicals normally results in environmental pollution that negatively affects nature. Pesticides are costly to most farmers and very few can use them sustainability (Bui *et al.,* 2016). Farmers at times use cultural practices that are normally referred to as field sanitation. Field sanitation is important in controlling and preventing banana parasites such as nematodes from spreading from one place to another.

The practices under field sanitation include removal of affected banana plants from the plantation, control weeds through hand weeding to reduce on the alternative hosts for the nematodes (Fianko *et al.,* 2011). Farmers do regular pruning of green leaves to increase light penetration. Other important field practices involve de-trashing, de-suckering, and intercropping (Sivirihauma *et al.,* 2017).

Crow and Dunn (2016) noted that farmers amend soil with crop residues and green manure not only to control nematodes but also provide an environment intended to slow down banana weevil activity. The decomposition of organic matter increases *Ox-amyl* with its nematicidal effects in the soil including aggressive action by some of the small organisms against nematode activities. Animal, industrial and agricultural wastes have a significant effect on the nematodes within the soil and increase productivity and yield of the banana. This is because the application of these wastes and manure improves the soil structure and fertility. Organic amendments give the *nema-toxic* compounds and other bio-control agents that are influential against nematode multiplication but improve on the plant growth Erick (2014). Forster *et al*. (2013) noted that the application of the integrated pest management (IPM) approaches in banana orchards has lasting effects of production and reduction of banana weevils and nematodes. Such approaches involve biological control, application of the organic amendments and responsible use of chemical pesticides (Zhang *et al.* (2018). While the approach reduces the multiplication of nematodes, it is also significant in enhancing environmental protection, increases food stability and productivity, good working conditions and human health (Jarvis *et al.,* 2013). This approach can serve as a long-lasting alternative solution in managing parasitic nematodes in banana plantations.

At times, the soil factor is important against the nematodes population that can raise or reduce in a plantation (Fanzo *et al.,* 2011). The soil factor is mostly attributed to the farmers' practices that increase soil fertility. The resistance of a plant against external and internal forces is attributed to optimal physical, chemical and biological traits of the soils. In fact (Joseph *et al.* 2010) reaffirms the use and application of fertilizers in increasing soil fertility, enhancing soil pH, soil electro-conductivity, and increasing content of moisture in the soil, nitrogen (N), phosphorus (P) and potassium (K).

The variety of nematodes in the soil is much influenced by soil chemical and physical characteristics soil (Neher, 2010). These are explained by microenvironments where nematodes interact among themselves and with other organisms. The relationship between nematodes and soil properties largely depends on the farmers' management practices of the soil. Other factors that reduce or increase nematodes within the soil include; the texture of the soil, nitrogen density, the presence and availability of the food sources as well as the capacity of the natural enemies to suppress nematodes. This suppression is normally attributed to the nature of the landscape, temperature, pH, and vegetation among others (Steel and Ferris, 2016).

2.6. Research gaps

Past research on bananas in general largely focused on pests and their response to soil management. However, currently, other factors other than declining soil fertility, moisture stress, and pests that are a constraint to banana production are diagnosed. Yields obtained on smallholder farms may be as a result of the interaction of a number of socio-economic, managerial and biophysical factors across wide-ranging altitudes and cross-cutting rainfall ramps (FAO, 2004; Van Asten, *et al.,* 2011). Plant and pest responses with respect to soil inputs by smallholder farmers as well as the farmers' perceptions form a comprehensive and coordinated system approach to understanding the factors limiting TCB adoption and production. This necessitated research on specific factors that determine the choice for adoption of TCB technology. The Response of pests notably weevils and nematodes to singular or combined application of cultural concoctions available to smallholder farmers need to be scientifically interrogated. A combination of the concoctions and mineral soil amendments may provide better options for repelling weevils, and nematodes due to synergetic effects. The addition of organic materials leads to improved water infiltration, a better soil structure and increased faunal activity (Ssali *et al.,* 2003; Ssango *et al.,* 2004; Van Asten *et al.,* 2011; Ayuke, 2010). This improves the recovery efficiency of mineral fertilizers. However, the availability of organic materials and labour are key constraints.

CHAPTER THREE

FACTORS THAT INFLUENCE TISSUE CULTURE BANANA TECHNOLOGY ADOPTION BY SMALLHOLDER FARMERS[1] IN WESTERN UGANDA

Abstract

The rate of adoption of tissue-culture banana technology at smallholder farmer level in Uganda has been slow since the late 1990s. The study assessed the factors influencing the adoption of TCB technology by smallholder farmers. The study was conducted between April and December 2018. A total of 280 smallholder farms were sampled in western Uganda and the responses from smallholder farmers subjected to principal component analyses. The proportion of farmers using conventional suckers as planting materials was 83% while 17% of them use tissue culture plantlets. In terms of willingness to allocate the land resource, simple majority (42%) of the smallholder banana farmers were willing to apportion less than 25% of the owned land to TCB production. 71% of the banana farmers inherited the orchards from the parents, and 81% of the inherited orchards were non TCB orchards. The proportion of smallholder banana farmers growing diminutive amounts of tissue culture originated bananas is less than 20%. Males (61%) aged 30-49 (41%) were perceived to be the backbone for the decision to adopt TCB or not. Family labour (73%) sustained the banana production value chain. About 91% perceive non tissue culture to have high market demand with attractive prices, with 81% preferring consumption of non-tissue culture cooking banana type. While expected yield from a banana production technology is a precursor to its adoption, demographic and perception characteristics shape the practices that enhance the yield of TCB technology ($p \leq 0.05$) and subsequent decision to adopt or reject a technology. A comprehensive and coordinated systems' approach is needed to develop mechanisms that would stimulate smallholder farmers to adopt the technology in order to realize the immense potential of tissue-culture banana technology.

Keywords: Tissue culture banana; adoption, rejection, socio-economic, banana yield

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3.1. Introduction

Banana *(Musa spp*), is one of the earliest domesticated crop plants (Kamira *et al*. 2016) originally planted, and adapted to the humid tropics subtropical climatic environment (Murielle *et al*. 2015). Bananas are a source of food for a myriad of people of diverse ethnic groups in Africa Surendar *et al*. (2013), and Ochola *et al*. (2015), and are consumed in various forms (Anyasi *et al*., 2013). Much as it is true that bananas are versatile, the present discussions have more often than not; fallen short of addressing the socio-economic dynamics within smallholder farmers affecting the adoption of the new technologies that come along with the development of this fruit crop. Some studies generally tag adoption of the new banana technologies to the levels of diversity of cultivars on the market (Changadeya *et al*., 2012), and the extent to which the technology addresses smallholder farmers' agronomical problems Changadeya *et al*. (2012), Langat *et al*. (2013), and; Husen *et al*. (2017), as well as how the new technologies lead to increased production and profit (Dube, 2017). Such factors inform farmers' cultivar predilections and socio-economic needs to be met when choice from the available diversity is made.

The smallholder farmers are the major implementers of the developed banana production technologies and also co-experimenters in the development of agricultural technology (Bongers *et al*., 2012), and live by the results of research. These farmers' knowledge allows for the development of farming systems and procedures essential in accepting banana cultivars that give a good yield. The cultivars usually adopted are those adapted to the social and ecological circumstances within which the smallholders live and operate (Mwangi and Kariuki 2015). Recent trends in increased suburbanization (UBOS, 2010) and a significant drop in the incomes of traditional cash crops in Uganda (MAAIF, 2011), gradually led to the commercialization of banana production in the country (UBOS, 2016).

Tissue Culture Banana is a biotechnological agricultural improvement based on the ability of many plant species to regenerate a whole plant from a single shoot tip; developed widely for use in commercial banana production. (Wandui *et al*., 2013). The technology was extended to the smallholder farmers as a package that included disease and pest free plantlets, information on crop husbandry, and post-harvest handling practices (Nguthi, 2007). The introduction of TCB technologies between 2002 and 2008 to smallholder farmers in Uganda was primarily aimed at meeting the commercial demands in banana production (Mbaka *et al*. 2008) draw smallholder farmers out of poverty (IFAD, 2009), and enhance food security across the East African countries (Kalyebara *et al.,* 2007; IFAD, 2009; MAAIF, 2011; Bwogi *et al.,* 2014; Alex *et al.,* 2016). However, the acceptability of the technology by smallholder farmers has continued to wobble. For instance, by 2003, according to Akankwasa *et al.* (2016), two hundred and fifty mother gardens had been established and 40,000 tissue cultured plantlets distributed in Uganda, however, results of the same study show that about 6% of the farmers are willing to select varieties that have gone through the tissue culture production process. Many of the smallholder farmers chose local types as their most preferred varieties (Akankwasa *et al.,* 2016; Mwangi and Kariuki 2015). Smallholder farmers were able to compare production potentials of tissue culture originated banana against the landraces. In the choice of planting materials, the smallholder farmers tend to ignore the current tissue culture technology products and remain hooked to land race banana types (AAA genomes) with Matooke and Mbidde being the most common of the landraces. It is uncertain which specific socio-economic factors are major players in the rejection and discontinuance of the tissue-culture banana technology. Therefore, the study set out to assess the factors for non-adoption and discontinuance after the adoption of TCB by smallholder farmers in Western Uganda was inevitable.

3.2. Materials and methods

3.2.1. Study area description

A survey was done in Uganda, specifically among smallholder farmers in the mid-western region comprising of the districts of Mbarara, Ibanda, Kiruhura, and Isingiro. The specific attributes of the districts targeted in this study area are summarized in Table 3.1, and farmer specific locations are geo-referenced in figure 3.1.

Table 3.1: Location-specific aspects of Mbarara, Ibanda, Isingiro and Kiruhura Districts

District	Mbarara	Ibanda	Isingiro	Kiruhura
Total Area (Km^2)	1,846.4	964.8	2,655.6	4,605
Land (Km^2)	1,778.4	771.8	2,496.3	4,516
Elevation (ft.)	5,900	5,900	5,900	5,900
Temp. Range (˚C)	17-30	14-28	14-27	13-30
Coordinates	00˚36′S 30˚36′E	00˚07′S 30˚30′E	00˚50′S 30˚50′E	00˚12′S 31˚00′E
Rainfall (mm)	900-1200	1000-1250	800-1200	700-900

Table 3.1 summarizes the site (location) characteristics that have an effect on the practices in general agriculture, and banana production in particular. A mixture of fairly rolling and sharp hills, fairly deep and shallow valleys and flatlands, characterize the districts. The proportions for water bodies' vis-à-vis the arable land varies between 2%, and 6% where the land is covered with lakes, rivers, and gazetted swamps. The area is largely covered with savannah woodlands type of vegetation with a wider coverage of thorny shrubs, which are gradually being replaced by banana orchards. The soils are loamy with proportions of sand and rocks in some districts. The soils are fertile due to manure deposits resulting from the historical pastoral activities that have characterized the area over a long time.

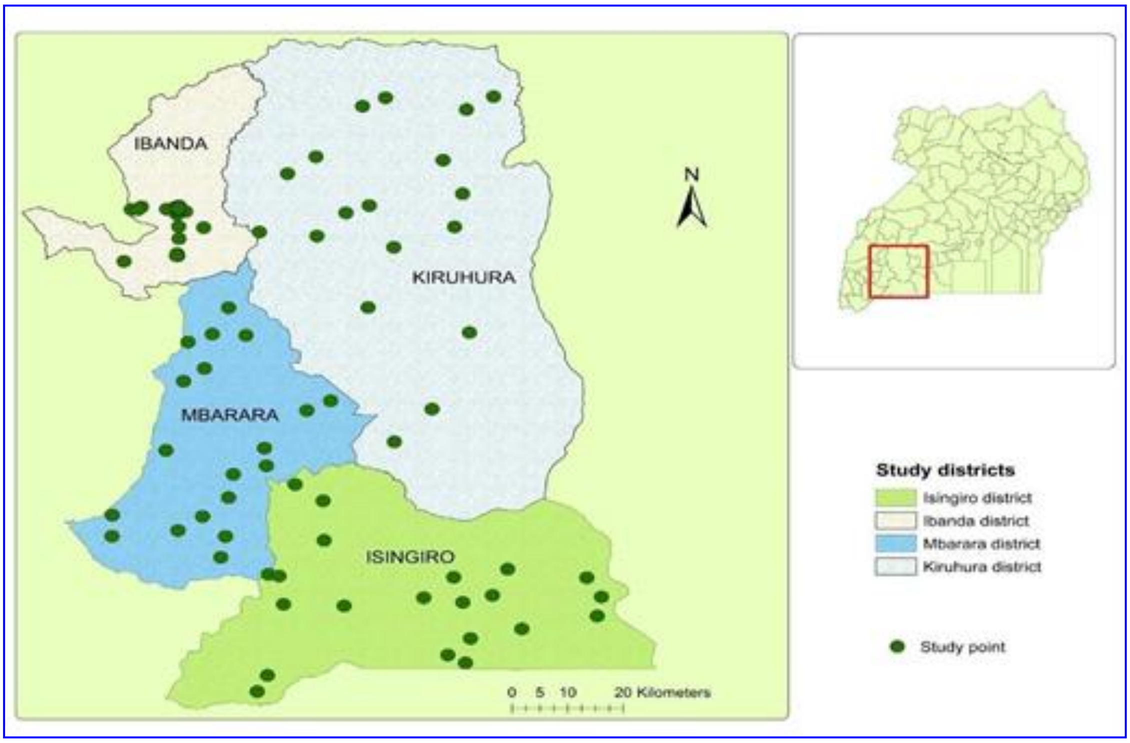

Figure 3. 1. The location of the study area and smallholder study points in Uganda

This study area was a beneficiary of the "Agricultural Productivity Enhancement Program" (APEP) technology transfer program of Uganda, which used field demonstrations as a means to increase banana productivity. Through the demonstration sites, some farmers were exposed to appropriate technology transfer packages that included improved banana crop management practices involving the use of both organic fertilizers (e.g. manure and mulch) and inorganic fertilizers to restore soil fertility. In addition, selected farmers received planting materials including TCB plantlets.

3.2.2. Study design

An explanatory mixed methods research design was followed. Quantitative data were backed up with qualitative information from focus-group discussions and interviews. A cross-sectional survey was used to obtain factors limiting smallholder farmers to adopt TCB technology. Surveys are done to obtain information relating to the respondents (Denscombe, 2010). The questionnaires were used to elicit socio-economic information relating to general banana production at the smallholder farm level. Through triangulation, various aspects of TCB socio-economic factors were compared. Such phenomena included among others, comparing age against the preference for the tissue-culture banana, household leadership and the type of banana grown. Triangulation further helped in validating and verifying the accuracy of quantitative information (Ajay and Micah, 2014).

3.2.3. The unit of analysis and target population

The “unit of analysis” for this study was the smallholder farmer. The study defines smallholder farmer as a farmer who has grown bananas and lived on the same land, shared banana food resources from a common source and contributed to the resource pool of the household for a period not less than fifteen years. This definition became part of the specific criteria developed to determine the purposive sample population for the study.

Resident banana farmers in the study area formed the target population. Smallholder farmers who have been in banana production for at least fifteen years were largely considered. This span of time covers the pre-TCB period to the present period of TCB technology in the study region. Key informants included agricultural extension workers and researchers. These provided extensive and reliable information required to validate the data provided by other respondents.

3.2.4. Sample size and sampling design

Before the actual sample size was determined, it was necessary to determine the population size of the target population. However, for this study, the actual population of the smallholder farmers engaged in tissue culture production was not known from the start due to limited databases available at the districts, the mosaic nature of the farmers, as well as the absence of records from the farmers themselves. Further still, TCB-growing follows a fluid-miscellany character. The study employed the Hyper-geometric method adopted from (Wackerly, *et al.*, 2008), to estimate the unknown population. The population was then estimated using the Margin of Error of ±0.05 as defined by Ajay and Micah (2014). A deviation higher or lower than 5% from the mean was accepted thus giving a confidence level at 95%. Standard of deviation i.e. the degree of variance the study expected from the responses was 0.5. (Ajay and Micah, 2014). This figure was a safe estimate for the surveys that have not been administered. For this study, 50% was the most lenient estimation, which ensured that the population size was large enough. The confidence level selected corresponds to a Z-score of 1.96; hence, the estimated population size determination followed the formula.

$$N = (Z - score)^2 * SD * {(1 - SD)}/{(mE)^2}$$

……………………………………….Equation 1

Where,

N is the required sample size

SD is the standard deviation = (0.5)

mE is the margin of error = (0.05)

$$N = (1.96)^2 * 0.5 * {(1 - 0.5)}/{(0.05)^2}$$

(3.8416 x .25) / .0025

.9604 / .0025

384.16

385

At a margin of error of 0.05, the standard deviation of 0.5, and a confidence level of 95%, the population size for the study was 385 smallholder farmers. Ajay and Micah (2014), recommended that in sample size determination using the hyper geometric calculation, decimal points should be taken as additional respondent. Since the estimated study population is small, the study, assumed the calculated population size to be the sample size of the survey. However, there was the need to further calculate the true sample of the population in order to determine the minimum number of smallholder banana farmers that would be sufficient to have a 95% Confidence interval, with a 5% margin of error in the results. Hence, the finite population was determined using the formula;

$$Ts = \frac{(n \times N)}{(n + N - 1)}$$ ………………………………………………………………Equation 2

Where,

Ts = True sample of the population

n = sample size of the study

N = Population of the sample

$$Ts = \frac{(385*385)}{(385*385-1)}$$

Ts =192.75

True Sample =193

The minimum number of respondents for the survey that would achieve a CI of 95% and 5% margin of error was 193 smallholder farmers. The respondents were proportionally distributed in each of the districts in the study region, such that the maximum number of respondents for each of the four districts did not exceed 95 and did not decline below 48. The distribution was further guided by purposive sampling in three major ways. Purposive sampling placed the farmers into categories based on resource endowments, and the ability to sufficiently grasp the issues of TCB production.

3.2.5. Data collection

The survey was conducted between August 2017 and January 2018 in four districts of Ibanda, Isingiro, Kiruhura, and Mbarara, from the western region of the country in a multi-phase data collection strategy that involved orientation, key informant interviews, and focus group discussions. A structured questionnaire was administered face to face to 280 farmers to collect quantitative data on the study parameters. The face to face approach provided an opportunity for auxiliary probing into the parameters under assessment. A composite index of descriptive criteria was developed with categories including; extraordinary, ordinary, peasant categories (Table 3.2), to facilitate the composition of focus group discussions. The classification used was not mutually exclusive, but those who fulfilled most of the criteria were assigned to a specific category.

Table 3.2: Descriptive criteria for resource bequest classification of farmers

Respondent category	Description characteristics
1. Extraordinary	• High level of education (tertiary education) • Landholding above 5 acres • Regular contact with researchers and extension staff • Recurrently used hired professional labour in banana production • Have permanent and pensionable employment • Have means of communication and get quick feedback
2. Ordinary	• Young households with moderate resource base • Variable land holding between 1-3 acres • Limited access to credit due to lack of, or insufficient mortgage • Irregularly hire in labour or provide outside labour • Minimal access to researchers and extension agents
3. Peasant	• Inadequate income to buy inputs for banana production • Landholding below one acre • Not regular members of social groups • They are a major source of labour for the first two groups • Very low levels of education

For each district, nine farmers constituted a focus group discussion, with priority being given to the farmers who possessed knowledge and experience about banana production. Four

Focus Group Discussions [FDG] were carried out with a total of 36 farmers from the four districts in the region.

3.2.6. Data analysis

Data were analysed with Statistical Package for Social Sciences software (SPSS, version 16.0; Kirkpatrick and Feeney, 2008). Statistical results were regarded as significant at P-values ≤ 0.05. Variables were classified as explanatory, and response variables. Only the explanatory variables that showed significant responses towards the adoption and production of TCB were included in the analysis. The factors were isolated through principal component analysis (PCA). Principle component analysis was further used to check for multi-colinearity. Multi-colinearity can inflate the standard errors in explanatory variables (Myers and Well, 2003), causing failure to reject the null hypothesis when the data actually support its rejection (Denscombe, 2010), and thus lead to the wrong conclusions (Akinwande *et al*.,2015). The variables that returned the eigenvalue of ≥ 1, Variance Inflation Factor (VIF), between ≥ 1 and ≤ 10, and tolerance levels above 50 % (Akinwande *et al*., 2015), showed that there were no multi-collinearity symptoms and so the factors were used in further analysis.

3.3. Results

3.3.1. Principle component analyses

The empirical estimation to test the influence of farmer related factors on TCB technology adoption at smallholder farm level is highlighted in this section. Principle components of the factors under study were isolated. The first two components with the highest eigenvalues (4.719) and (3.599), respectively accounted for 25.2% of the total variance of all factors with first and second components accounting for 14.3% and 10.9% variance, respectively, the progressive leftover variances as accounted for by other component factors continually reduced to 4.02%; accounted for by the last component. This distribution gave a sense of how much alteration there was in the eigenvalues from one component (Table 3.3)

Table 3. 3: Cumulative proportion of variance of the major factors that influenced the adoption of TCB at smallholder farm level

Component		1	2	3	4	5	6	7	8	9	10	11
Initial Eigenvalues	Total	4.72	3.60	2.57	2.38	1.78	1.73	1.45	1.32	1.17	1.07	1.02
	% of Variance	14.30	10.91	7.79	7.21	5.39	5.25	4.41	4.01	3.53	3.24	3.08
	Cumulative %	14.30	25.21	32.99	40.20	45.59	50.83	55.24	59.25	62.78	66.03	69.10
Sum of Squared Loadings	Total	4.72	3.60	2.57	2.38	1.78	1.73	1.45	1.32	1.17	1.07	1.02
	% of Variance	14.30	10.91	7.79	7.21	5.39	5.25	4.41	4.01	3.53	3.24	3.08
	Cumulative %	14.30	25.21	32.99	40.20	45.59	50.83	55.24	59.25	62.78	66.03	69.10
Rotated Sums of Squared Loadings	Total	3.58	3.35	2.45	2.23	1.89	1.80	1.65	1.57	1.55	1.41	1.33
	% of Variance	10.86	10.16	7.42	6.77	5.72	5.44	5.01	4.76	4.69	4.26	4.02
	Cumulative %	10.86	21.02	28.44	35.21	40.93	46.37	51.38	56.14	60.83	65.08	69.10

NOTE: Numbers 1 to 11 represented the components under which the eigenvalues isolated for the factors involved in TCB adoption, grouped themselves.

The sum of all PCA canonical eigenvalues showed that the component factor loading related to the type of banana grown explained 47.2% of the total 69.1% cumulative proportion of variance among the major factors that influenced the adoption of TCB at smallholder farm level.

Components with eigenvalues ≥1 (in this case explaining less than 4.02% variance) were regarded as diminutive for use in further analysis. This is because they accounted for a non-significant variance from the original variable whose initial significance was 1. Principal components' analysis redistributed the variances in the correlation matrix for the first components extracted, and so controlled multi-colinearity. The factors whose absolute values were not closer to 50%, were excluded from further analysis (Kaiser, 1974; Anastasiadou, 1996; Vertania, 2011; Newing *et al*., 2011). The 18 factors that met the Kaiser Normalization criteria were placed between component 1 and 11 (Table 3.4).

Table 3.4: Major factors influencing tissue culture banana production

Component	1	2	3	4	5	6	7	8	9	10	11
Gender of the farmer							0.703				
Household management			0.682								
Age of the farmer									0.533		
Size covered by TCB			0.765								
Land tenure							0.578				
Type of banana grown		0.931									
Variety of TCB grown		0.66									
Propagation materials		0.938									
Source of the materials		0.84									
Materials Management	0.829										
Labour for the value chain	0.621										
Cost of production					0.667						
Source of income				0.8							
Product preference										0.747	
Land use/tenure											0.902
Yield of cooking banana						0.467					
Yield of beer banana						0.531					
Yield of dessert banana						0.695					

NOTE: The factors were obtained from Rotated component matrix of factor loadings from Principal Component Analysis. Numbers 1 to 11 represented the components under which the eigenvalues isolated for the factors involved in TCB adoption, grouped themselves.

The study rotated component factors to reduce the number of factors on which the variables under investigation had high loadings. Management of the planting materials and labour for the value chain substantially loaded onto component 1, at 82.9% and 62.1%, respectively. Type of banana grown, the variety of the TCB treatment of propagation materials, and source of planting materials substantially loaded variables onto component 2 with strengths above 65% for each of the loading factor. Household management and the total size coverage by

TCB loaded substantially onto component 3, at 68.2% and 76.5%, respectively. Source of income loaded, at (80%) onto component 4. Cost of production factor loaded onto component 5 (66.7%), while all estimated banana bunch yield factors substantially loaded onto component 6 (46.7%, 53.1%, and 69.5%). Substantial loadings onto factor 7 included the gender of the farmer (70.3%) and land tenure (57.8%). Age of the farmer loaded onto component 9 at (53.3%) substantial strength. Preference factors substantially loaded onto component 10. Finally, land use type heavily loaded onto component 11 with a substantial loading strength of 90.2%. Whereas more than 50% variance is explained by the first six components, and substantially would be considered for further analysis, the other component loadings after component six (gender, age, land use, land tenure, and product preferences) were retained due to their contribution in qualitative socio-economic aspects.

3.4. Survey descriptive

3.4.1. Explanatory factors

The largest number of participants by gender were male 61.1% (n=171) versus 38.9 % (n=109) females. Gender distributions cut across several age categories. Three forms of land tenure were considered and responses indicated that 71.4% (n=200) of the smallholder farmers operate on land inherited from their parents and benefactors, while the remaining 28.6% operated on leased land hold or freehold land tenure systems. The responses on labour for the value chain in TCB production indicate that 73.2 % (n=205), rely on family labour for production while the remaining 26.8 % on hired professional labour and community labour. Responses on the cost of production indicated that 60% (n=168) viewed as the factor limiting the production of TCB. Other factors include the cost of planting materials (11.8% n=33), limitation by transportation costs for the materials (18.9% n=53), expenses on field hygiene (7.5% n=21), and land acquisition costs (1.8% n=5) (Table 3.5).

Table 3.5: Explanatory variables in the adoption of TCB by smallholder farmers

Gender of the farmer	Male	171	61.1
	Female	109	38.9
Age of the farmer	18-29	57	20.4
	30-49	114	40.7
	50-74	102	36.4
	75+	7	2.5
Land tenure	Land inherited from parents	200	71.4
	Leased land	36	12.9
	Freehold	44	15.7
Labour for the value ch	Hired/Professional labour	40	14.3
	Family Labour	205	73.2
	Community Labour	35	12.5
Cost of production	Costs of labour	168	60.0
	Cost of TCB planting materials	33	11.8
	Costs for Field hygiene(pesticides, nu	21	7.5
	land acquisition costs	5	1.8
	Transportation costs	53	18.9
Household Head	Male Headed	155	55.4
	Female Headed	88	31.4
	Children- headed	9	3.2
	Guardian headed	28	10.0
Farmers' main source o	Permanent/pensionable source	14	5.0
	Wage employment	26	9.3
	Sales from subsistence production	192	68.6
	Agricultural Loans	17	6.1
	Gifts and donations	31	11.1

Another concern on Farmer perception aspects manifested in household management dynamics. About 55.4% (n=155) respondents indicated that households are mainly headed by the males although a significant number of households are headed by females (31.4% n=88). In some instances, 3.2% (n=9) of the households are headed by children, while 10% (n=28) of the households are under the charge of guardians and benefactors. For the smallholder farmers' source of income, most of the farmers 68.6% (n=192) depend on income arising from sales from subsistence produce. The remaining 31.4% depend on a number of sources among them gifts and donations (11.1%, n=31), wage employment (9.3%, n=26) agricultural loans (6.1%, n=17), and permanent and pensionable employment (5.0%, n=14).

3.4.2. The response factors

Response factors summarized in Table 3.6 indicated that 80.7 % (n=226) are non-adopters of TCB production technologies. Farmers who have adopted or those willing to adopt the technology, 42.1% (n=118), can only allocate less than 25% of the total land to the production of tissue culture under smallholder production. Meanwhile, 83.2% (n=233) of the smallholder farmers did not use tissue culture plantlets for the establishment of new banana plantations or for replacement of the damaged plants. Responses on the source of planting materials showed that 68.9 % (n=193) used planting suckers from their own farms as opposed to 31.1 % (n_{total}=87) of the farmers who received suckers from government projects, undefined neighbourhood plantations, or research outlets.

Table 3.6: Response variables in the adoption of TCB technology

Variables	Category	Frequency(n)	Percentage	Mean
Type of banana grown	Tissue culture banana	54	19.3	1.81±.395
	Non-tissue culture bana	226	80.7	
Type of propagation ma	Plantlets	47	16.8	1.84±.374
	Conventional suckers	233	83.2	
% of land size Farmers	1-25%	118	42.1	2.17±1.217
	26-50%	65	23.2	
	51-75%	28	10	
	75-100%	24.6	24.6	
Source of planting mate	Research outlet centres	15	5.4	2.86 ±0.674
	Government projects	40	14.3	
	Farmers' own suckers	193	68.9	
	From neighbourhoods	32	11.4	
Variety of the Banana g	Tissue culture cooking b	53	17.9	1.97±0.735
	Non-tissue culture cook	210	75.7	
	Non-tissue culture Beer	14	5.4	
	Tissue culture Dessert b	1	0.4	
	Non-tissue culture Dess	2	0.7	

More than 75% of the farmers grow non-tissue culture cooking banana, whereas 24.3% grow tissue culture cooking banana, and other varieties. Notable among this category, was the (0.4%) single farmer growing tissue culture dessert banana, and 18% (n=53) of the farmers in the region growing tissue culture cooking banana. This distribution is an epitome of the non-adoption of the technology by smallholder farmers.

3.4.3. The yield factor variation

Smallholder farmers used banana bunch as a unit of measurement for banana yield. Use of banana bunch as a unit of measurement is an infrequent way of articulating units of measurement for the banana. It is incoherent with the metric system in establishing the exact quantity of solid banana in possession. The total yield (in bunches) for cooking banana, brewing banana and dessert banana types was compared. (Figure 3.5).

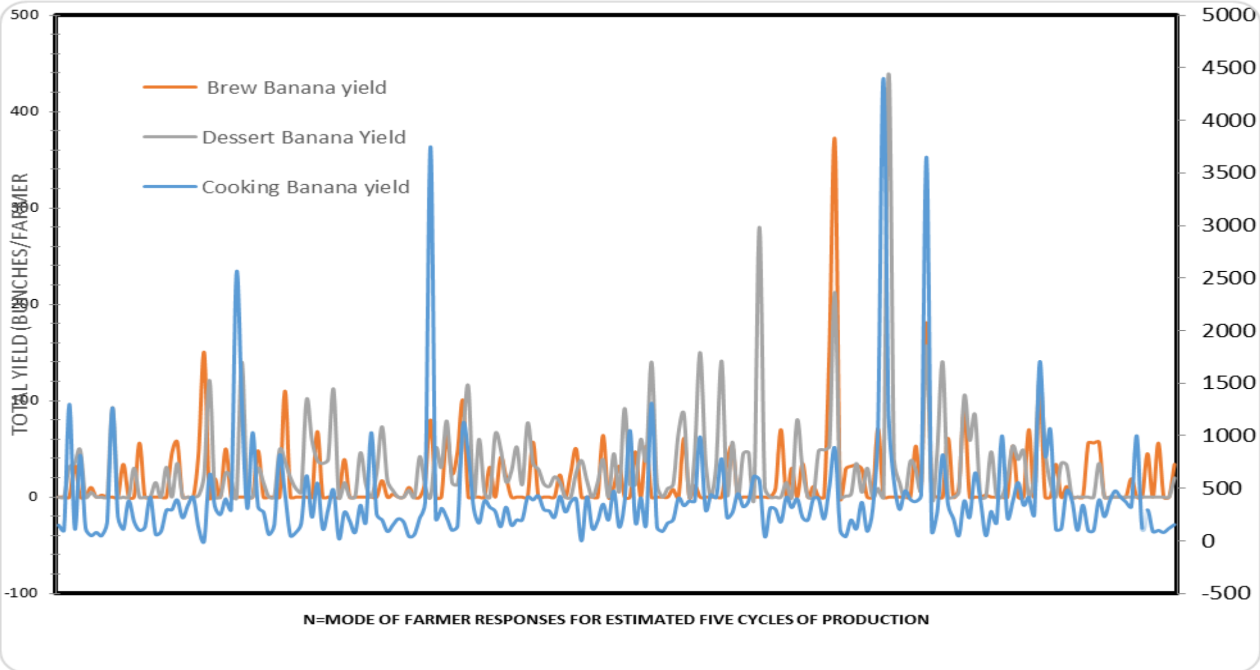

Figure 3.2: Yield factor estimations for the adoption of TCB

The yield for non-tissue culture cooking banana was higher for all responses. The mode for yield occurrence indicates lower numbers for the yields between zero and 500 bunches for estimated five consecutive production cycles, with the extraordinary farmers producing above 4,500 bunches for the five cropping cycles.

The production of dessert banana was much lower compared to the cooking type. Farmers produce about 3-5 bunches of dessert banana through the five production cycles. The highest production was 280 bunches of dessert banana over the five production cycles. Meanwhile, the production of beer banana in the region is not given much importance compared to cooking banana, although, beer banana production is much higher compared to dessert banana types. There are observable lower modes of occurrence at lower numbers of bunches produced for beer banana (figure 3.2), with the highest single farmer producing about 470 bunches for the five consecutive production cycles.

A reasonably interesting input about the comparison of yield for Banana types of the tissue culture origin and the non-tissue culture landrace banana from the interviews and ratified by Focused group discussions, all key informants agree that TCB gives good yield because they are clean; free from pests and diseases. The participant further revealed it during the FDG 1 thus;

"It is not because the "Kawanda Bananas[2]" do not give a better yield, but because this better yield is short-lived. The TCB types hardly sustain productivity for five years. It is, therefore, not necessary for [us] to venture into a project that would not last".

3.4.4. Survey on market and preference factors

Market for the different types of banana grown in the region and the preference for consumption of the banana products were interrogated in the field (Table 3.7).

[2] The name by which tissue culture bananas and other hybrid banana types are called by the small holder farmers.

Table 3.7: Market and Preference considerations in smallholder banana production

Banana type has a high market with attractive prices							
	Valid						
	1	2	3	4	5	6	Total
Frequency	6.0	167.0	8.0	8.0	1.0	90.0	280
Percent	2.1	59.6	2.9	2.9	.4	32.1	100
Valid Percent	2.1	59.6	2.9	2.9	.4	32.1	100
Cumulative Percent	2.1	61.8	64.6	67.5	67.9	100.0	
Banana type is most preferred for consumption							
Frequency	13	228	1	2	34	2	280
Percent	4.6	81.4	0.4	0.7	12.1	0.7	100
Valid Percent	4.6	81.4	0.4	0.7	12.1	0.7	100
Cumulative Percent	4.6	86.1	86.4	87.1	99.3	100	

1= Tissue culture cooking banana, 2= Non-tissue culture cooking banana, 3= Tissue culture brewing banana, 4= Non-tissue culture brewing banana, 5= Tissue culture dessert banana, 6= Non-tissue culture dessert banana

About 91% of the responses indicated that non-tissue culture cooking banana types (59% [n=167]) and non-tissue culture dessert banana types (32% [n=90]), have high market demand with attractive prices. However, in terms of preference for consumption, it was shown that 81% (n=228), of the population, prefer to consume non-tissue culture cooking banana type. Responses on Market demand and consumer preferences for all TCB types were less than 13% for all the types combined together. A peculiar submission on preferences during FDG 2 in Ibanda district, a female participant expressed concern about the current generation bananas.

> "I sell bananas in my stall. Usually, the 'Kawanda Bananas' are given a higher price, because they appear big in size, and have smooth skin. Our local bananas are small and often times spotted, but in a single day, I receive more clients demanding for local types than the Kawanda types except in cases where these bananas are purchased for parties, then we benefit from their high prices".

This qualitative submission brings out the background meaning embedded in the preferences and cost attached to the types of banana. It further gives a clue on the identification and differentiation of tissue culture and NTCB types.

3.5. Regression analyses

Smallholder farmers used a linear model to estimate the probability of a positive influence of explanatory factors towards the adoption of TCB technology. Marginal effects computed for the social factors and their influence on TCB technology adoption in this model measured the expected change in the probability of observing a positive influence on the TCB technology with respect to a change in the particular yield response variable. In terms of the overall percentage of predictions correctly classified, the model performed well for all PCA isolated explanatory and response variables, thus implying a good fit. "Tolerance" and "Variance Inflation Factor"(VIF) values for all the predictor variables ruled out multi-colinearity to a higher estimation. The tolerance value indicates the fraction of variance in the predictor that cannot be accounted for by the other predictors. Tolerance values obtained for this study (Table 3.8a, b, c) explained variances that were large enough (all above 60%) to rule out predictors that were redundant (small values ≤ 10%). The most independent predictor at a 98% level of tolerance was the costs of production involved in the production of TCB. Labour for the value chain independently predicted 98%, while land tenure systems variance prediction could be tolerated at 90%. The age of the farmer could be tolerated as an independent predictor of yield at 77%. Household management independently predicted yield by 71% level of tolerance. Farmer’s source of income and gender of the farmers showed the least levels of tolerance at 69% and 67%, respectively. All predictor variables indicated variance inflation factor values ≥1and ≤ 10 (Table 3.8a, b, and c), thus, the variables did not merit further interrogation and exploration.

Table 3.8a: Regressed predictor factors for yield approximate for cooking banana

l	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Tolerance	VIF
(Constant)	7.69E+02	2.89E+02		2.66E+00	0.008	2.00E+02	1.34E+03				
Gender	-2.57E+02	9.13E+01	-0.199	-2.82E+00	0.005	-4.37E+02	-7.73E+01	-0.142	-0.168	0.669	1.50E+00
Age of the farmer	-5.86E+01	5.25E+01	-0.073	-1.12E+00	0.266	-1.62E+02	4.48E+01	-0.169	-0.067	0.772	1.29E+00
Level of education	3.53E+01	4.58E+01	0.052	0.772	0.441	-5.48E+01	1.26E+02	0.046	0.047	0.736	1.36E+00
House hold management	1.19E+02	4.59E+01	0.178	2.59E+00	0.01	2.87E+01	2.09E+02	0.13	0.155	0.713	1.40E+00
Labour for the value chain	-1.53E+02	7.18E+01	-0.125	-2.13E+00	0.034	-2.94E+02	-1.13E+01	-0.152	-0.128	0.963	1.04E+00
Land tenure	240.498	48.7	0.286	4.938	0.001	144.621	336.375	0.25	0.287	0.897	1.12E+00
Cost of production	63.469	22.374	0.158	2.837	0.005	19.42	107.518	0.134	0.17	0.975	1.03E+00
Farmers' source of income	4.99E+01	4.93E+01	0.07	1.01E+00	0.312	-4.72E+01	1.47E+02	0.031	0.061	0.692	1.45E+00

Gender, household management, labour sources for banana production value chain, land tenure systems, and costs involved in the production of banana were significant contributors to yield of cooking banana, $P<0.05$. (Table 3. 8a)

Table 3.8b: Regressed predictor factors for yield approximate for beer banana

	Unstandardized		**Standardized**	**t**	**Sig.**	**95% Confidence Interval for B**		**Correlations**		**Collinearity Statistics**	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Tolerance	VIF
(Constant)	17.06	16.833		1.046	0.297	-15.537	50.741				
Gender of the	-4.57	5.323	-0.062	-0.859	0.391	-15.049	5.909	0.047	-0.052	0.669	1.495
Age of the farmer	8.633	3.06	0.19	2.821	0.005	2.609	14.658	0.161	0.168	0.772	1.296
Level of education	-2.485	2.668	-0.064	-0.931	0.352	-7.738	2.768	-0.099	-0.056	0.736	1.358
House hold management	2.545	2.676	0.067	0.951	0.342	-2.723	7.813	0.035	0.057	0.713	1.402
Labour for the value chain	-6.846	4.182	-0.099	-1.637	0.103	-15.081	1.388	-0.088	-0.099	0.963	1.038
Farmers' source of income	0.816	2.874	0.02	0.284	0.777	-4.842	6.473	0.1	0.017	0.692	1.445
Land tenure	3.222	2.996	0.067	1.075	0.283	-2.676	9.12	0.063	0.065	0.897	1.115
Cost of production	-0.669	1.376	-0.029	-0.486	0.627	-3.378	2.041	-0.03	-0.029	0.975	1.025

Only the age of the farmer, significantly contributed to the yield of beer banana, $P=0.005$. (Table 3.8b).

Table 3.8c: Regressed predictor factors for yield approximate for dessert banana

	Unstandardized coef.		Standardized coef.	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
(Constant)	26.05	16.50		1.58	0.12	-6.42	58.53					
Gender of the	-5.94	6.26	-0.07	-0.95	0.34	-18.27	6.39	-0.11	-0.06	-0.05	0.67	1.49
Age of the farmer	8.79	3.62	0.16	2.43	0.02	1.68	15.91	0.14	0.15	0.14	0.77	1.30
House hold management	-6.58	3.20	-0.14	-2.05	0.04	-12.89	-0.27	-0.22	-0.12	-0.12	0.69	1.45
Land tenure	6.54	3.53	0.11	1.85	0.07	-0.41	13.48	0.09	0.11	0.10	0.90	1.12
Labour for the value chain	7.55	4.93	0.09	1.53	0.13	-2.17	17.26	0.14	0.09	0.09	0.96	1.04
Farmers' source of income	-9.47	3.17	-0.19	-2.99	0.00	-15.70	-3.24	-0.24	-0.18	-0.17	0.79	1.26
Cost of production	2.19	1.62	0.08	1.35	0.18	-1.01	5.38	0.11	0.08	0.08	0.98	1.03

Age of the farmers, household management and farmers' source of income significantly contributed to the yield of dessert banana, $P<0.05$. (Table 3.8c).

Table 3.9: The relationship between response factors and yield of cooking banana

		A	B	C	D	E	F
Sig.(1-tailed)	Yield of Cooking banana (A)	.	.296	.093	.253	.000	.000
	Type of banana grown (B)	.296	.	.000	.000	.000	.133
	Variety of TCBB grown (C)	.093	.000	.	.000	.000	.360
	Type of propagation materials(D)	.253	.000	.000	.	.000	.025
	Source of the materials (E)	.000	.000	.000	.000	.	.000
	Management of the materials (F)	.000	.133	.360	.025	.000	.
	N	280	280	280	280	280	280

The source of the materials and management of the planting materials significantly determined the yield of the cooking banana type ($P < 0.005$). There is a very strong and significant relationship between the source of the materials, and the type banana grown, a variety of TCB and management of the sourced materials ($P<0.05$).

Table 3.10: The relationship between response factors and yield of beer banana

		A	B	C	D	E	F
Sig. (1-tailed)	Yield of Beer banana (A)	.	.233	.101	.143	.221	.213
	Type of banana grown (B)	.233	.	.000	.000	.000	.133
	Variety of TCB grown (C)	.101	.000	.	.000	.000	.360
	Type of propagation materials(D)	.143	.000	.000	.	.000	.025
	Source of the materials (E)	.221	.000	.000	.000	.	.000
	Management of the materials (F)	.213	.133	.360	.025	.000	.
	N	280	280	280	280	280	280

Whereas there is a significant interaction between individual factors that act together to determine the yield of beer banana, the overall factors' interaction shows no effect on the yield of beer banana. Each of the factors significantly interacts with at least one factor to determine the yield dynamics of the beer banana.

Table 3. 11: The relationship between response factors and yield of dessert banana

		A	B	C	D	E	F
Sig. (1-tailed)	Yield of Dessert banana (A)	.	.217	.362	.172	.276	.241
	Type of banana grown (B)	.217	.	.000	.000	.000	.133
	Variety of TCB grown (C)	.362	.000	.	.000	.000	.360
	Type of propagation materials(D)	.172	.000	.000	.	.000	.025
	Source of the materials (E)	.276	.000	.000	.000	.	.000
	Management of the materials (F)	.241	.133	.360	.025	.000	.
	N	280	280	280	280	280	280

There is a significant relationship when two individual factors interact in causing an effect on the yield of dessert banana; however, when all factors are combined together, their overall effect on the yield of dessert banana is insignificant. Each of the factors significantly interacts with at least one factor to determine the yield dynamics of the dessert banana.

3.6. Discussion

The study hypothesized that the smallholder farmer perceptions are not linked to factors affecting the TCB technology adoption at smallholder farm level. For smallholder farmers to accept TCB technologies, the foremost consideration is the yield benefit accruing from the technology. The study established that the yield potential of up to 4,500 bunches is sufficient to keep the smallholder farmer in the production of non-TCB. The yield benefits are related to inputs such as land, labour and other accessory costs involved in the production of the technology. Besides yield, smallholder farmers are cognizant of the fact that their social values as largely shaped by the culture are preserved. Therefore, a high yielding technology, which corroborates the perceived orientations of the farmers, is easily accepted. Actually, (Smith, 2007), earlier argued that technology is often valued according to whom it is associated, with, rather than by its utility. Even with a clear comprehension of the “yield decline” narratives in banana production, threats to the economy, livelihoods and food security, a desirable internal momentum within the smallholder farmers has not been created to adopt TCB technology to solve the threats. Small-scale farmers still associate technology with scientists and policymakers. To these farmers, the technology, in reality, is more of a burden than a necessity.

3.6.1. Levels of tissue culture adoption in Uganda

This study has revealed that adoption of TCB is rated at 19%. The adoption rate is too low in view of the fact that the technology was introduced close to 30 years ago. The level of adoption for TCB technology was found to be very low on all traits ranging from acceptance of plantlets, marketing and finally to consumption. Farmers rejected the TCB products including the plantlets and the harvested products. Fall back for those who had accepted the technology remains eminent. Indicators for non-adoption were evident in the allocation of available resources to the accepted technology. Allocation of land resources to TCB production was diminutive. Research centres and other government projects lack the capacity/ability to shoulder the socio-economic demands that would support the acceptance of TCB technologies.

The farmers argue that TCB gives good yield and the reason advanced in their arguments that the planting materials are clean and free from pests and diseases holds truth and corroborates with (Singh *et al.,* 2011), who ,gave deeper meaning to development of tissue culture technology as a foundation of high quality. He fronted the fact that planting materials are disease-free. An outstanding reason established by this study as to why smallholder farmers hesitate to adopt the technology is mainly the sustainability of the technology.

Customarily, banana is grown as a perennial crop where the plant marts produce continuous shoots from subterranean corms and depending on the level of management, yield may start to decline after ten to fifteen years. In TCB technologies, the yields fall rapidly after three to five years, thus creating a need to shift to cyclic replacement with a new plantation. This practice is expensive and incomprehensible to the smallholder farmer.

The current study established that 69% of the Smallholder farmers use suckers from their own orchards. The orientation of planting suckers from the farmers' own orchards suggests a direction of thought that diverges from (Tushemereirwe *et al.*, 2003), who assert that use of suckers and corms in banana production perpetuates the banana weevil and diseases. The suckers obtained from farmers' own orchards and from the neighbourhoods continue to take precedence. This is due to low cost and availability when compared to plantlets developed by tissue culture processes. The TCB plantlets are limited to the "resource endowed" farmers. The resource -endowed farmers have the ability to foot the high costs involved in buying, transporting, and maintaining the TCB plants into the fields. It, therefore, follows that small-scale farmers who are largely not resource bequest keep within the confines of a cheap source of planting materials. The satisfaction derived from farmers' utilization of their own suckers curtails the need to use cleaned suckers from other sources. Therefore, propagation of the orchards using conventional suckers surpasses the acceptance and use of TCB plantlets for orchard propagation.

The study established that production of cooking banana stands at 94% out of which 76% was for NTCB against 18% for TCB. There is a very strong attachment to the production of cooking banana for both social and economic reasons. Actually, smallholder farmers insist on having good and well-tendered orchards in order to raise their social status, improve on their social capital, and most importantly, guarantee the food security of the household. Smallholder farmers who make substantial food contributions to the communities' social functions are often more respected than those who don't (Obisesan, 2014). There is, however, a moderate improvement in the production of beer banana types regardless of whether they are TCB or NTCB. The explanations are vested in the versatility of the products and bi-products, most of which have socio-economic perceptions. For instance, drawing from the farmer-focused discussions; banana brewing process produces *Waragi*[3] that significantly contributes to the income base of the households and the social status of the farmers. Residues from the brewing process are ploughed back into the soil for the production of other banana types. The residues are also important sources of mulch and feed for animals.

An understanding of the responses in this study is drawn from the fact that the largest number of participants by gender was male at 61%. A review by Mwangi and Kariuki (2015), indicated that gender issues in agricultural technology adoption have been explored for a long time, although, the studies have not been explicit regarding the different roles men and women play in technology adoption (Mignouna *et al.,* 2011; Obisesan, 2014; Mwangi and Kariuki,2015). Social systems appear to assign the male gender those practices that are more economically superior. The participation of the male gender is an indicator of the profitability of the banana-growing project even at smallholder farmer level.

Whereas the females' practices and involvement in banana production projects may greatly be driven by food security orientation (Husen *et al*. 2017), the men's impetus is in most cases a financial perspective (Alinovi, *et al.*, 2010). This understanding contravenes earlier arguments that the association between gender and the probability of adoption of agricultural technology is rather not significant. This could be true for other crops such as maize, but untrue in the case of TCB adoption. Majorly, men are the bread earners in the local family settings and therefore, quickly adopt a practice that supports the economic status of the families. If in this context males have an obligation to provide for the family, and NTCB provides a greater solution to this duty, then the TCB technologies cannot benefit either

[3]The local name of the spirit distilled from fermented banana juice and yeast. It is used at social functions and for commercial processing of other spirits.

gender in the same way. Equally, male farmers are more likely to fall back to TCB production if it enhances the role of the head of the family.

The study established that age has a stake in the adoption of new agricultural technology Mature and experienced farmers have a long term understanding and experience hence are better placed to evaluate new technology practices and demands than younger farmers. Whereas there is increased risk aversion and decreased interest in long-term investment as the farmers grow old (Obisesan, 2014), it would be argued that younger farmers are less risk-averse and therefore would be more willing to take up TCB production as new technology. On the contrary, the products from the tissue culture process are stagnated even with an increased number of younger farmers (20.4%) venturing into banana farming. Dynamics in banana production are largely influenced by 40% of the farmers in the middle age category (30-49 years). This age bracket is indeed a working group and most often result- oriented. The high number of young people engaging in smallholder banana farming is not due to passion as such, but rather an alternative occupation due to limited opportunities for formal employment.

Supporting structures in banana production practices are enhanced by land tenure systems. Most of the operational land (71%) is inherited from the fore-parents, and the orchards therein (over 80%) are traditional; implying that they have been perpetuated from generation to generation. The social systems usually dictate the conditions for use of such inherited land systems. It can be concluded that TCB technologies in Uganda are nascent and probably have not caused a strong impact that can be inherited, defended, and sustained by smallholder farmers. Inherited social systems in banana production stretch to the use of labour in banana production (Komarek. *et al.,* 2013).

Repeatedly, smallholder farmers rely frequently on family labour. Family labour benefits from the household size, an indicator of the extent of labour availability in smallholder production systems. It determines the adoption process in TCB production in that, larger households have the capability to subdue the labour limitations vital for TCB introduction. Other forms of labour, including professional labour, are left to the resource endowed and extraordinary farmers. The low adoption rates reflect the nature of households such that households cannot raise sufficient labour to offset TCB production demands.

The study established that above 50% of the households are male-headed. Social and economic decisions to accept or reject TCB production are often vested in the household leadership. Even though much of conservative research accepts that the 'head' of the household is male, farmers' experiences in Uganda currently challenge this orientation. What is conventional in this study is that both male-headed and female-headed households make decisions that seem not to support the production of TCB technology products. Otherwise, 31% of the households headed by females would make a significant contribution to the acceptance of TCB products. It is argued in this study that introducing TCB products to a predominantly subsistence banana biased production systems, creates a need for socio-economic change first. However, earlier Etwire *et al.* (2013), Geoffrey (2016), and Bandewar *et al.* (2017a), observed that farmer perceptions are rarely captured and later on change them in the process of introducing new farming techniques. As long as the smallholder farmer tenaciously holds to NTCB production as a practice that is socio-economically gratifying, acceptance of the TCB may not be a priority.

3.6.2. Yield factor variations and their influence on the adoption of TCB

The premise of the study in this area was that yield is a pertinent factor in the adoption of TCB technology. This premise is backed by Chitamba *et al.* (2016), that a technology that brings forth a sustainable yield is definitely accepted by smallholder farmers. An honest;

though misleading understanding by the smallholder farmers was that the ability of the banana plants to produce a sustainable amount of bunches to meet family survival needs depends on the total number of suckers a local banana mart holds. The number of suckers produced would be the number of bunches at the harvest period. However, yield performance of the banana plant depends on the management by the farmers amidst a host of other biophysical interactions (Wairegi and Asten, 2011; Nyombi, 2013; Nakato *et al*., 2017; Bandewar *et al.,* 2017). The management practices are constrained by land tenure systems, labour dynamics, as well as the level of income and income sources.

The yield for non-tissue culture cooking banana was higher, with farmers extraordinarily producing about 4500 bunches through the five cropping cycles, while production of beer banana is slightly higher compared to dessert banana types. Discussions with the farmers showed that there are changes in current social systems. The changes promote the use of different types of bananas variedly. The variations are attributed to the societal dynamics that spill over to the production systems of the banana type involved. For instance, the traditional beer parties that indirectly promoted the production of beer banana types have since reduced, but the processing of *Tonto*[4] into a spirit attracts slightly high prices. It is the perception of the market changes of beer banana products that slowly attracts the households into the production of beer banana. Cooking banana, on the other hand, is an item that forms part of the valued gifts during spiritual and social household gatherings. These social household gatherings directly and positively influence the production of cooking banana.

[4] The local name of the brew from fermented banana juice and yeast mainly used for social functions and for commercial processing of other spirits

3.6.3. Market and consumer preferences

Non-tissue culture bananas attract good prices on the market, and in terms of preference for consumption, the populace prefers Non-tissue culture cooking banana type. This result generally agrees with FAO, (2014), and UNCTAD (2016), who asserts that inclination for the traditional banana, can incline the preference factors towards the market potential of this banana. This caused dissenting assertiveness towards TCB result of market considerations for the different types of banana grown in the region. The attitude towards TCB products is wanting even when there are free channels for the farmers to receive plantlets.

The idea as to whether consumers and sellers can tell the difference on-site between TCB and the landraces is inconsistent although several discussions point to a near judgment. It is observed that the cost of the banana vaguely shows which type it is. It was shown that higher prices are attached to TCBs but their actual consumption is limited to big social functions. The second aspect is the size, where the bigger the size of the banana, the higher the likelihood of that banana being a 'Kawanda Banana'. The third aspect is the texture. Whereas the landraces are rough and spotted, the bananas of the tissue culture origin are herein described as smooth skin bananas.

3.6.4. Demographic features and their influence of adoption

The study established that gender, household management, labour sources for banana production value chain, land tenure systems, and costs involved in the production of banana were significant contributors to the yield of cooking banana. Marginal effects figured out for the socio-economic factors' and their influence on TCB technology adoption in the linear model measured the expected change in the probability of observing a positive influence on the TCB technology with respect to a change in the particular yield related to a response variable. Social demographics contribute positively to the decision to adopt a particular banana type and its related technology. In the study, males formed the largest response rate and following studies by Dube (2017), the male gender social construct role directly links to products that attract high prices. It can then be argued that the economic returns of the NTCB technology are sufficient enough to attract males more than any other gender. This study established that NTCB products attract higher prices on the market compared to any other banana type. The decision to accept, support and finance the new TCB technology is greatly attached to the male-gender social construct. Males dominate household leadership, thus, they have control over labour, land and are entitled to the inheritance of other livelihood enhancing resources. Can the same be said for women? Certainly not! What is certain and conventional is that, regardless of age, this gendered 'order' places the women in the responsibility of much of the day-to-day household, family, and on-farm labour activities (Rosemarie, 2010). A popular understanding of a "good wife" varied from district to district. However, the common understanding was that a good wife relates to a measure of how she positively realizes her multiple responsibilities to the household, especially through her prominent role as a farmer contributing to sufficient production of landrace banana.

Households rely mainly on family labour. In most cases, family labour is too rudimentary to match the labour demands for TCB production. Besides, the smallholder farmers allocate labour to the banana type that is marketable and consumable. Therefore, the available force is maximized for the production of NTCB due to high market and preference requirements. It can further be argued that the labour requirements for the production of NTCB are lower within the management by the smallholder farmer. Other forms of labour are rather expensive to be managed by smallholder farmers. Besides, particular farmers in the region are worried that if they employed professional labour, it would result in the introduction of the "*Kawanda*

Bananas[5]". Professional labour force is visibly insufficient to explain to farmers some of these concepts. As a matter of fact, the smallholder farmers blend their understanding of TCBs, improved or hybrid, bananas and the genetically modified bananas. To farmers, all the three types are the same and are from the same source, meant to dilute their local landrace types.

The results of the study clearly showed that land owned by the smallholder farmers is inherited from the previous owners. The significance of land tenure in influencing the yield and acceptance of NTCB production draws from the fact that land on which production is made is inherited from the fore owners, whose interests and social dictates are usually followed. The source from which land is acquired usually dictates the continuity of the land use and type of production carried out on the same land. Therefore, the inherited and long-lasting non-tissue culture traditional banana orchards provide socio-economic benefits that cannot be surpassed by the new technology. Otherwise, the latter would lead to the destruction of the old plantations for re-establishment of TCB types. This understanding is backed up by yet another finding of the study that the costs involved in tissue culture production value chain in terms of plantlets' development; purchasing, transportation and management in the field are a burden to the smallholder farmers. The alternative plan for the smallholder farmers is to use the farmers' own suckers, and those obtained from the neighbourhood. These edges out the production of TCB products in preference to the conventional less expensive banana type.

Components within the demographic characteristics are significant factors in shaping decisions regarding the uptake of TCB technology. The attributes attached to the social

[5] The name by which smallholder farmers know the banana products from the National Research Organization, located at Kawanda.

factors lead to significant yield levels ($P \leq 0.05$), for at least one type of banana produced by smallholder farmers (table 3.8a, 3.8b, 3.8c) Interests for adoption vary with age and gender. Age and gender are associated with a short time preference for the types of banana. Hence, they determine the decision to sustain the adoption or fall back to rejection. Other than age, the other demographic variables progressively become negatively associated with the probability of adoption and production of beer banana as the productivity proceeds from cycle to cycle. Although Husen *et al.* (2017) indicated a negative relationship between age and the adoption of some agricultural technologies in Ethiopia, and Rosemarie (2010), and Ssentamu *et al*. (2012), disassociated gender issues as a factor in new technology acceptance in Kenya and Philippines, respectively and these are contrary to the findings of this study for Uganda as far as TCB technology is concerned.

3.6.5. The contributing effect of farm characteristics

Yield remains a precursor to the adoption of TCB technology. The enablers for this yield as predicted by the total number of bunches estimated for five production cycles are the source of the materials for planting and the management approaches of the planting materials. They extend to the type of banana grown, method of propagation and the variety of banana grown. These significantly determine the yield of the different banana types ($P < 0.005$). The inter-factor interactions were very strong and significant ($P<0.05$), in determining the yield of the cooking banana. The overall factors' interaction shows no effect on the yield of beer banana ($P>0.05$), but the inter-factor relations in beer banana production are significant, with at least one factor interacting to determine the yield dynamics of the beer banana. Hence, non-adoption of TCB technologies cannot be blamed on the social and economic factors alone. There are other interacting factors in the process.

3.7. Conclusions

The study established that the level of adoption of tissue culture technology is still low, with 83% of the farmers growing NTCB. The production of NTCB type gives a sustainable yield and productivity last longer. This perception leads to an increased number of farmers getting interested in the production of NTCB, and those already in production to increase acreage under production. TCBNTCB presents better taste for consumption than TCB, hence, market and preference for consumption are factors that greatly influence the uptake of TCB technology. In order for adoption to increase, TCB technology must become convincing enough to overcome the perceived mind-set of smallholder farmers. Smallholder farmers are solely responsible for the decision to adopt or reject TCB technology. Age, household leadership, land tenure systems, gender and sources of labour enhance this decision. The allocation of resources to the TCB production technology is influenced by the subjectivity and/or objectivity of the farmers towards the technology. Farmers who may have subjective impressions about the TCB technology will limit resource allocation to the technology, than the farmers who are objective about the same technology. These are reflected in the size of the land allocated to the technology, choice of the propagation materials, source of the materials for propagation, and types of banana grown. Whereas the percentage adoption rates for TCB are generally low for farmers in Uganda, the conclusion may not be generalized for the rest of the banana-growing countries of the world, except those that present similar social dynamics under which this study was conducted. There is a need to understand the smallholder farmers' perceptions of user attributes and the performance of TCB technologies as compared to the traditional/landrace banana production technologies to give farmers options by context. Finally, there should be a deliberate effort to respond to TCB adoption problems through processes that would establish a self-sustaining system of production, distribution, and utilization of farmer-preferred varieties of TCB in Uganda. For instance, TCB processes, and hardening orchards should be exposed to the farmers not only to reorient the farmers' negative perceptions of the technology but also to facilitate farmers' access to banana planting material.

CHAPTER FOUR

BIOTIC AND ABIOTIC FACTORS INFLUENCING TISSUE CULTURE BANANA PRODUCTIVITY IN SMALLHOLDER FARMS

Abstract

Banana productivity is constrained by a wide range of factors that act individually or in combinations. Nested Case-Control design was used to determine the spatio-temporal factors that influence the distribution of banana weevils and plant parasitic nematodes in tissue culture and NTCB orchards within smallholder farms in Ibanda, Isingiro, and Kiruhura and Mbarara districts of western Uganda. The four districts represented the spatial aspect whereas the dry/and or rainy season represented the temporal aspect. Plant parasitic nematodes were extracted from root samples and identified to the genus level. The disc-on-stamp and split pseudo-stem methods were used to trap banana weevils in 20 orchards. A total of 1,280 banana mats were surveyed between December 2018 and May, 2019. Mean weevil and nematode population densities were established. Nested analyses of variance with R i386.3.3.1version indicated significant relationships *(Pr (>F)* that were lower than 5% critical value between the banana type, mean numbers of banana weevils, nematode densities and the location of the orchards. Mean numbers of weevils and nematodes were higher in TCB than in NTCB during the dry season. Among the plant parasitic nematodes, *Helichotelenchus multicinctus* and *Radopholus similis* were the most prevalent in western Uganda, with the highest mean nematode density found in Ibanda district. The split pseudo stem technique was more effective in attracting weevils compared to the disc-on-stump trap during the dry season. The interactions between the season and locations with banana weevils and nematodes had a significant and negative effect on the distribution of tissue culture and NTCB in space and time (0.0343 *). Adoption into smallholder banana orchards of the banana type is significantly (P<0.0001), influenced by location characteristics, and the prevalence of the banana weevils (P< 0.001).Interactions between banana weevil, nematodes and temporal characteristics significantly (P<0.01), influenced the distribution of different types of banana. The incidences of the weevil and nematode pests and an understanding of their seasonal and spatial distribution should form a basis for developing strategic and affordable treatments meant to maintain the pest numbers below economic threshold levels.

Keywords

Spatio-Temporal, Banana weevil; nematode, banana type; temporal; spatial; seasonal distribution; mean population density.

4.1. Introduction

Banana production as an income-generating practice in Uganda is steadfastly increasing and is likely to replace the traditional cash crops (Namanya, 2011). The crop has become an alternative to the unstable market for extremely perishable unprocessed animal products (Speijer, 2017). Nonetheless, its production is constrained by pests and diseases (Nakato *et al*., 2017). TCB production technology was introduced in Uganda mainly to address the pest and disease menace in the banana production industry (Okech *et al*., 2004; Langat *et al*., 2013). Additionally, the introduction was to enhance productivity, fill income gaps and ultimately improve food security at smallholding farm level (Mbaka *et al.,* 2008; Ssebuliba *et al.,* 2016; Nakato *et al*., 2017). The tendency to accept planting materials by the smallholder farmers are stuck to the choice of NTCB suckers than the TCB plantlets. This tendency is energized by the socio-economic factors within the environs of the smallholder farmer, and the ability of the farmers to compare the survival time periods of TCB versus the conventional banana plantations (Murongo *et al.,* 2018). Smallholder banana farmers need to understand that environmental factors such as temperature, wind, light, and water supply, as well as erraticism of the soil physical and chemical structural composition vary both spatially and temporary. The spatial and temporal variability contributes to the distribution of biotic components in the farming system especially effect on yield (Machado *et al.*, 2014). The banana weevil and some genera of parasitic nematodes are some of the biotic factors that have led to the destruction of banana orchards. Smallholder farming communities are largely not cognisant of some of the factors acting together or individually to distribute the pests in the banana orchards.

Bananas are susceptible to banana weevil and nematode attack under a wide range of conditions. The severity and occurrence of these biotic risk factors and plant damage depend on the prevailing environmental conditions, and specific banana cultivars. Such occurrences within the smallholder farms are prevented by implementing cultural treatment practices, preceded by careful selection and handling of pest free and, where possible, resistant banana planting materials. Traditionally, farmers remove all leaves, outer leaf sheaths, roots, dead parts of the plant and pare the corm to eliminate weevils and weevil eggs. Pared corms and suckers are soaked in soapy water overnight to eliminate weevil eggs and nymphs. The suckers should be planted within one week after treatment to avoid re-infestation. Although less information is given on the control of nematodes, use of improved banana cultivars with high levels of resistance/tolerance and proper management of the banana residues could offer a solution to banana weevil and nematode damage.

Traditional practices suggest that at planting time, the planting materials are treated for control of weevils and nematodes, but during the development process in real-time across the seasons, the bananas are re-infested with the banana weevils and the parasitic nematodes. High prevalence rates of the banana weevil and the parasitic nematodes influence the survival, development and evolution of the crop under production (Ayuke, 2010). The biotic risk factors are also influential in the deterioration and degeneration of many other living organisms; the banana inclusive (Speijer, 2017). Banana varieties planted in Uganda are prone to detrimental biological interactions with the banana weevil and the parasitic nematode (Alou *et al.,* 2014). The interactions lead to the collapse of the orchards (Ocan *et al*., 2008), damage the roots rapidly, provide space for the infection by pathogens, destroy the banana plant stability (Arinaitwe *et al.*, 2014), and result in serious yield losses (Grant, 2012). This study, therefore, sought to determine the distribution of banana weevils and parasitic nematodes as biotic risk factors in banana production, and how they relate to abiotic (Spatio-temporal) factors within smallholder farming communities in western Uganda.

4.2. Materials and Methods

4.2.1. Study Design and conceptualization

Nested Case-Control Design was adopted to retrospectively determine the exposure of the banana orchards to the risk factors in space and time (Kuller *et al.*, 2018). The design was deemed appropriate since the distribution of study units and observations were done on study points determined from a population of banana orchards that had been established over a period of time by smallholder farmers. The study design was mainly observational because no intervention was attempted and no attempt was made to alter the course of pest prevalence at that level. The "*banana types*" were conceptualised to denote the technology through which farmers' planting materials were developed. The type was considered NTCB if the original planting materials were the traditional conventional suckers, but if the banana orchard was established from tissue culture plantlets, the type was considered TCB. Risk factors naturally prevail in the smallholder banana orchards, and the banana types are naturally exposed to these risk factors. Upon exposer to the risk factor, over a period of time under natural conditions, the banana types have an equal chance of getting infested or resisting infestation with the risk factors. The plants within a type that are not infested under similar orchard conditions after a period of time were the "*controls*" while those that are infested regardless of the degree of infestation were the "*cases*". The study assumed that there was a uniform inherent nature of the banana cultivars regardless of the type, conferred by their genetic stature to resist against attack by the risk factors. The districts formed the major block. The seasons and banana types were nested within the districts. The districts were conceptualized to represent the spatial aspect since they represent varying aspects. The dry season and rainy seasons epitomize the temporal aspect. The selected methods of capturing weevils were nested with the seasons and applied to the banana type in different districts (Figure 4.1). Extraction of nematodes was not done following the seasons and particular method per se, but collection and examination of samples was done at random. However, the total nematode counts were nested with nematode genera, within a banana type in and a district.

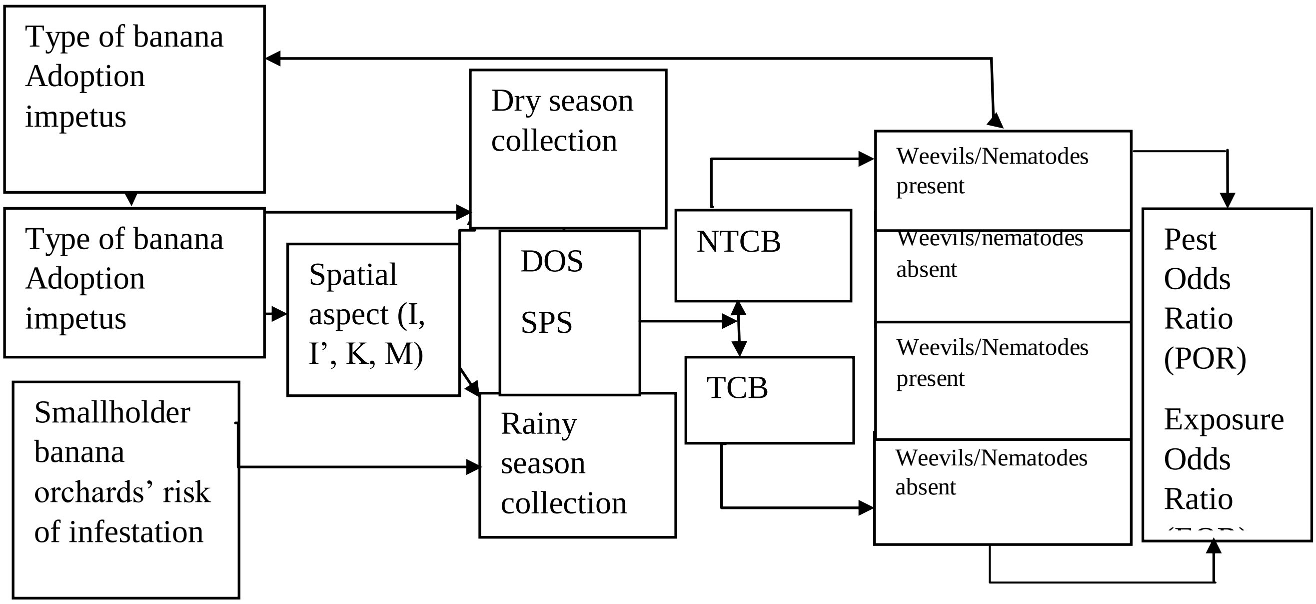

Figure 4. 1: Summary conceptualization of the design for spatial and temporal banana weevil study in Uganda

The spatial aspect in this concept is the location representing I=Ibanda district, I'=Isingiro district, K=Kiruhura district and M=Mbarara district. Disc on Stamp (DOS) and Split Pseudo stem (SPS), respectively represent the method used to capture the banana weevils. The banana type NTCB and TCB, represent Non-tissue culture banana and tissue culture banana, respectively.

The study was conducted in the existing sites previously identified. However, it was assumed that sustained production, rejection and /or fall back into the production of any cultivar of banana by the farmer is influenced by farmers' location and the season in which the practices on banana production are carried out. The study further assumed that the exposure of the banana orchards to the risk factors is enhanced by the season of the year as well as the location of the banana orchard. Non-Tissue Culture Banana and TCB types as previously adopted was expected to show variations in pest incidences according to space (district) and time (season), following the two major methods of banana weevil pest traps i.e. the Disc on Stamp [DOS] traps and Split Pseudo stem [SPS] traps.

4.2.2. Characterization of the location

The seasonal capture of the weevils was spread over four districts of Mbarara, Ibanda, Isingiro, and Kiruhura. A summary of the geographical aspects for the districts is shown in Table 3.1 section 3.2.1. Undulating hills and shallow flatlands characterise the area. The proportions for water bodies, compared to the arable land vary considerably. For instance, about 6% of the total land is covered with lakes, rivers, and gazetted swamps, but the coverage varies with different districts. The soils are loamy with some districts characterised with sand and rocks. Nonetheless, the soils are fertile perhaps due to manure deposits that came especially from livestock farming activities. The soils were classified largely as weathered ferralsols, Kaizzi (2010).

4.2.3. Sampling and selection criteria

The banana orchards were selected based on whether they were raised from tissue culture plantlets or conventional suckers. A record from Agricultural Productivity Enhancement Program (APEP), a banana technology transfer program was used to identify smallholder banana farmers who benefited from the program during the 2005-2008 field demonstrations in western Uganda. At the end of the field demonstrations, approximated 320 farmers across the four districts received TCB plantlets, fertilisers, and information kits for developing modern banana plantations. The current study considered these farmers for selection of orchards for further study. Banana farmers were actively involved in the identification of the banana type and occurrence of the required cultivars of banana. During the identification process, emphasis was placed on the origin of planting material of the banana orchard under observation other than the use of the banana cultivars within the orchard.

Further selection depended on areas that have been under banana based cropping systems for a period not less than 15 years as well as the smallholder farmers' resource bequest (Murongo et al., 2018). Representative local orchards that had more than five genotypes and at least 150 genets enough to provide adequate sample size were further selected. The minimum average distance in kilometres between the individual farmers' orchards was approximated to 0.5–2 km. Banana farmers were actively involved in the identification of the banana type and occurrence of the types of banana. During the identification process, emphasis was placed on the origin of planting material of the banana orchard under observation other than the use of the banana cultivars within the orchard. The distribution of the banana type was estimated as a percentage of total farmers who reported to have received planting materials.

4.2.4. Assessment of biotic factors

The biological components of economic importance to this study were banana weevils and nematodes. Twenty orchards were randomly selected by taking five farmers from Ibanda, Isingiro, Kiruhura and Mbarara districts as sites for the determination of the banana weevil and nematode population densities. The densities were used to determine the spatial and seasonal distribution within the farmers' orchards.

4.2.4.1. Banana weevil population density determination

Two basic approaches were used to quantify the weevils in the farmers' fields; the Disc on Stump (DOS), and the Split Pseudo Stem (SPS) traps. The DOS was made by cutting a harvested stump, 5-10 cm above ground, and placing a 5-10 cm thick pseudo stem disc on top of the stump. The SPS was made from pseudo stem pieces split longitudinally and placed near a target plant with the split surface inverted onto the ground. Although the DOS method is inflexible and limited only to harvested, broken or damaged plants (Nankinga and Moore 2016), it captures more weevils than the SPS (Ocan *et al*., 2008). The DOS method was restricted to plantations that were old and had the required number of harvested stumps. Five traps each for DOS SPS were randomly laid in each of the five selected plantations per district.

Young and newly established orchards were appropriate for the use of the SPS method (Jallow and Achiri 2016). The young plantations have not been harvested many times to provide many stumps to sufficiently support the use of DOS. The method is easy to set under the widest range of conditions and trap materials are readily available. The variation in trapping conditions such as trap lengths, placement, duration of trapping and soil moisture conditions may significantly influence the catches in split pseudo stem traps Ogenga-Latigo and Bakyalire (1993), and Ocan *et al*. (2008),. Therefore, the traps' lengths were limited to 30 cm, placed horizontally onto the surface and weevils checked after 24, 36 and 48 hours, respectively. The time schedules were used to maximise and increase the duration of trapping weevils. The traps have the ability to remain active for 1-2 weeks. The first collection of the weevils was done after 24 hours by opening up the inverted traps and the adult weevils handpicked. The same trap materials were inverted again until the 36th hour. A thin layer provided by a banana leaf in between the stump and the disc for DOS method, and between the ground and the split stem for the SPS was replaced after the 36$^{th's}$ hour collection until the 48th collection. The total for the three collections was put together to form one single *genet* count. The weevil density was related to the type of banana on which the trap was set to determine the pest odds in the smallholder banana orchards. The density was based on the average number of weevils captured from the selected smallholder banana plantation. The pest populations were collected for two months in both the rainy dry seasons to give concrete variations of the weevils across the seasons of the year.

4.2.4.2. Nematode population density determination

Nematode population were determined by taking a composite root sample of 5g obtained by collecting five roots per mat from five randomly selected mats per orchard. The samples were collected twice per month, for two months during a rainy season, and two months in a dry season. Nematodes were extracted from fresh banana roots following the modified Baermann's Funnel technique and protocol described by (Coyne *et al.,* 2007).

4.2.5. Data analysis

The study retrospectively examined the effect of banana weevils and nematodes on the distribution of banana types in space and followed the banana types back in time to check for the prevalence of the banana weevils and nematodes. The study units were assumed to have been "pest-free" at the time of planting and thus classified the planted materials based on the presence and or absence of the pest factors. As such, 1,280 samples were observed during the survey that spanned a period of 14 months, from September 2017 to December 2018. The measures of association between the risk factors and the type of banana were obtained by analysing the Pest Odds Ratio (POR), and the Exposure Odds Ratio (EOR). The POR would be the orchards that were exposed to risk factors' but were not actually infested. However, under natural conditions, it is rather unusual to have pest odds.

The EOR were the orchards that were exposed to the risk factors and were actually infested. The association between POR and EOR is the Risk Ratio (RR). Where the Risk Ratio was low and cumulative, the incidence of the pest infestation was concluded to be diminutive. The risk ratio was determined by;

$(B/N1)\ /\ (C/No)$ ………………………………………...……………….equation 3

Or, $(B/C)\ /\ (N1/No)$,……………………………………………….……...equation 4

where ***B*** was the number of infested banana mats, ***N1*** was the total number of sampled banana mats, **C** was the number of uninfected banana mats ***No*** was the total number of exposed banana mats. Spatial data was arranged using arc-GIS, graphics developed with MS Excel 2013 and statistical analyses run with R version i386.3.3.1. Nested Analysis of Variance was run because the distribution of banana types and the risk of exposure to pest infestation of the banana orchards both depend on the geographical aspect and the various seasons through which the banana orchards develop.

4.3. Results and Discussion

4.3.1. Mean banana weevil and nematode densities

Figure 4.2 shows the mean weevil density distribution in NTCB and TCB types. It was observed that out of the 1,280 observations, all the banana mats naturally exposed to the banana weevil infestation were actually infested. Therefore, there were no pest odds to recommend as case controls.

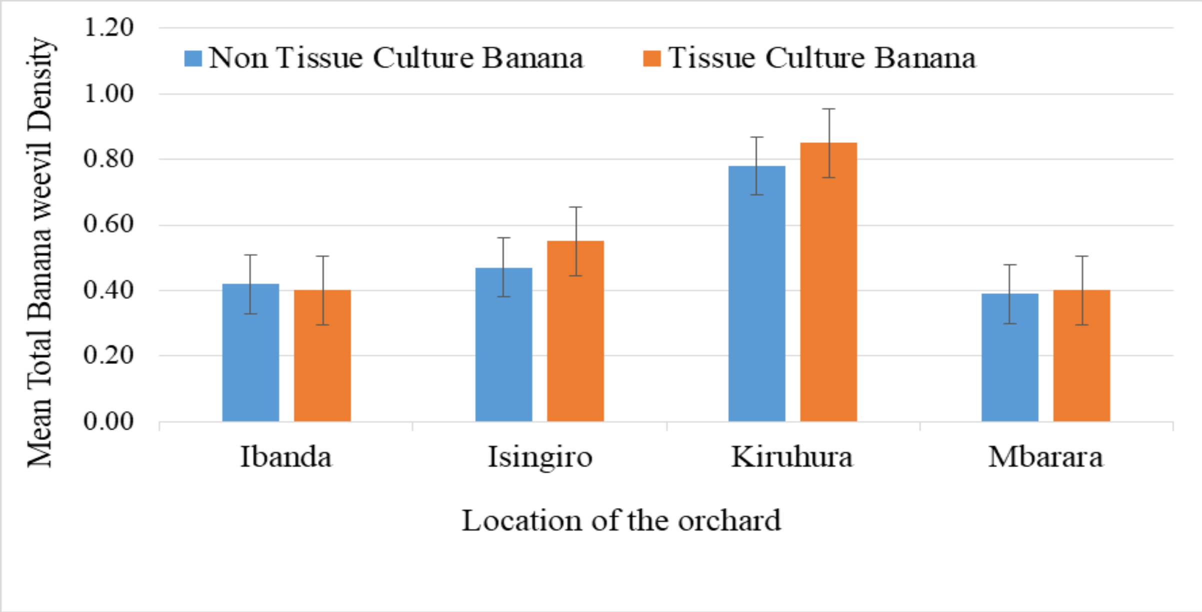

Figure 4.2: Total weevil density distribution within banana types in different districts

Figure 4.2 further indicates that TCB was more infested in Kiruhura district compared to any other district. Essentially, the overlaps in the confidence intervals/error bars may predict insignificance of the interaction between the banana type and the weevils in a given district. Conversely, the non-overlapping confidence intervals would suggest the significance of the interactions. However, the standard error bars say nothing about the statistical significance of infestation for both banana types in Isingiro, Kiruhura, and Mbarara districts.

Figure 4.3 shows the methods used to determine the density of banana weevils in the study area. The Disc-on-stamp method of trapping banana weevils captured a higher number of weevils compared to the Split pseudo stem. The split pseudo stem performed better in Ibanda and Mbarara districts.

Figure 4.3: Total banana weevil density capture by use of Disc on Stamp and Split pseudo-stem in different districts

The smallholder farmer orchards of the TCB origin were slightly more infested with the banana weevil, than the orchards developed from the conventional traditional suckers. Banana weevil problems appear to be more serious in the tissue culture highland-originated cooking banana types in western Uganda. Tissue culture plantlets are fragile, and smallholder farmers must employ appropriate management practices to harness the potential of the tissue culture technology, especially at the initial stages of growth after transplanting into the field. Usually, farmers transplant the plantlets into fields that are already prone to banana weevil pest pressure alongside other abiotic constraints. In a low input situation of the smallholder farmers, standards for quality management during the production process may not only be a serious limiting factor but also an enabling factor in the multiplication of banana weevil in smallholder fields.

Figure 4.4 shows the distribution of nematodes within the banana type. There was a higher population density for nematodes in tissue culture originated banana plantations than the banana weevils in both plantations.

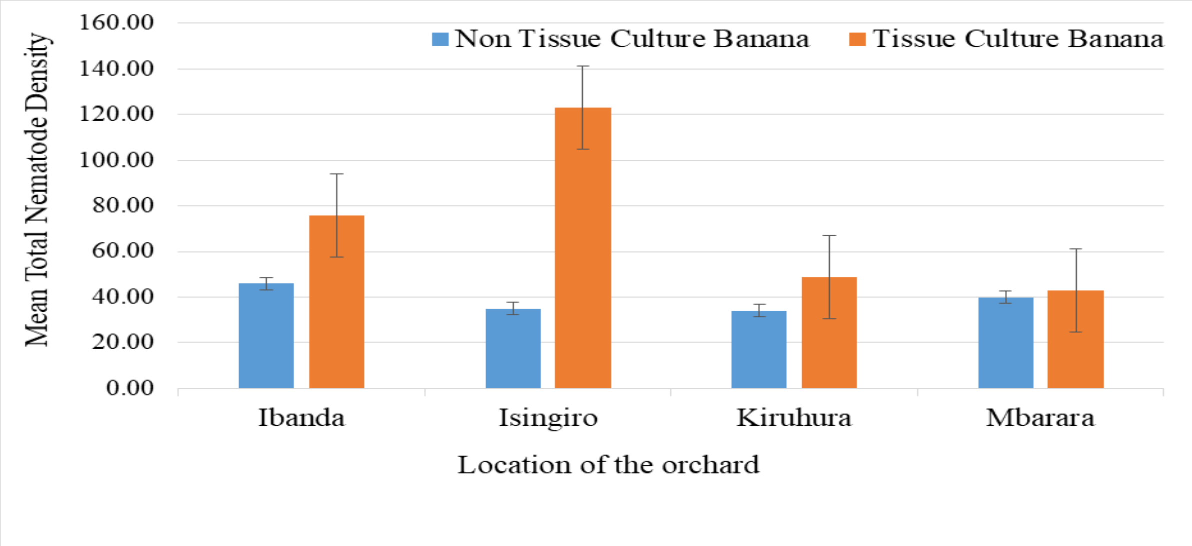

Figure 4.4: Total plant parasitic nematode density distribution in banana types in different districts

The distribution of nematodes in smallholder farmers' orchards by species; Figure 4.5, indicate a higher prevalence of *H. multinctus* in Ibanda and Isingiro districts. *R. similis* densities are also high in the same districts. *P. goodeyi* was more prevalent in Kiruhura and Isingiro, while *Meloidogyne spp* was mostly found in Isingiro.

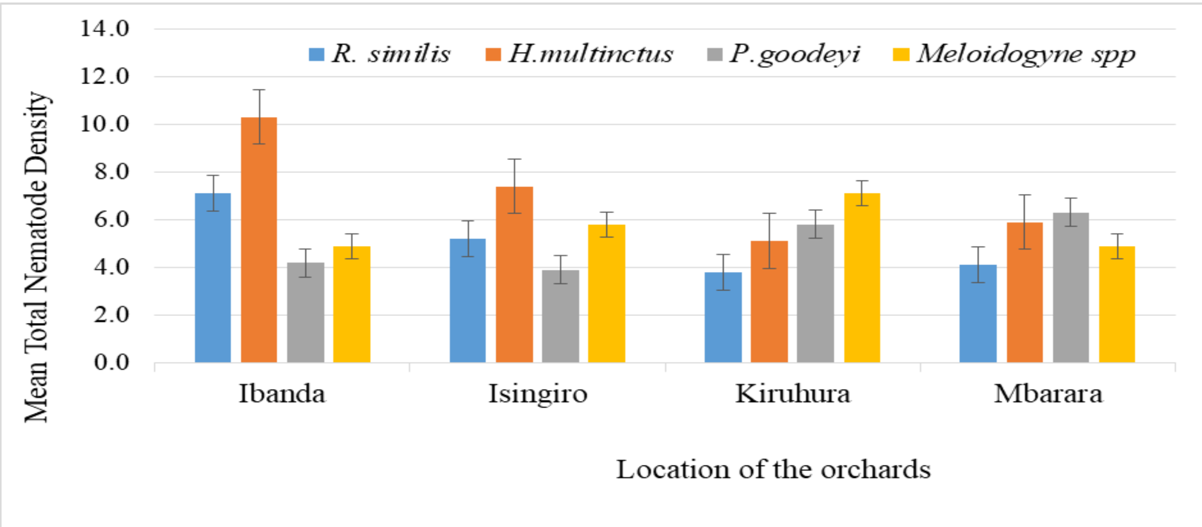

Figure 4.5: Total Nematode density distribution by Nematode Genera in different districts

Factors summarised in Table 3.1 including but not limited to the type of soil, moisture and temperature have a bearing on the distribution of the nematode genera. These factors have a direct effect on the growth of banana types that are hosts to different nematodes. In the south and Central Africa, *Meloidogyne spp* and *P. goodeyi* have been found most prevalent. The current study findings contravene that by (Daneel *et al.*, 2015), who found that *Meloidogyne* and *P. goodeyi* were the most widespread genera in South Africa. Nonetheless, the study results agree with Gowen *et al*., (2005), whose report explicitly indicates that the root system of banana is attacked by several nematode species triggering coincident infections. In this present survey, *R. similis* and *H. multinctus* were the most frequent and widely distributed in all sampled locations and on all surveyed mats. An earlier survey conducted in Swaziland by Daneel *et al.* (2002), the mean densities were higher for *H. multinctus*, and *P. goodeyi* than *R. similis*, with nearly 90% of the root samples infested with *H. multicinctus*, and the present results corroborate these findings. In the neighborhoods of the study area, a survey conducted in the Democratic Republic of Congo by Kamira *et al.*, (2013), showed that *H. multicinctus* was present in 89% of the samples whereas *Meloidogyne* was found in 54% of the samples. On the other hand, *R. similis*, was present in 30% of the samples which appears considerably higher than in the Western region of Uganda.

4.3.2. Spatial distribution of Banana weevil and nematodes

The study considered the districts as a representation of the spatial characteristics. The study points were geo-referenced (Figure 4.6A). Geo-referenced smallholder farmers' orchards were used to set up traps to capture the weevils. The results of the survey explicitly show that all the geo-referenced study points indicated the infestation of both NTCB and TCB types with of both banana weevils (Figure 4.6B) and the nematodes (Figure 4.6C). Spatially, there were higher nematode densities in all the districts than the densities for banana weevils.

Isingiro district returned the highest density for banana weevil. Ibanda district returned the highest degree of infestation with the nematodes.

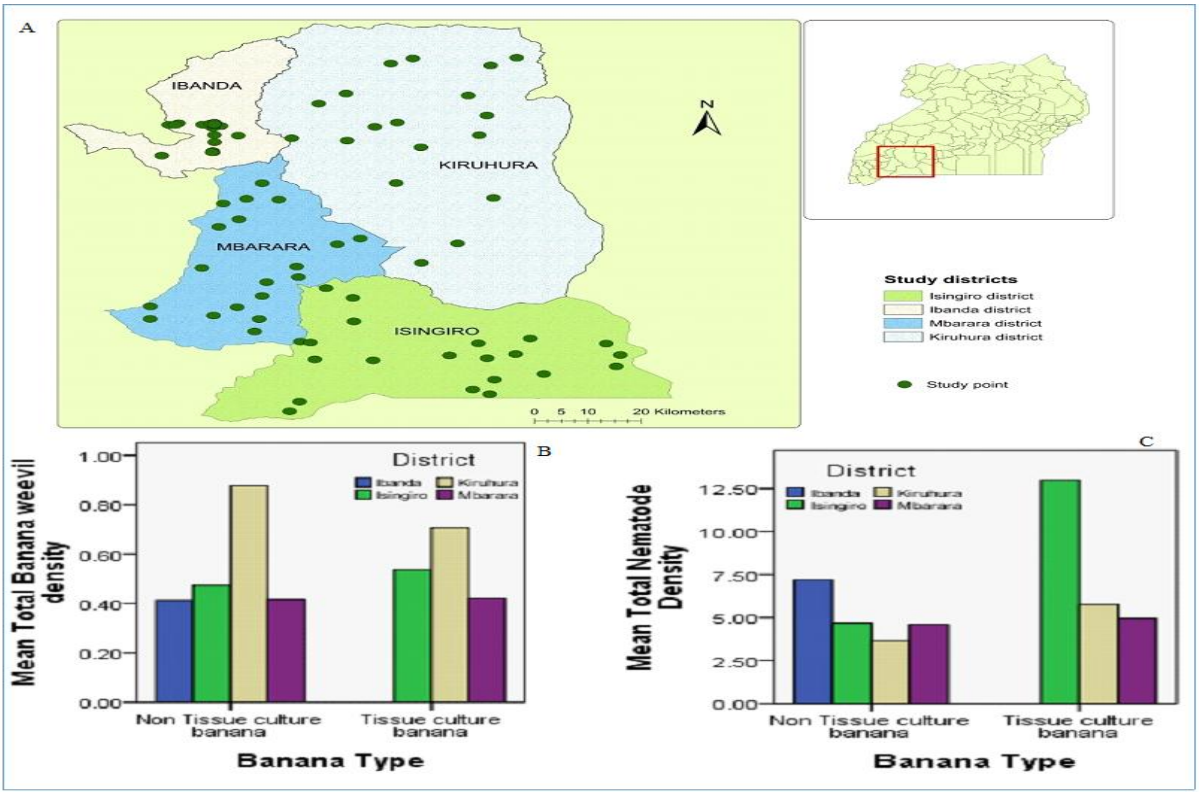

Figure 4.6: Spatial distribution of weevil and nematode densities within Non-tissue culture and Tissue culture banana in the western region of Uganda

The districts are a common denominator characterizing the spatial aspect. A-shows the geo-referenced study points, B-shows the weevil density established from the geo-referenced orchards, C- shows the nematode density established from the geo-referenced orchards**.**

The elevations, temperature and rainfall ranges for the study area do not differ significantly from one spatial location to the other. The relatively similar characteristics provide similar conditions for the distribution of studied biotic components within the districts. The current spatial distribution of the banana weevil and the nematodes ought to be considered in line with Okech *et al.* (2004), who postulated that above 1400m asl, certain insect pest incidences are not a serious problem. The study area lies within altitudes that are above 1400m asl, which suggests that the insect pests problem including the banana weevil should be less of a risk (Okech *et al.,* 2004; Arinaitwe *et al.,* 2014). For this study, it could be argued that at altitudes above 1400m asl, the associated spatial characteristics support banana crops to subsist with the observed densities for banana weevils and nematodes. In such cases, Queiroz *et al. (*2017), suggests that the general pest problem can be managed by improving cultural practices. Studies have indicated that the banana weevils are largely less immobile and their genetic mobility is generally slow (Twesigye *et al.*, 2018). Likewise, nematode mobility is quite slow. Therefore, self-mobility by the weevils and the nematodes cannot be a factor to explain satisfactorily the current spatial distribution observed in the study. Chitamba *et al.* (2013) identified long-term monoculture practices as a contributing factor towards such spatial distributions, while Daneel *et al*. (2015) suggested the use of tissue-culture banana plants as mitigating factor for the spread of the nematode and the banana weevil. Murongo *et al.* (2018), established that 83% of the smallholder farmers in the current study area use conventional suckers as planting material. This is done without any intensive or effective quarantine system to prohibit infected materials dispersing within the region. Therefore, the current spatial distribution of the two biotic components is due movement of banana plant materials and residues from smallholder farm to the next.

4.3.3. Temporal distribution of the banana weevil

Infestation of the banana mats by the banana weevil was high during the dry season for Isingiro and Kiruhura districts, respectively (Figure 4.7A). The infestation was higher in TCB in the dry season compared to the same season in NTCB (Figure 4.7B). Finally, both the DOS and SPS trap methods effectively captured a significantly high number of weevils in both seasons; however, the SPS returned a higher density during the dry season capture (Figure 4.7C).

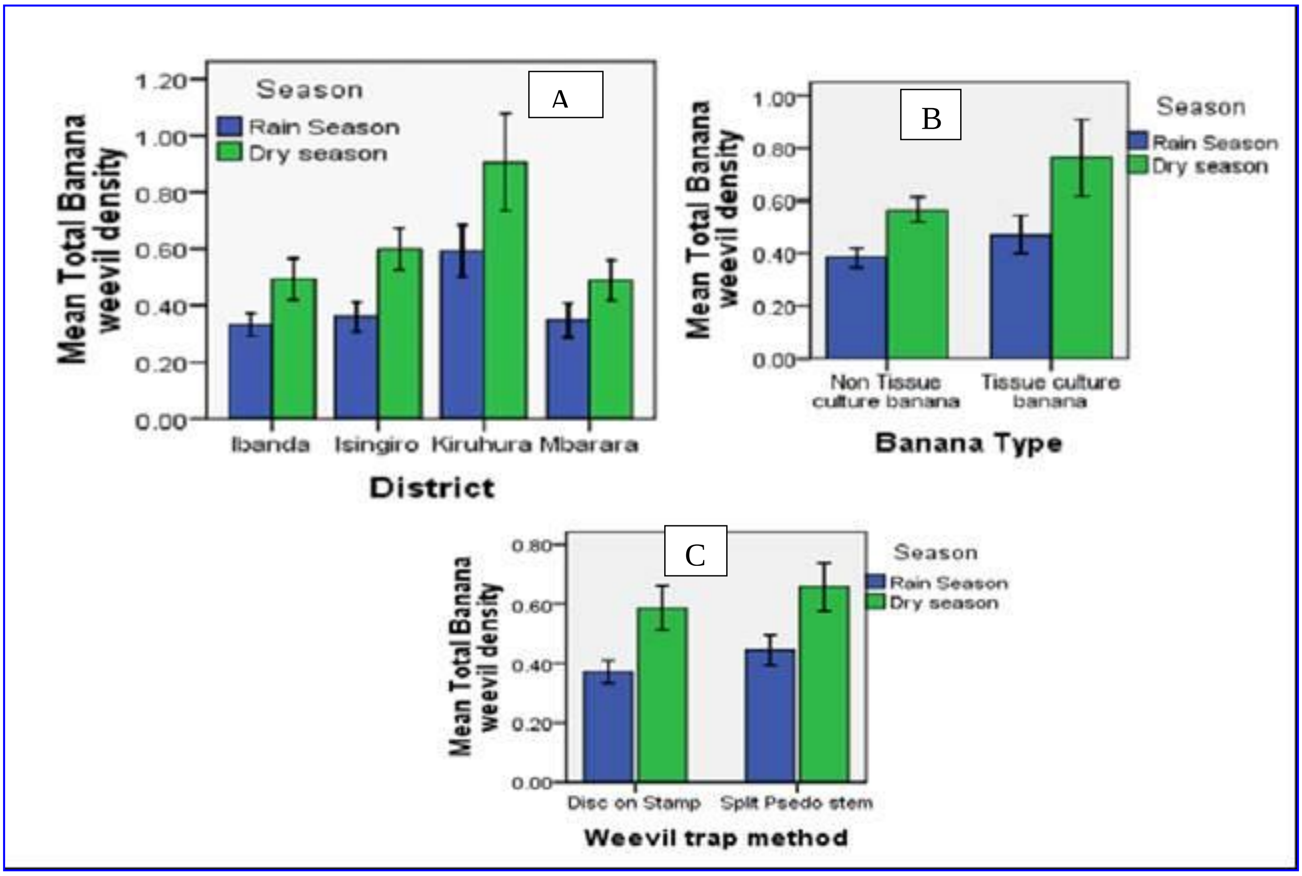

Figure 4.7: Seasonal distribution of banana weevil in Western Uganda

Temporal distribution of weevil within NTCB and TCB in the western region of Uganda. A- shows the seasonal weevil distribution following the location (Districts), B-shows the weevil density established in the banana types following the season, C- shows the weevils captured by different traps in the seasons.

The results show that banana weevil population during the dry season were significantly high for the method of capture, within the banana type, and for locations of the banana orchards. The densities for the banana weevil according to the method of capture, within the banana type and the locations, were lower for the rainy season. The smallholder farmers can understand this phenomenon from the point of view of the orchard management practices. Towards the end of the rainy season, farmers remove the old and dry leaves of *ramets* of each mat. The leaves, in addition to other external materials such as lemongrass, are used to mulch the plantations in the dry season. According to findings by Gold *et al. (*2006), mulched banana plantations whether on research station or in farmers' fields have high banana weevil infestation.

Temporal factors affect the distribution of banana weevil and the banana weevil has an effect on the distribution of different banana types. The weevil incidences between 20-90%, are capable of destroying a banana orchard in the shortest time of its existence (Katungi *et al*., 2006; Njau *et al.*, 2011; Speijer, 2017). Although the current study did not correlate the mean banana weevil densities with banana orchard damage, the results place the smallholder farmers' fields within the banana weevil destructive bracket. Persistent seasonal shifts in temperature and rainfall that have led to the general decline of 27% in plantain production in Uganda. According to Sabiiti *et al.* (2016), such variations in weather and climate have had a significant impact on rain-fed banana yields in East Africa. Mean banana weevil densities need to be monitored alongside the seasonal variations to understand the relationship between the seasonal pest variations and the total banana production yield. The paradox is that despite the high mean weevil densities established by the study, the national statistics UBOS (2010), UBOS (2016), and UBOS (2017), consecutively identified the same regional districts as the largest producers of banana (2,883,648 tonnes) in the whole country.

4.3.4. Effect of interaction between banana weevils, parasitic nematodes and the abiotic factor on banana distribution

4.3.4.1. Interaction with banana weevil

The distribution of the banana type, that is whether smallholder farmers chose to sustain the production of banana either from TCB products, or conventional plantations was significantly determined by the spatial characteristics ($P<0.0001$) and the prevalence of the banana weevils ($P< 0.001$). The temporal aspect as represented by the season and the interactions that exist between the banana weevil densities, the season and the location significantly determined the distribution of different types of banana ($P<0.01$). Interactions between the mean banana weevil density and the seasons were significant in the distribution of the type of banana at (P<0.05) (Table 4.1).

Table 4.1: Variance for spatio-temporal banana weevil interactions with banana type

	Df	*Sum Sq.*	*Mean Sq.*	*F value*	*Pr (>F)*
Weevil density	1	5.13	5.13	29.706	6.04e-08 ***
Season(Dry/Rainy)	1	1.04	1.04	6.020	0.0143 *
Location(District)	1	35.51	35.51	205.70	< 2e-16 ***
Season: Method(DOS/SPS)	1	0.00	0.00	0.014	0.9051
Weevil Density: Season	1	0.56	0.56	3.225	0.0728.
Weevil Density: Season: Location	1	0.78	0.78	4.490	0.0343 *
season: Location	1	0.04	0.04	0.255	0.6138
Weevil Density: Season: Season: Method	1	0.24	0.24	1.368	0.2425
Season: Method: Location	1	0.00	0.00	0.009	0.9239
Weevil Density: Season: Season: Location	1	0.01	0.01	0.070	0.7909
Season: Method: Location	1	0.00	0.00	0.004	0.9471
Residuals	1268	218.9	0.17		

The asterisks [***], [**], [*], [.] Show significance at “0%”, “0.1%”, “1%” and “5%” critical values, respectively

The proportions of the variance in the distribution of banana type and the risk of infestation of the farmers’ banana orchards that could not be explained by other effects other than the location, mean weevil density and season were very low.

The type of banana is a representation of the smallholder farmers’ orchards exposed to the risk of infestation by the weevils under natural conditions. Banana weevil equally affects both conventional plantations and TCB plantations across the locations and seasons. The response of the type of banana-to-banana weevil densities in smallholder farm fields cannot be dissociated from the effect attributed to the mean density of the weevils as established by the current study. Studies by Wairegi *et al*. (2010) and Sabiiti *et al*. (2016), argued that smallholder farmers’ choices for plantain production are enhanced by the prevailing climatic conditions such as a stable balance between the rainy and dry seasons that characterise the environment of the smallholder farmers. The current study assumed that the banana types have inherent ability conferred by their genetic stature to resist harmful interactions with the biotic factors. In such cases, plant-based secondary metabolites exuded by the different types of banana with respect to the spatial and temporal prevailing conditions may indirectly contribute to significant mean weevil densities. For instance, spatial and temporal conditions that stimulate the banana plant (whether tissue culture or conventional) to exude Terpenoids, may have a high banana weevil infestation. According to Ndiege *et al*. (1991) and Gunawardena and Dissanayake (2000), Terpenoids are secondary metabolites that are weevil attractants. Whereas it may be possible that the two banana types could be exuding similar weevil attractants, the exudates may be varying according to the season, and perhaps the location of the orchards. The accumulated mean banana weevil density, in turn, exerts a negative effect on the banana type in question thus impacting on the general distribution.

4.3.4.2. Interaction with parasitic nematodes

Location-and the mean nematode density significantly determined the distribution of banana types ($P<0.0001$, 0.001, respectively). The temporal aspect as represented by the season, the interactions that exist between the mean nematode densities and the location significantly determined the distribution of different types of banana ($P<0.01$) (Table 4.2). The proportions of the variance in the distribution of banana type and the risk of infestation by the nematodes in the farmers' banana orchards that could not be explained by other interactions apart from the location and mean nematode density were very low.

Table 4.2: Variance for spatial-temporal Nematode interactions with banana type

	Df	*Sum Sq.*	*Mean Sq.*	*F value*	*Pr (>F)*
Nematode density	1	1.69	1.69	9.652	0.00193 **
Season(Dry/Rainy)	1	0.00	0.00	0.000	1.00000
Location(District)	1	37.82	37.82	216.12	<2e-16 ***
Season: Method(DOS/SPS)	1	0.00	0.00	0.000	1.00000
Nematode: Season	1	0.000	0.000	0.000	0.000
Nematode: Season: Location	1	0.83	0.83	4.722	0.02997 *
season: Location	1	0.000	0.000	0.000	1.00000
Nematode Density: Season: Season: Method	1	0.000	0.000	0.000	1.00000
Season: Method: Location	1	0.000	0.000	0.000	1.00000
Nematode Density: Season: Season: Location	1	0.000	0.000	0.000	1.00000
Season: Method: Location	1	0.000	0.000	0.000	1.00000
Residuals	1268	221.9	0.17		

The asterisks [***], [**], [*], Show significance at "0%", "0.1%", and "1%" critical values, respectively

The study established that both conventional banana and TCB plantations are similarly negatively affected by the parasitic nematodes regardless of the location and season, although the degree of infestation varies across spatial and/or temporal scales. Even though various surveys have confirmed the presence of nematodes on bananas, abundance and frequency vary between genera (Daneel *et al*. 2015). The distribution of the banana type in smallholder banana orchards is linked to the effect attributed to the mean population density of the parasitic nematode. However, the banana plants survival against the nematodes may depend on other factors including the genetic constitution of the plants. According to Ndiege *et al*. (1991), the plant may exude secondary metabolites that enhance the plants' inherent ability to resist nematode destruction. For instance, Ndiege *et al.* (1991), established that *1, 8-cineole* exudates are nematode repellents. Such exudates may also vary with respect to the spatial and temporal prevailing conditions, and like in the case of banana weevil, they may indirectly contribute to significantly higher mean parasitic nematode densities if the concentration of the metabolite is high. The variations in mean nematodes' density would negatively affect the distribution of the banana type in question. For instance, the presence of the nematodes may have no effect on the distribution of banana weevil but the effect of the weevil on the banana may be associated with the prevalence of the nematodes. Speijer (2017) earlier established that the banana weevil damage to the roots could be high in nematode infested areas in mulched plots. Other than mulching, Speijer (2017) identified the cycle of production as an enabler, where, nematode infested mulched banana plots suffer grave banana weevil damage after the fourth cycle. The current study did not consider the degree of damage of either the roots and or corms by the two pests but the implied argument is that nematodes and banana weevil independently damage banana crops under homogenous field conditions unless variations occur within field conditions.

4.4. Conclusions

This study has shown that under natural conditions when smallholder banana farms are exposed to weevil and nematode pests, both tissue culture and non-TCB are susceptible to banana weevil and nematode infestation. The season and locations interaction with Banana weevils and nematodes influences the distribution of tissue culture and NTCB and negatively affects the adoption of TCB. The location and season within which the banana orchard is found, enhance the variations in the levels of infestation by the banana weevil and parasitic nematodes. TCB is more infested with both banana weevils and parasitic nematodes of the four main species covered by this study. *Helichotelenchus multicinctus* and *Radopholous similis* were most prevalent in the 1,280 root samples examined from Western Uganda smallholder banana orchards.

This knowledge is important in shaping the adoption and sustenance of the adopted banana types. Farmers are most likely to accept the type of banana that co-exists with the pests' infestation in those management practices that are affordable by the smallholder farmers. The incidences of the weevil and parasitic nematode pests and an understanding of their seasonal and spatial distribution should form a basis for developing strategic and affordable treatments meant to lower the occurrence of banana weevil and parasitic nematodes below the threshold level in smallholder banana farms of Uganda. Hence, regional and season-specific control strategies should be developed for sustainable traditional production systems for conventional banana orchard management and adoption of the TCB technologies.

CHAPTER FIVE

SOIL BIOPHYSICAL FACTORS INFLUENCING THE ABUNDANCE OF TISSUE CULTURE BANANA UNDER HETEROGENEOUS ON-FARM CONDITIONS AMONG SMALLHOLDER FARMERS IN UGANDA

Abstract

Bananas are primarily grown in Uganda for domestic consumption and regional trade. Production is constrained by several factors such as declining soil fertility, pests and disease, and erratic rainfall. TCB were introduced partly to solve some of the challenges in banana production, though uptake of such technologies by smallholder farmers is still low. A survey on plant parasitic nematodes, banana weevils, and selected soil factors was done to analyse their effect on the abundance of TCB and NTCB. Soil and banana root samples were surveyed from heterogeneous on-farm orchard conditions in smallholder farms. Composite banana root samples and composite soil samples were collected from banana orchards already established by farmers. A total of 1,280 *genets* from 20 orchards were surveyed. Composite soil samples were analysed for pH, potassium, phosphorous, nitrogen, and organic matter. Endo-parasitic *Helicotylenchus multinctus*, *Platylenchus goodeyi*, *Radopholous similis* and *Meloidogyne spp* were isolated from the composite root samples. Banana weevils were captured using the disc-on-stamp and split-pseudo stem traps. Redundancy Analysis (RDA) and logistic regression were run to ascertain the relationship between variations in biotic [Nematodes and weevils] and abiotic [pH, K, Av.P, N, and OM] factors affecting the abundance of the banana type. Canonical eigenvalues showed that both biotic and abiotic variables significantly affected the abundance of TCB and NTCB banana types. Abundance of TCB was influenced by the banana weevil ($P<0.05$) than it was by nematodes in the same farmers' fields. Infestation with nematodes for TCB and NTCB banana types was not different (P-value <0.05). The banana weevils were significantly (P-value <0.05) distributed within the districts. Relative abundances for the pH, phosphorous, potassium, nitrogen (%), organic matter (%) within districts were significant (P-value <0.05). Variations in soil pH and nitrogen availability resulted in significant interactions ($P<0.05$) that affected the abundance of the TCB types more than their contribution to the abundance of NTCB. The awareness that the interactions between nematodes, banana weevils, phosphorous, nitrogen, potassium and pH determine the abundance of banana types is important in shaping the adoption and production of the adopted banana technology. Moderation of pH, K, Av.P, N, and OM for soil fertility, and reduction of the abundance of nematodes and weevils below the threshold, will enhance banana production among small-holder farms in Uganda.

Keywords: abiotic, adoption, banana distribution, biophysical interactions, biotic, tissue culture banana

5.1. Background

The banana is a perennial monocotyledonous herb whose importance and level of production are vindicated by bananas' distinctive support to food, feed, and fuel and, fibre production in East Africa (Van asten *et al.*, 2011). Most production of the banana takes place in homestead gardens where the production fields are non-uniform but heterogeneous (Komarek *et al.*, 2013). Due to harmful biotic and abiotic interactions, banana production is susceptible to yield decline in some agro-ecological zones in Uganda since the 1940s (Ayuke *et al.*, 2011; Pawar and Shah, 2009). In other studies Nyombi (2013), and Arinaitwe *et al.* (2014), farmers cite soil fertility decline, as well as pests and diseases as factors responsible for yield decline. Efforts to solve the problem through the use of organic and mineral fertilizer applications have achieved little success. Banana yield declines provoked scientific research on technologies to solve the pest-disease-yield challenge worldwide. TCB technologies were introduced in Uganda increase the yield and production of the banana. However, adoption of TCB technology at smallholder farmer level in Uganda has been slow since the late 1990s, with NTCB production exceeding that of TCB by 83% Gaidashova *et al.* (2009) and Murongo *et al.* (2018).

The biotic and abiotic factors are biophysical environmental aspects surrounding an organism (Mahajan and Tuteja, 2005). They influence the survival, development, evolution, some of which lead to the destruction of interacting organisms Ayuke (2019), and Speijer (2017) Variability in mineral nutrients, organic matter and human migrations occasionally affect banana production in east African countries (Wachira *et al.*, 2013). The banana weevil, *Cosmopolites sordidus* (Germar) of the order *Coleoptera*, family *Curculionidae* and the parasitic nematodes are biotic risk factors of economic importance in banana production (Gowen, 2005; Nankinga and Moore, 2016). The severity of banana damage by weevils depends on the prevailing environmental factors (Dubois *et al.* 2013; Huang and Yeung 2015). Interactions between the banana weevil, nematodes and other environmental factors may be fatal to orchard development, as they may damage the roots, distort plant stability, and expose the plant to pathogens. The grubs of banana weevil tunnel the corms causing decay and exposing the plant to fungal infection. Nematodes clog into the root and corm tissue causing topling as a result of destruction of roots (Alou *et al.,* 2014; Ocan *et al.,* 2008). For tropical crops such as banana, nematode parasitism in roots is characterized by simultaneous infestations by several genera including *Radopholus similis, Pratylenchus goodeyi, Helicotylenchus multicinctus,* and *Meloidogyne spp* as the most common nematodes found in banana plantations at different altitudes in Africa. Most investigations have concentrated on yield loss factors in bananas. The investigations often consider single-constraint-on station trials with very few studies focusing on multifaceted constraints in homestead gardens (Sabiiti *et al.,* 2016). Interactions between such complex factors need to be adequately investigated to provide answers for the surging abundance and low adoption of tissue culture technology. The current study sought to determine whether the abundance of TCB or NTCB depends on interactions between banana weevil, nematodes as “biotic factors” and pH, nitrogen, potassium, phosphorus and organic matter as “abiotic factors” factors.

5.2. Materials and methods

5.2.1. Sites description

The study was undertaken in western Uganda districts of Mbarara (00°36′S 30°36′E) Ibanda (00°07′S 30°30′E), Isingiro (00°50′S 30°50′E), and Kiruhura (00°12′S 31°00′E) (Figure 5.1). The area is elevated up to 5,900 ft. above sea level. Currently, moist evergreen planted and natural forests, banana plantations, small-scale agriculture, and animal pasturelands, as well as national parks, are the dominant land cover in the area. The area receives bimodal rainfall occurring from March to May and from September to November.

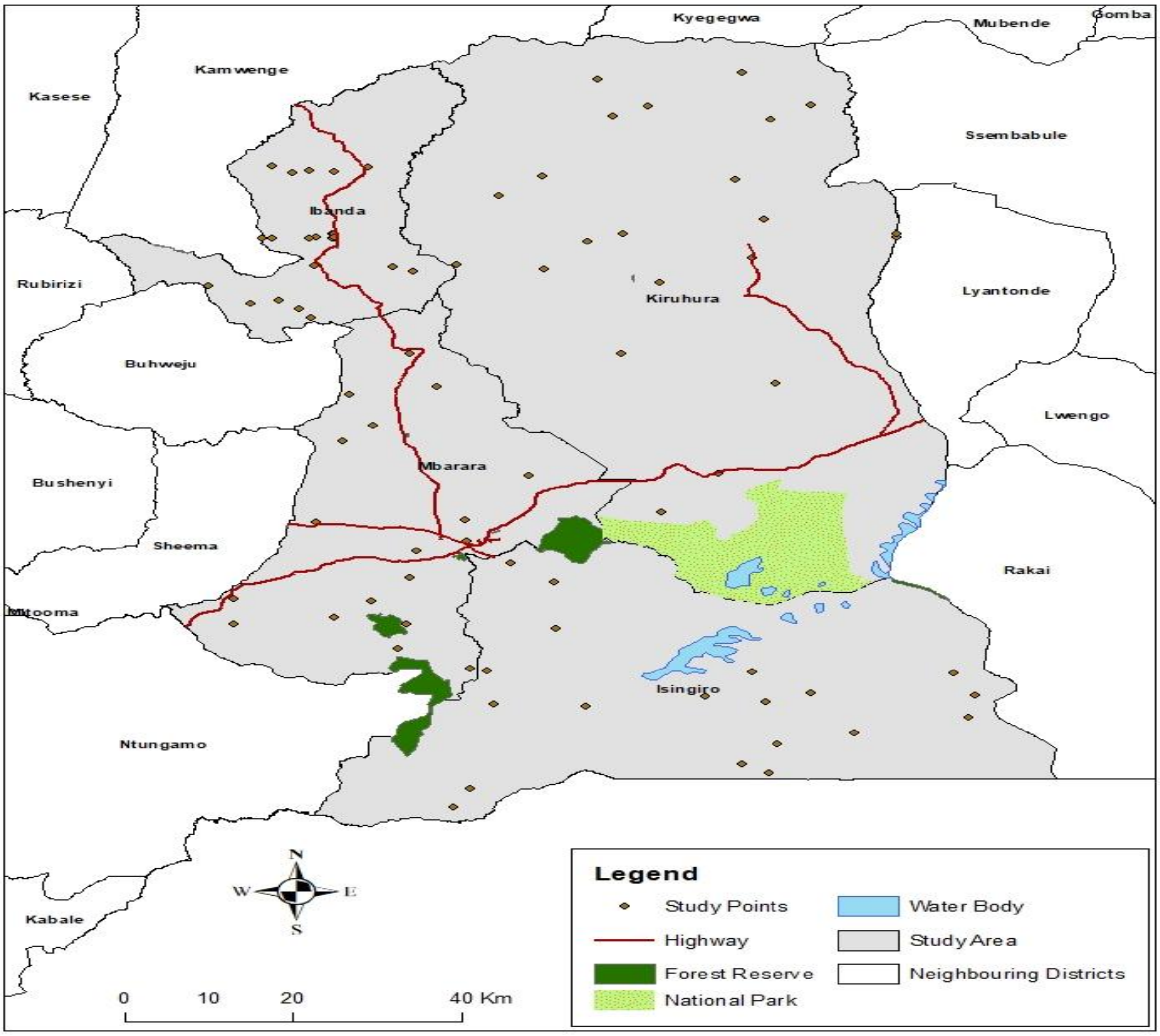

Figure 5.1: location and physical characteristics of the study area

The mean annual rainfall in the region is 1450 mm whereas the mean daily minimum and maximum temperatures are 17 ˚C and 30˚C, respectively (Majaliwa *et al.*, 2010). Farmers following the epipedon characteristics of such as color, thickness, surface gravel and clay and sand mainly classify the soils. The soils are mainly black in color with scattered surface gravels. The soil characteristics vary along the different landscape summits. Averagely, the soils are highly weathered ferralsols (Kyebogola, *et al.,* 2020) which are fertile due to manure deposits especially from historical livestock farming activities. High temperatures assist in inorganic chemical reactions and biological activity (Lysenko, 2004) Undulating hills and shallow flatlands characterise the area. The proportions of water bodies, compared to the arable land vary considerably but about six percent of the total land is covered with lakes, rivers, and gazetted swamps.

The area has good infrastructure such as highway roads and feeder roads, aerodrome, and lakes for road, air and inland water transport which facilitate efficient connectivity, and ease the movement of agro-produce, and the provision of services.

5.2.2 Study design

The biological components of economic importance to this study were banana weevils and nematodes. Composite Soil samples were collected from banana orchards already established by smallholder farmers. Composite root samples for extraction of nematodes were obtained from banana genets already established by the farmers. Weevil traps were set up only on those genets around which soil samples and root samples were collected in the same fields to establish the average weevil density in the plantations. Twenty (20) orchards were purposively selected by taking five farms per district from Mbarara, Ibanda, Isingiro, and Kiruhura districts on the basis that the orchards had tissue culture and NTCB types. A mat is horticultural term that specifically refers to the clump formed by the rhizome, the fruit-bearing stem and the suckers of banana. This is sometimes called a *stool*, but the botanical term is of the stool or mat is a *genet*. Five *genets* per orchard were randomly selected. Five roots per *genet* were obtained from each orchard. The five roots per *genet* were put together to form a composite sample such that, each orchard per district provided five samples for nematode extraction. The composite root sample was standardized to a five-gram weight root sample. The nematode counts were nested with nematode genera and banana type for a sampled location

5.2.3 Banana weevil population density determination

Two basic approaches were used to quantify the banana weevils; the Disc on Stump (DOS), and the Split Pseudo Stem (SPS) traps. The two approaches were used to maximise capture of banana weevils. The DOS was suitable for old genets with harvested stumps while the SPS was suitable for genets that are young; where there has not been any harvest done to create stumps. The DOS was made by cutting a harvested stump, 5-10 cm above ground, and placing a 15-30 cm thick pseudo stem disc on top of the stump. The DOS traps' lengths were limited to 30 cm long and placed horizontally onto the harvested stump surface. The SPS was made from pseudo stem pieces split longitudinally and placed near a target plant with the split surface inverted onto the ground. Five traps each for DOS and SPS were randomly laid in each of the five selected plantations per district. The weevils were collected after 24, 36 and 48 hours to maximise duration and catch of trapped weevils (Jallow and Achiri 2016). The totals for the three collections were put together to form one single *genet* count. The average banana weevil density were collated to tissue culture and NTCB on which the trap was set to determine effect of the relationship on the abundance of the banana type.

5.2.4 Nematode population density determination

The samples were collected twice per month, for two months during a rainy season, and two months in a dry season. Nematodes were extracted from fresh banana roots following the modified Baermann's Funnel technique (Coyne *et al.,* 2007). Collecting samples more than once, and at different climatic conditions was meant to maximize extraction of nematodes. This is because some nematode characteristics such as size, surface structure and motility are shaped by time, plant and [soil] sample composition, compactness and organic matter content

(EPPO, 2013) all of which could be affected by climatic conditions. The modification of Baermann's Funnel technique was devised to facilitate the collection of large numbers of nematodes in a small volume of water with the slightest of plant fragments present (Staniland, 1954). This study followed details of modification described by Adl (2008).

5.2.5 Soil sampling

Soil sampling was done using the soil auger at a depth of 32 cm to obtain samples for soil nutrient determination. Random soil samples were taken in a zigzag pattern, and 20 samples from homogeneous [with no major variation in slope, drainage, or previous off-farm input history] farmers' field were collected and formulated into a composite soil sample for analysis. Soil samples were collected from 20 orchards, selecting five orchards per district basing on the homogeneity observations. From each selected orchard, six composite soil samples were obtained bringing the total number of composite soil samples for the four districts to 120 samples.

5.2.6 Nitrogen, phosphorous and potassium determination

The soil samples were air-dried, pounded in a ceramic motor with a pestle, screened through a 2.0mm sieve to remove any debris. Available nitrogen (%) was determined by Kjeldahl digestion and semi-micro Kjeldahl distillation. Available phosphorous was extracted using Bray 1, and determined using the molybdenum blue colorimetric method and quantified by the spectrophotometer (model TUV, 2500; TRULAB INDIA) while potassium was extracted using ammonium acetate at neutral pH and determined using a flame photometer (model; ANALAB Flame Photometer, FlameCal10, India).

5.2.7 Organic Matter

Soil organic matter was determined by first determining soil organic carbon (Wakley and Black, 1934). The resultant soil organic carbon was converted to soil organic matter by multiplying the SOC by the "van Bemmelen factor" of 1.724 (Douglas, 2010).

5.2.8 Soil pH

The pH meter method was used in the determination of soil pH. About 20 gm. of 2.0 mm air-dry soil was weighed and placed into a beaker. To the air-dry soil in the beaker were added 50ml of distilled water and the mixture stirred with a glass rod thoroughly for about 5 minutes. The mixture was kept for half an hour. Meanwhile, the pH meter (Model **PX-104,** Panomex Inc., India) was turned on and allowed to warm up for 15 minutes. The glass electrode was standardized using standard buffer of pH = 7 and calibrated with the buffer pH = 9.2. The electrodes were dipped in the beakers containing the soil-water suspension with constant stirring. While recording pH, the pH meter was switched to pH reading 30 seconds before sample pH recording was done. The pH values were recorded to the nearest 0.1 unit (Okalebo, 2002).

5.2.9 Data analysis

The total Nematode counts, banana weevil counts, potassium (ppm), phosphorous (ppm), nitrogen (%), organic matter (%) data was normalised to a Z-score; [mean=0 and standard deviation=1] hence all the variable values were on an equal pedestal. The standardised data was subjected to Detrended Correspondence Analysis (DCA) using R i386.3.3.1 version to direct whether Redundancy Analysis (RDA) for the constrained variables was possible (Table 2). Data was further subjected to correlation and covariance analyses to identify the factors affected by multi-collinearity (Figure 1). In each case where multi-collinearity occurred, only one variable was selected for further analysis unless there were justifications for the retention of a given factor. The study sought to determine whether the abundance of TCB and/or NTCB is dependent on variations between selected "biotic factors" and "abiotic factors". Logistic regression was used to model a relationship between the total Nematode counts, banana weevil counts, potassium (ppm), phosphorous (ppm), nitrogen (%), organic matter (%) as predictor variables and the abundance of a dichotomy of TCB and NTCB as categorical response variables. The terms fitted in the model were, Constant + Banana weevil population + nematode Counts in 5g of composite root sample + pH + percentage nitrogen + phosphorous (ppm) + potassium (ppm) + percentage organic matter. The logistic model was run using Genstat; VSNi, 2012 version.

5.3 Results and discussion

5.3.1 Abundance of biotic and abiotic factors

Results in Table 5.1 summarised descriptive and inferential data for banana weevils, *H. multicinctus, R. similis P. goodeyi* and *Meloidogyne spp*., and their relative abundance in TCB and NTCB types in the districts of Ibanda, Isingiro, Kiruhura and Mbarara. Both banana types were infested with banana weevil and nematodes with different abundances across all the districts.Although there were more nematodes extracted from TCB than the NTCB, the infestation for both banana types were significant (P-value <0.05). There were more banana weevils captured in Isingiro and Kiruhura districts than in Ibanda and Mbarara districts. However, the distribution for banana weevils was significant (P-value <0.05) within the districts. According to Nyombi (2013), bananas are susceptible to banana weevil and nematode attack under a wide range of interacting conditions. Therefore, the type of banana, the location and the variations in abundance of soil factors form part of the wide range of conditions that may enhance attack on bananas by the weevils.

Table 5.1: Descriptive and inferential prevalence of biotic and abiotic parameters from banana orchards surveyed from Western Uganda

	Ibanda	Isingiro	Kiruhura	Mbarara	P-value-x	SEDy	TCB	NTCB	Pvalue-x	SEDy	1	2	3	4	Pvalue-x	SEDy
Nematode_D	890a	768b	729c	715d	***	0.43	850a	591b	**	1.5	486b	53d	235a	247c	***	0.53
Weevils_D	97d	132a	124b	118c	***	0.81	113a	131b	*	1.15	118a	118a	118a	118a	NS	0.71
pH	5.8b	6.4ab	6. 4a	6.7a	*	0.16	6.3	6.6	*	0.16	6.4a	6.4a	6.4a	6.4a	NS	0.17
P(ppm)	56.04d	60.32c	89.32a	82.56b	***	0.4	70.5b	75.89a	**	0.02	72.07a	72.07a	72.07a	72.07a	NS	0.38
K(ppm)	262.09d	566.02a	371.6c	414.74b	***	0.03	400.4b	411.6a	NS	0.56	403.6a	403.6a	403.6a	403.6a	NS	0.09
N (%)	0.19b	0.26a	0.18b	0.18b	*	0.11	0.11a	0.19a	NS	0.01	0.20a	0.20a	0.20a	0.20a	NS	0.1
OM (%)	5.05b	5.53a	4.86c	4.03d	***	0.01	4.90a	4.78a	NS	0.06	4.87a	4.87a	4.87a	4.87a	NS	0.06

SED_Y and P-value-x Significant effects were obtained from one-way analysis of variance: *, **, *** significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively; Means followed by the same letter in each column are not significantly different at $p \leq 0.0\ 5$ using Tukey HSD. Nematode_ D and Weevil_ D refer to nematode and banana weevil densities, respectively, OM= Organic Matter, numbers 1, 2, 3, and 4, represent *R. similis, P. goodeyi, H. multicinctus, and Meloidogyne spp* in that strict order

Table 5.1 shows that the relative abundances for the pH, phosphorous, potassium, nitrogen (%), organic matter (%) within districts were significant (P-value <0.05). The pH recorded for NTCB orchards was 6.6 that was closer to the neutral. This pH is preferred for the growth and productivity of banana since it does not contribute to the highly acidic soils (pH<4) (Nyombi, 2013) that have been known to significantly affect banana yields since the 1940s. Phosphorous levels were higher for the districts of Kiruhura (89.32 ppm) and Mbarara (82.56 ppm), respectively and slightly lower for Isingiro and Ibanda (Table 5.1). Slightly higher concentrations of Phosphorus (411.67 ppm) were prevalent in NTCB orchards compared to the TCB orchards (400.37 ppm). As supported by (Doran, *et al.,* 2003), the presence of phosphorous in smallholder banana orchards may arise from the utilisation of old and dry banana leaves as mulches. The soil potassium concentrations (ppm) were higher in NTCB compared to TCB orchards. Nitrogen contents varied slightly from one district to another, with Isingiro district recording the highest mean percentage of 0.25%. The nitrogen content recorded for NTCB orchards was higher (0.2%) compared to (0.1%) found in the TCB orchards (Table 5.1). The organic matter content was higher for Isingiro and Ibanda districts than for the districts of Kiruhura and Mbarara. Such differences may be due to the location and the orchard management dynamics by the smallholder farmers. However, the differences in the availability of nutrients, could be attributed to the location of the orchards (Jallow and Achiri, 2016) and the cultivar efficiency with probably TCB slightly more efficient in utilisation of the nutrients than NTCB.

5.3.2 Biotic and Abiotic factor relationships

Table 5.2 shows the DCA segments rescaled to four iterations. The gradient axes of DCA1 to DCA4 is less than four, thus supporting RDA.

Table 5.2: Detrended correspondence analysis with 26 segments, rescaling of axes with 4 interactions

	DCA1	DCA2	DCA3	DCA4
Eigenvalues	0.3809	0.3343	00.16108	0.08508
Decorona values	0.3935	0.3208	0.06535	0.04533
Axis Lengths	2.5618	2.7338	1.70473	1.64218

*Decorana, refers to Detrended correspondence analysis.

The correlation matrix (Figure 5.1) indicate that both positive and negative correlations between study parameters were weak, further supporting RDA and Logistic regression. Weak correlations indicated that there was no multicollinearity among independent variables.

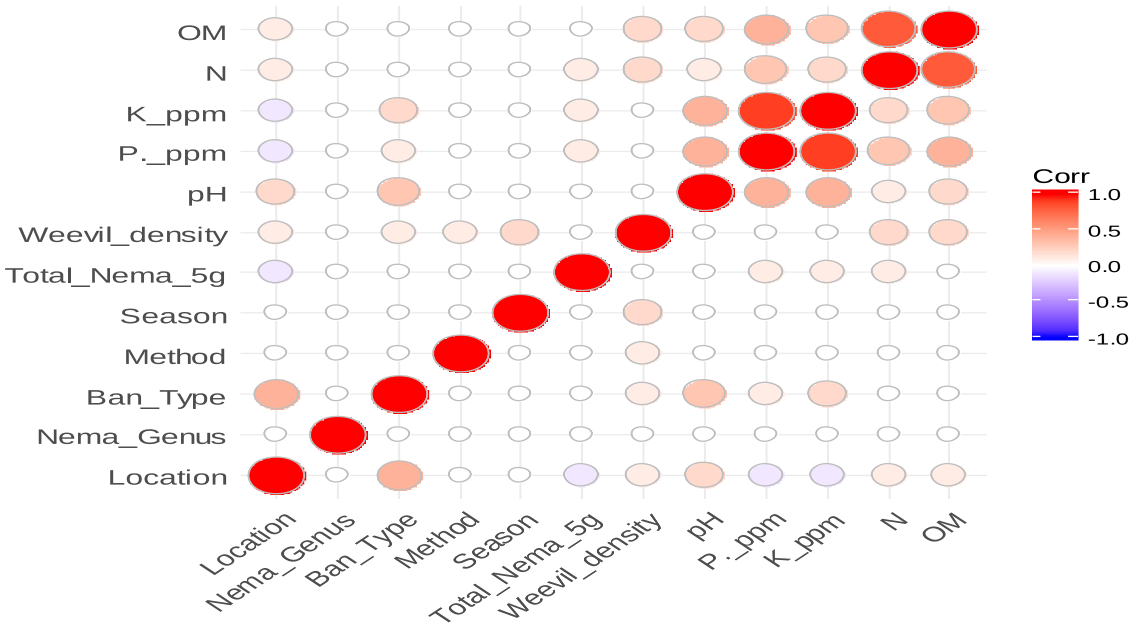

Figure 5.2: Correlation coefficients for the P-values for the biotic and abiotic parameters*:*

Positive correlations are displayed in red and negative correlations in blue. The intensity of the colour and the size of the circles are proportional to the correlation coefficients for the P values The initials "Location" represent the districts, "Nema_Genus"=Nematode genera, "Ban_Type"= the Banana type, "Method"= DOS and SPS,, "Season"= the dry and wet seasons, "Total_Nema_5g"=the nematode population density in 5g of the root sample "Weevil_density"=banana weevils desnsity "P_ppm" represents the measure of phosphorous in parts per million, K_ppm, is potassium in parts per million, "N" is the measure of percentage nitrogen, " OM" is the measure of percentage organic matter.

Organic matter and nitrogen available in the soil were collinear (Figure 5.2). The organic matter content cannot be increased without simultaneously increasing its nitrogen content hence the interdependence of carbon and nitrogen cycles on soil organic matter (Yagi, *et al.*, 2005), organic matter plays other roles important in banana production. The sum of all canonical eigenvalues showed that both biotic and abiotic variables influence the distribution of banana types in the farmers' fields (Table 5.3).

Table 5.3: Eigenvalues for the constrained and unconstrained environmental variables.

RDA (X = Response, Y = Explanatory)				**Eigenvalues for constrained axes**		**Eigenvalues for unconstrained axes**	
	Inertia*	Proportion	Rank	RDA1	RDA2	PC1	PC2
Total	1.45598	1.00000					
Constrained	0.14474	0.09941	2	0.12201	0.02273	1.1638	0.1475
Unconstrained	1.31124	0.90059	2				

*Inertia is variance

The eigenvalues for the first and second RDA constrained to location and the type of banana in the farmers' fields were 0.122 and 0.023, respectively, explaining 14.54% of the variance (1.4598) in the distribution of banana cultivars vis-à-vis interactions that are either biotic or abiotic (Figure 5.2). The x-axis (PC1) explains 79.7%, and (PC2) 10.1% of the total inertia, respectively. However, the percentage variance explained by the y-axis RDA1 (8.3%) and RDA2 (1.5%) is minute. The proportion of unconstrained variation (90%) is larger than the constrained variation, implying environmental constrained factors are largely non-redundant. For this study therefore, the interactions between the banana type and parasitic nematodes, banana weevils, soil pH, phosphorous, potassium, nitrogen and organic matter, [explanatory variables] were non-redundant in affecting the abundance of banana types in Western Uganda.

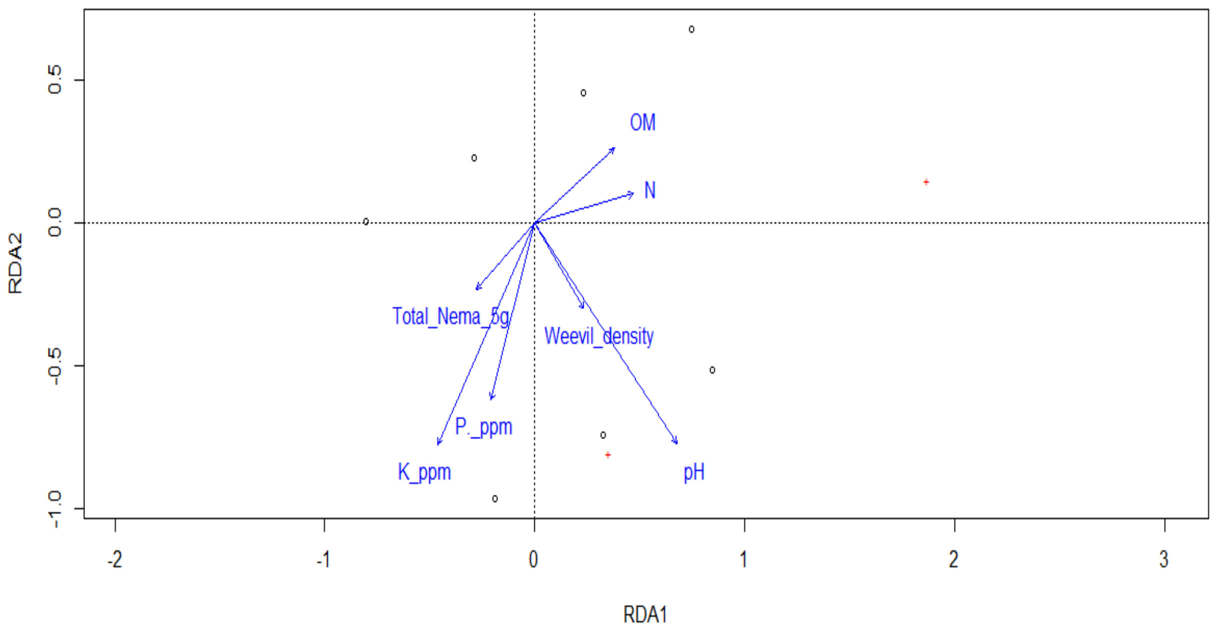

Figure 5. 3: RDA with two response variables; Banana type and location

Parameter representations; Total Nematode counts in 5g of composite root sample (Total_Nema_5g), potassium ppm (K_ppm), phosphorous ppm (P.ppm), banana weevil population density (Weevil density), percentage nitrogen (N), percentage organic matter (OM). The red and grey plain dots represent the banana type and location, respectively.

Results presented in figure 5.3 indicate a positive relationship between organic matter, nitrogen, and pH with banana weevils. Variations in pH enhance the population of banana weevils, than the variations between organic matter and nitrogen. At the average pH of 6.4, and the average percentage of organic matter and nitrogen of 5% and 0.2%, respectively, the population of banana weevil was high (Table 5.1). Increase in weevil population results in high banana orchards', and the *genets*' infestation hence low banana productivity (Twesigye, *et al.*, 2018).

There was a negative relationship between phosphorous (ppm) and potassium (ppm) and parasitic nematodes. Variations in the concentrations of Potassium and to lesser extent phosphorous negatively affected the abundance of parasitic nematodes. The concentration of phosphorous and Potassium was high at 70.5 (ppm) and 400.3 (ppm), respectively (Table 2), in TCB orchards. However, the concentration (ppm) of the same elements in NTCB was higher, at 75.89 (ppm) and 411.66 (ppm), respectively. Declines (ppm) of phosphorous and potassium (Table 5.2) corresponded with high population of nematodes in the same location. Consequently, nematodes are destructive to banana orchards thus, the increased nematode populations negatively affects the TCB abundance. The environment of the crop plays a significant role in the availability of soil nutrients and the abundance of organisms important in that crop's productivity (Risede, 2010). The availability of phosphorous, Potassium, organic matter and nitrogen enhance the location of the orchards. The location may determine the abundance of weevils and nematodes.

5.3.3 Significance of factors in banana distribution

Table 5.4 shows varying interactions between biotic and abiotic factors determining the abundance of the banana type as a response variable. The dichotomy was between the NTCB and TCB distribution. High banana weevil and nematode population reduced the abundance of TCB ($P<0.001$). Variations in soil pH and N (%) significantly ($P<0.001$) influenced the distribution of tissue culture type. Soil pH was a significant factor in the distribution of banana due to its ability to influence the availability of other interacting banana weevil and phosphorous. At pH above 8.0 phosphorous becomes unavailable to plants, but may also be a reason for the increase in the total population of the nematodes in the field. The significance of nitrogen cannot be dissociated from the high percentage of organic matter availability. Organic matter has a favourable effect upon soil physical properties, hence the amount of organic carbon in soil serves indirectly as a measure of available nitrogen. The critical value for total nitrogen in soils for East African Highland banana in Uganda on average is 0.2%. The estimated value for nitrogen in TCB fields is deficient to sustain the production of the banana type.

Banana weevils significantly affected the production of both TCB (P=0.001), and NTCB (P=0.006). (Table 5.4.). Nematodes on the other hand, significantly (P=0.001), affected the production of TCB, but their effect appeared insignificant (P=0.097) for NTCB production. The results implied that individually, banana weevils negatively affect the production of both tissue culture and NTCB orchards, although the effect is more serious with TCB types. Presence of nematodes in larger populations and their interaction with banana cultivars poses a greater negative effect on the TCB types compared to NTCB culture banana types. Therefore, the adoption and distribution of NTCB cultivars were linked to the banana weevils' presence in the farmers' fields (P<0.05) than they were linked to nematode population in similar fields (p>0.05).

The study established that the production of TCB is significantly affected by plant-parasitic nematodes that live in soil and roots. The most damaging species of the nematodes in banana production spend most of their life cycle in the roots and corms tissues (Yagi, et al., 2005). Multitudes of individual nematodes of various genera develop in root tissues and consequently alter the physical and functional aspects of the plant the effect of which is reduced productivity of the plant. The proliferation of endo-parasitic plant-parasitic *R. similis, P. goodeyi, H. multicinctus* and *Meloidogyne ssp* in the roots of banana disrupt the uptake of phosphorous, potassium and nitrogen, in a well-manured orchard. Whereas, *R. similis, P. goodeyi, H. multicinctus* and *Meloidogyne ssp* form poly-specific communities of millions of individual nematodes within the roots, they may not develop a resting stage for long-term persistence in soils. The study established that a strong relationship existing between nitrogen and organic matter in the farmers' orchards (Figure 5.2). This relationship was significant in the production of TCB (P=0.001), and NTCB (P=0.009). The significance is; an indicator of sufficient organic matter in the farmers' orchards in western Uganda. Application and accumulation of organic matter is a soil prophylaxis that may be efficient in slowing down population dynamics of endo-parasitic *R. similis, P. goodeyi, H. multicinctus* and *Meloidogyne ssp* in banana production.

Table 5.4: interactions between biotic and abiotic factors in the distribution of the banana type

TISSUE CULTURE BANANA PARAMETERS														
	Biological parameters							**Chemical parameters**						
Parameter	**Const.**	**Weevils**	**Const.**	**TNC(5g)**	**Const.**	**pH**	**Const.**	**OM (%)**	**Const.**	**N (%)**	**Const.**	**P (ppm)**	**Const.**	**K (ppm)**
Est.(E)	-8.10	$3.2*10^{-3}$	-7.61	-14.9	-9.10	0.21	-7.4	-0.05	-6.88	-4.19	-7.74	$4.56*10^{-4}$	-7.73	$6.4*10^{-5}$
s.e	0.082	$5.37*10^{-4}$	0.04	$3.19*10^{-5}$	0.27	0.04	0.15	0.03	0.14	0.72	0.05	$3.95*10^{-4}$	0.06	$1.03*10^{-4}$
t(*)	-102.34	5.96	-184.5	-3.42	-34.14	5.34	-50.74	-1.84	-48.35	-5.83	-163.18	1.16	-137.8	0.62
t pr.	<.001	**0.001**	<.001	**0.001**	<.001	**0.001**	<.001	0.066	<.001	**0.001**	<.001	0.248	<.001	0.534
^E	$3.02*10^{-4}$	1.00	$4.8*10^{-4}$	1.00	$1.12*10^{-4}$	1.24	$5.85*10^{-4}$	0.95	$1.03*10^{-3}$	0.02	$4.35*10^{-4}$	1.00	$4.38*10^{-4}$	1.00
NON-TISSUE CULTURE BANANA PARAMETERS														
	Biological parameters							**Chemical parameters**						
Parameter	**Const.**	**Weevils**	**Const.**	**TNC (5g)**	**Const.**	**pH**	**Const.**	**OM (%)**	**Const.**	**N (%)**	**Const.**	**P (ppm)**	**Const.**	**K (ppm)**
Est.(E)	-7.33	-20.70	-7.63	$3.50*10^{-5}$	-6.92	-0.09	-7.60	0.02	-7.81	1.53	-7.48	-23.40	-7.73	$6.4*10^{-5}$
s.e	0.08	$6.08*10^{-4}$	0.0414	$2.11*10^{-5}$	0.24	0.04	0.13	0.03	0.13	0.59	0.04	$3.75*10^{-4}$	0.06	$1.03*10^{-4}$
t(*)	-94.49	-2.75	-184.59	1.66	-29.01	-2.4	-57.32	0.82	-61.9	2.61	-176.44	-0.52	-137.8	0.62
t pr.	<.001	**0.006**	<.001	0.097	<.001	**0.016**	<.001	0.41	<.001	**0.009**	<.001	0.604	<.001	0.534
^E	$6.57*10^{-4}$	1.00	$4.84*10^{-4}$	1.00	$9.86*10^{-4}$	0.91	$5.02*10^{-4}$	1.02	$4.07*10^{-4}$	4.62	$5.65*10^{-4}$	1.00	$4.38*10^{-4}$	1.00

Parameter descriptions; Constant-(Const.), Banana Weevil density-(Weevils) Total Nematode counts in 5g of composite root sample-TNC(5g), Percentage organic matter in the soils - OM(%), percentage nitrogen availability-N(%), phosphorous in parts per million-P(ppm), potassium in parts per million-K(ppm).

Heterogeneity in backyard orchards varies from observable improved fallows, water management channels, and plant biodiversity within the orchards. The study established that banana weevil affected the productivity of both TCB and NTCB with the effect appearing rather more severe with TCB types. Improved fallows may clean the soil of the endo-parasitic nematodes thus reducing re-infestation of plantlets when the fallowed gardens are replanted with banana. It practical to remove systematically the volunteer suckers as they can host and multiply residual nematode populations but the practice may not be effective in removing the banana weevil eggs, and the adults which, unlike the nematodes, can survive better and longer in the soil. Therefore, the introduction of cleaned tissue culture plantlets will be infested faster from the pest reserves resting in the soil. Section 2.1 indicates that farmers' orchards are situated in undulating hills. According to Majaliwa *et al.* (2010) the area also receives bimodal rainfall patterns with the minimum range between 800-1500 mm. This rainfall results in runoff water that must be managed by smallholder farmers. Runoff water is a source of contamination for both nematodes and banana weevil. Some farmers dig channels up to 100cm deep around plots efficiently prevent the dispersion of not only the plant-parasitic nematodes but also the adult, larvae and eggs of banana weevils swimming in runoff from contaminated orchards to relatively sanitized orchards. Where isolation channels are dug by farmers, re-infestation of banana fields by parasitic nematodes and weevils is delayed, however, further studies need to be conducted on whether re-infestation by these two risk factors is rather virulent in cleaned TCB than in the conventional suckers. Finally, smallholder farmers rarely plant sole banana crop. A variety of so many other crops including weeds exist in the production process of the banana at the field level. Non-host and alternative-host plants contribute to soil sanitation and prophylaxis against banana weevils and nematodes. Non-host plants break the cycle of both the banana weevil and the nematode. Sanitation plant-parasitic nematodes in banana agro systems is achievable through planting nematode-resistant plants as rotational or associated crops. Alternative host plants share the burden of the banana weevil and the nematodes on the main crop by enabling a wider ecological niche. Plant biodiversity in banana cropping systems promote more beneficial soil biota some of which such as. Fungi are antagonistic to nematodes (Seenivasan, 2017; Hennessy *et al*., 2005; Sjakir *et al*., 2015; Lambert and Bekal, 2002).

Smallholder banana orchards have diverse plant biodiversity as part of heterogeneous environment. Plant biodiversity is a further step towards sustainable control of nematodes. Some Nematodes species have a broad host range thus lessening the risk of perishing with the one host, however, as they move from host to host, such nematodes get exposed to predators or pathogens, and while they may survive in the alternate host they reduce the burden on the banana. The banana weevil is monophagous (Nyombi, 2013), hence solely depends on the banana plant corms, pseudo stems, leaves and roots. This behavior contributes less to reducing the burden of banana weevil whether on TCB or NTCB. This forms a basis to why the banana weevil is linked to destruction of banana in smallholder banana orchards. However, the weevil aggressively destroys the TCB upon re-infestation than the conventional suckers. The causes for this variation need to be further investigated.

5.4 Conclusion

Under heterogeneous conditions in smallholder banana farms, high banana weevil and nematode population densities independently limit the abundance of both TCB and NTCB. Variations in soil pH and Nitrogen availability result in significant interactions ($P<0.05$) that affect the abundance of the TCB types better than their contribution to the abundance of NTCB. The study further established that nematodes are widespread in western Uganda, with *H. multicinctus* and *P. goodeyi* as the most prevalent. TCB orchards were more infested with nematodes than NTCB orchards in a similar environment. NTCB orchards had higher counts in parts per million of phosphorus and potassium than the TCB orchards. The awareness that the interactions between nematodes, banana weevils, phosphorous, nitrogen, potassium and pH determine the fate of banana production is important in shaping the adoption and production of the adopted banana technology. Comprehension of the interactions that affect the abundance of banana types should form a basis for developing strategic and affordable management approaches to prevent faster degeneration of banana orchards. Soil nutrient treatments that enhance interactions that reduce the abundance of nematodes and weevils below the threshold and mitigate the effects of the nematodes and weevils parasitic to bananas while sustaining soil fertility should be developed for production of banana amongst smallholder farmers in Uganda.

CHAPTER SIX

EFFECT OF COMBINING ORGANIC AMENDMENTS ON BIOTIC AND ABIOTIC FACTORS THAT INFLUENCE PRODUCTION OF TISSUE CULTURE BANANA IN WESTERN UGANDA

Abstract

Effect of integrated soil amendments on biotic and abiotic factors and their association with TCB growth and yield were studied under randomized experiments established at Uganda Martyrs University Farm from November 2017 to February 2019. Banana cultivars Mpologoma and Kibuzi were treated with 0, 100g, 300g, and 500g of NPK, 0, 5, 10, and 15 litres per plant of sole liquid cow dung and banana brew bio-slurries. Additionally, mixtures of 100g of NPK in 5L of each bio-slurry, 300g of NPK in 10L of each bio-slurry, and 500g of NPK in 15L of each bio-slurry were applied to the two cultivars. Observations were made on the variation of growth parameters, soil analysed for potassium and phosphorous, percentage nitrogen and organic matter at 3, 6, 9, and 12 Months after Planting (MAP). Composite root samples were analysed for *Helicotylenchus multicintus*, *Radophorous similis Pratylenchus goodeyi*, and *Meloidogyne spp.* Disc on Stamp and Split Pseudo stem traps were laid to capture banana weevils. Phytochemicals were extracted from composite root samples by maceration at room temperature with n-hexane (50ml) for 48 hours and sample extracts were analyzed by GC-MS. ANOVA statistics were run at F pr <0.05 critical value using Genstat VSNi, 2016 version. Small amounts of organic and inorganic soil amendments equally caused normal TCB growth up to 12MAP, provided nutrients at variable depths, Cv. Kibuzi was more infested with *H. Multicinctus* than cv. Mpologoma while Mpologoma was more infested with *P.goodey*i. Generally, Mpologoma was found more prone to all nematode infestation. Application of organic amendments significantly ($p<0.001$) reduced the population of the nematodes and banana weevils compared with the control. The study established that there were variations in the occurrence of phytochemical compounds in the root of the banana of different cultivars as a result of treatments. The analysis of the n-hexane extracted root exudates showed absence in the control sample of phytochemicals with positive bioactivity against nematodes. Similarly, there were phytochemicals present in the control sample but generally absent from the rest of the treatment samples. Some of the phytochemicals particularly present in the control and absent in the treatment samples are probably nematode attractants and this could explain the high nematode densities recorded in the control plots. Co-application of NPK and organic bio-slurry, and the application of 10 liters of sole banana brew bio-slurry and cow dung bio-slurry resulted in proper growth of the TCB while minimizing the effects of banana weevils and nematodes in banana production. The knowledge of use of bio-slurries restricts the wastage of crop bi-products to support crop production.

Keywords; bio-slurry, organic amendments, banana brew, cow dung, phytochemicals, integrated

6.1. Introduction

There has been a general decline in banana growth and productivity across the globe that is large, attributed to pests and diseases (Nelson *et al.,* 2006). Other studies, further identified the decline in the soil fertility (Van Asten *et al.,* 2011) poor crop management (Bongers *et al*., 2012), failure to get clean planting materials (Bwogi *et al*., 2014) and lack of inputs (Alex *et al.,* 2016), as drivers that affect banana growth and productivity. Among the pests that affect tissue culture, banana growth and productivity include parasitic nematodes and the banana weevil (Alex *et al.* 2016). TCB technology approach has been one of the ways projected not only to draw smallholder farmers out of poverty and enhance food security across the East African countries (Kalyebara *et al.,* 2007; IFAD, 2009; MAAIF, 2011) but also solve the pest and disease challenge in banana production (Mbaka *et al.*, 2008). Subsequently, banana tissue culture planting materials have been developed. The plantlets have been accessible from both government and private companies in Uganda (Kikulwe, 2016). However, in their choice, the smallholder, farmers tend to ignore the current TCB planting materials and are wedged to the conventional banana suckers (Murongo, *et.al.*,2018). Farmers have a bias that banana plantations developed from TCB deteriorate soon after the first or second production cycle of orchard establishment (Qaim, 1999). Other than biological facets, physical-chemical factors, and soil exhaustion (Alou *et al*., 2014) are major players in the banana orchard deterioration. Amidst these challenges, appropriate simple and affordable solutions to curb banana plantation deterioration appear elusive to the smallholder farmers in sub-Saharan Africa (Salami *et al*., 2010). The purpose of this study was to assess the potential of local integrated soil amendments expected to supply nutrients for banana growth and in curtailing the populations of nematodes and banana weevils associated with TCB orchard destruction.

The integrated soil amendments have an influence on both biotic and abiotic factors in relation to the TCB growth and productivity (Thangavelu and Mustaffa, 2005; Mbaga *et al.*, 2014; Jansa, 2014). According to Rizvi *et al*. (2012), the population of the nematodes is higher in warmer areas than the cold places, therefore, soil amendments that minimise temperature can reduce parasitic nematode survival. According to Hussein (2012), nematode occurrence in a crop is enhanced by the type of soil and soil management by the farmers, as well as host plant roots. Dupont *et al*. (2009) showed that application of compost boosts plant immunity to resist against nematodes, but most importantly, it introduces some antagonistic nematode agents in the soil.

Farmers in developing countries normally apply synthetic nematicides in order to control nematodes (Benard *et al.,* 2017; Agbenin, 2011). Despite their role against such parasites, research has shown that some chemicals have adverse effects on human (Kumar *et al*., 2012), animals and the environment (Mahmood *et al.,* 2015). Pesticides are costly to most farmers and very few can use them sustainably (Bui *et al*., 2016), hence use of cultural practices in field management. The cultural practices involve application of crop residues, green manures, animal, industrial and agriculture wastes (Crow and Dunn 2016), to improve on the soil structure and fertility. Some organic amendments produce *nema-toxic* compounds and other bio-control agents that reduce nematode multiplication but improve plant growth (Erick, 2014).

The banana weevil, parasitic nematodes and soil nutrient instability may cause faster deterioration of TCB orchards. However, the same factors may react differently under different conditions within which the TCB grows. The study compared the effect of integrated application of organic slurry from the animal source and from the plant source, respectively. The integration included NPK both as a sole application and in mixed proportions with the bio slurries. The effect of the treatments was observed on the variation of potassium (ppm), phosphorous (ppm), nitrogen (%) and organic matter (%) in an experimental field where tissue culture plantlets of cv. Mpologoma and cv. Kibuzi were used. The effects of the treatments on general banana plant growth and on the populations of banana weevils and nematodes were compared. The banana weevil, nematode and soil nutrient variations in selected treatments were examined and related to growth and yield parameters of the banana.

6.2. Methods and Materials

6.2.1. Experimental site

The study was carried out at Uganda Martyrs University (Latitude: 0° 00' 10.80" N Longitude: 32° 00' 32.40" E) from November 2017 to August 2019. The predominant soil type of the area are ferralsols (Isabirye *et al.*, 2004). The area receives a mean annual rainfall of about1390 mm per annum. The minimum temperature range between 20-23°C and a maximum range of 24-30°C. The selected site had no history of bio-slurry application.

6.2.2. Study design treatment combination and agronomy

Treatments were laid in a split-split- plot design (Sokal & Rohlf, 2015). Each of the cultivars; *Mpologoma* and *Kibuzi* formed a major block. Each block received eight treatments (split-plot). The treatments were applied at different rates (split-split plot) within a plot (Sokal & Rohlf, 2012). The treatments used were three rates of banana bio-slurry, cow dung bio-slurry and recommended rate of NPK. The application of different rates of the bio-slurry was adopted and modified from (Bonten *et al.*, 2014). The eight major categories of treatments were replicated four times to raise 32 replicates and a total of 64 banana plantlets for each block. The field was divided into uniform units to limit any variations so that observed differences were due to true differences between treatments. Treatments included sole inorganic fertilizer (NPK), sole cow dung bios-slurry and sole banana brew bio-slurry at a rate of 5 L, 10 L and 15 L. Sole cow dung bio-slurry was obtained by mixing 25 kg of fresh cow dung in 100 liters of water and fermented for three weeks. Sole banana bios-slurry was a residue obtained from the process of distillation of ethanol brewed from banana juice and sorghum 25 kg of the residue was mixed with 100 liters of water and the solution fermented for three weeks. The fermentation for the bio slurries was done temperature and rainfall conditions described under the study area above. The treatments were applied by injection method in a 1.5m x 1.5m x 0.45m planting holes. The bio slurries were applied one week before the planting of plantlets to allow the slurries to blend with the surrounding soil temperature, and soil. The plantlets were planted at space of 3m x 3m between rows and between plants. The tissue culture plantlets were introduced to the field after completing 12 weeks of the primary hardening process, with each plantlet possessing 4-5 leaves and a well-developed root system. The plantlets were planted at the onset of rains. Mulching was done at 1.7m away from the plant to prevent accumulation of organic matter around the banana plants. Data was collected at 12 months after planting (MAP).

6.2.3. Soil abiotic data collection and laboratory analysis

Primary data was collected on variations on potassium (ppm), available phosphorous (ppm), nitrogen (%) and organic matter (%). Composite soil samples were collected around plantlets that received similar treatment rates. Every treatment as split into three rates provided three composite soil samples, giving a total of 18 samples collected at 12 MAP. The samples were collected 30cm away from the plant stems (horizontally) starting at three months after planting. Soil samples were collected at varying depth intervals hence; 0-8cm, 8-16cm and

16-30cm. This was because banana plants possess a shallow rooting system of which almost 90% of the rooting system is found in the top 30cm of the topsoil. The soil samples were air-dried to minimise biodegradation, pounded in a motor with a pestle, screened through a 2.0 mm sieve to remove any debris then subjected to analysis for a spectrum of characteristics pertinent to this study. Available nitrogen (%) were analysed by Kjeldahl digestion and semi-micro Kjeldahl distillation as described by Bremner (1960). Available phosphorous were extracted and determined using the molybdenum blue colourimetric method and quantified by the spectrophotometer while potassium were determined using flame photometer. (Bremner, 1960). Soil pH was measured in a soil to water ratio of 1:2.5 using a glass electrode pH meter (Anderson and Ingram, 1993). Total organic matter was determined by the colorimetric method (Schulte *et al.*, 2009).

6.2.4. Biotic data collection

6.2.4.1. Banana weevil density

Number of weevils for the banana plants per cultivar, per treatment starting at 6 MAP, 9 MAP and 12 MAP, respectively was established following the methods and materials described under section 5.2.3. However, for this objective, the data collected on banana weevil was to identify which soil amendment, other than supplying nutrients had the controlling effect on the banana weevil population in the field.

6.2.4.2. Nematode population

Nematode population per cultivar per treatment was determined from a composite root sample obtained by extracting 5 roots from a *genet* under the same treatment rate at 3MAP, 6MAP, 9MAP, and 12MAP. Similar procedure described under section 5.2.4 was followed in determining the nematode density. *H. Multicinctus, R. Similis, Meloidogyne spp* and *P. goodeyi*, were the four genera extracted from the roots in the experimental field. Several studies Chitamba *et al.* (2013), Speijer (1999), Speijer (2017), Swennen (2006) indicated that the four genera are parasitic nematodes of economic importance to the banana across the globe.

6.2.5. Plant growth and yield measurement

Plant growth was compared among treatments. Pseudo stem girth, number of suckers per plant per treatment per rate, size of the middle leaves (length and width), height of the mother plant were all measured up to 9MAP. Plant growth analyses were modified from (Ravi *et al.*, 2013). Specimens were harvested at specific 3, 6, and 9MAP, divided into their respective parts, and dried at 70°C in a hot air oven for 48 hours to obtain dry weight (W). The area of each selected leaf was calculated from the formula below.

$A = L * B$……………………………………………..…………………...Equation 5

Where; L=length of the lamina (in centimetres) of the middle leaf at 9 MAP, B= breadth of lamina (in centimetres) at its widest point. Leaf area was calculated in order to provide later data for establishment of the relative growth rate of the plants that received treatment.

Relative Growth Rate as attributed to the treatments (*RGR*) was estimated from the formula;

$$RGR = \frac{L_n W_2 - L_n W_1}{tMAP_2 - tMAP_1}$$ ……………………………………...………………Equation 6

Where; W_1 and W_2 are natural logarithms of plant dry weights at times $tMAP_1$, and $tMAP_2$, respectively. The above plant growth parameters were expected to vary with the different treatments. The variability was an independent and better predictor for resource capture and usage from the applied amendments that could predict persistence.

Yield was measured mainly using selected above ground parameters. Bunch weight (kg), weight of fingers of the first cluster (kg), number of clusters per bunch, number of fingers per first cluster were determined at 12MAP by weighing and direct counting. Pseudo stem girth was determined by measuring the circumference (cm) of the banana stems at 3MAP, 6MAP, 9MAP and 12MAP to give the average pseudo stem girth at 12MAP. The total number of leaves was determined by direct counting of the leaves before removal of dry and damaged leaves at 3MAP, 6MAP, 9MAP and 12MAP to give the cumulative average number of leaves at 12MAP. The number of suckers were determined by direct counting the suckers that developed on the mother plant at 6MAP, 9MAP and 12MAP to give the average total number of suckers at 12MAP.

6.2.6. Profiling secondary metabolites

Composite root sample was obtained by correcting discrete root samples from the banana plants that received a particular amendment and were of the same cultivar. The composite root samples of cv. Mpologoma were then linked to similar treatments for cv. Kibuzi. Therefore, cross-combined composite samples were obtained for laboratory analysis. The samples were corrected from the field within twenty-four hours to keep them fresh as much as possible and avoid loss of some volatile phytochemicals. The composite root samples were homogenised by maceration in the laboratory.

6.2.6.1. Analysis of phytochemical compounds

The banana plant composite root samples were dried at 40°C in an oven, powdered, and extracted (5g) exhaustively by maceration at room temperature with n-hexane (50ml) for 48 hours. The solvent was removed under vacuum in a rotary evaporator to yield dried crude extract that was dissolved in dichloromethane (DCM). The residue was then re-extracted with methanol (50ml) for 48 hours, filtered and the filtrate evaporated under vacuum in a rotary evaporator. The hexane and methanol residues were also dissolved in DCM and mixed in 2ml vial for Gas Chromatography-Mass Spectrometry (GC-MS) analysis.

6.2.6.2. Gas chromatographic conditions

The DCM sample extracts were analyzed by GC-MS, Shimadzu and model TQ 8040 triple quadruplet equipped with a split injector (Split ratio 1:0) at 250°C. The injected volume was 1µL, the column (ZB-5SMi, 30 m × 0.25 mm × 0.25 µm). The column temperature program was employed in which the initial temperature was 80°C, held for 20 min, followed by a temperature increase at 5°C min/min to 180°C, then held for another 5 min to 250°C, and 15 minutes to 310°C. Helium was introduced as the carrier gas at an average linear velocity of 44.5cm/sec, prime pressure of 500-900. The flow control mode had pressure at 99.8kPa, total flow (50mL/min), column flow (1.46mL/min), linear velocity (44.5 cm/sec), and purge flow (5.0 mL/min). Data were processed on GC-MS and phytochemicals were identified by comparison with the National Institute of Standards and Technology (NIST) in GC-MS library[6].

6.2.7. Data analysis

Descriptive and inferential analysis for variations of potassium, phosphorus, nitrogen and organic matter against rate of soil amendment application, nutrient variation by depths with time after planting (AP), variation of soil nutrients by depth within cultivars was done using Genstat VSNi, 2016 version. Variations of nematodes and banana weevils within cultivars, treatment type and rate were run for ANOVA. Growth progression with time after planting, Variation of growth parameters by cultivar, and yield parameters were analysed for variance. Extracted secondary metabolites were subjected to descriptive observation. The significant effects of all the data analysed for ANOVA were determined at ($p \leq 0.05$) critical value.

[6] NIST is a physical sciences laboratory and a non-regulatory agency of the united states department of commerce, whose mission is to promote industrial competitiveness

6.3. Results and Discussion

It was hypothesized that integrated soil amendments in TCB production have no effect on the biotic and abiotic interactions that are significant to TCB orchard degeneration, growth and productivity.

6.3.1. Variation of potassium, phosphorus, nitrogen and organic matter with rate of amendment application

The application of soil amendments at different rates significantly ($P<0.001$) increased the concentration of potassium, phosphorus, nitrogen and organic matter at all depths of extraction compared to the basal nutrients quantities and the control (Table 6.1). Generally, the amendment rate of 300 g of NPK in 5 litres of bio slurries and 300 g grams of a sole inorganic amendment increased proportions of potassium, phosphorus, nitrogen and organic matter at different depths of extraction. Accumulation of K (ppm) was high in the 8-16 cm depth for treatment rates of 500 g of NPK and the concoctions of 500 g of NPK in 15 litres of organic amendments. Proportional concentrations of P (ppm) were quite low in the upper 0-8 cm depth but significantly increased in the 8-32 cm depths for the 100g sole NPK treatments. N (%) and OM (%) were high in the upper 0-16 cm depths, for all sole organic treatments as well as the inorganic and organic amendment concoctions. Compared to basal concentrations, Soil chemical variations in the topsoil (0–32cm) were lower for the control for potassium, phosphorous nitrogen and organic matter. This could be due to the utilization of the nutrients by the growing banana cultivars.

Table 6. 1: Effect on soil K (ppm) P (ppm) N (%) and OM (%) variations in the topsoil (0–30cm) of different rates of amendments' application

	Potassium (ppm)			Phosphorous(ppm)			Nitrogen (%)			Organic Matter (%)		
Extraction depths	0~8	8~16	16~32	0~8	8~16	16~32	0~8	8~16	16~32	0~8	8~16	16~32
Basal Nutrient quantities	0.34*	0.64*	0.56*	0.07*	0.07*	0.45*	0.8*	0.6*	0.42*	0.55*	0.67*	0.46*
Control	0.28	0.5	0.41	0.05	0.04	0.74	0.51	0.41	0.41	0.67	0.44	0.43
100g of NPK in 5L of soil organic amendment	0.55	0.59	0.46	0.4	0.5	0.57	0.73	0.4	0.43	0.7	0.7	1.34
300g of NPK in10Lsoil organic amendment	0.48	0.61	0.85	0.06	0.48	0.52	1.48	0.82	0.86	0.69	0.37	0.64
500g of NPK in 15L soil organic amendment	0.92	0.9	1.07	0.12	0.61	0.76	0.74	1.01	1.01	0.89	0.71	0.75
100g of NPK	0.93	0.88	0.88	0.43	1.15	1.06	0.76	0.41	0.41	0.7	0.5	0.65
300g of NPK	0.71	0.61	0.44	0.29	0.42	0.53	0.86	0.84	0.83	0.62	0.52	0.74
500g of NPK	0.73	0.85	1.12	0.17	0.78	0.74	0.64	1.17	0.85	1.16	1.25	0.96
5L of soil organic amendment	0.57	0.57	0.63	0.13	0.7	0.76	0.55	0.41	0.44	0.68	0.67	0.91
10L of soil organic amendment	0.51	0.68	0.41	0.15	0.99	0.96	1.52	0.83	0.84	0.85	0.47	0.77
15Lof soil organic amendment	0.98	1	0.99	0.29	0.5	0.58	0.58	1.02	1.32	0.81	0.75	0.8
Grand mean	0.7	0.72	0.75	0.22	0.7	0.73	0.74	0.7	0.7	0.78	0.66	0.82
F pr.	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
cv%	0.3	0.1	0	197.4	0	0.1	0	0	0	0	0	0

F-pr = Fisher's Probability; CV%= Percentage Coefficient of Variations. The numbers with (*) are not part of the grand mean calculated the treatment rates

The study has demonstrated that the application of local organic amendments significantly contributed to the availability of potassium, phosphorous, nitrogen and organic matter. There were no observable symptoms to suggest acute potassium, phosphorous, nitrogen and organic matter deficiency for the first cycle of the two cultivars' growth. The results are supported by Taulya (2013), that potassium, phosphorus, nitrogen and organic matter are the key nutrient requirements that sustain production of TCB, the deficiency of which reduces bunch weight, and prolongs the crop cycle duration.

6.3.2. Nutrient variation by depths with time after planting (AP)

Potassium, phosphorous, nitrogen and organic matter variations with treatments were examined by extracting soil samples at different depths at intervals of three months after planting. Figure 6.1, shows the variations of P (ppm), K (ppm), N (%) and OM (%) at 3MAP, 6MAP, 9MAP and 12MAP in the 0-30 cm topsoil.

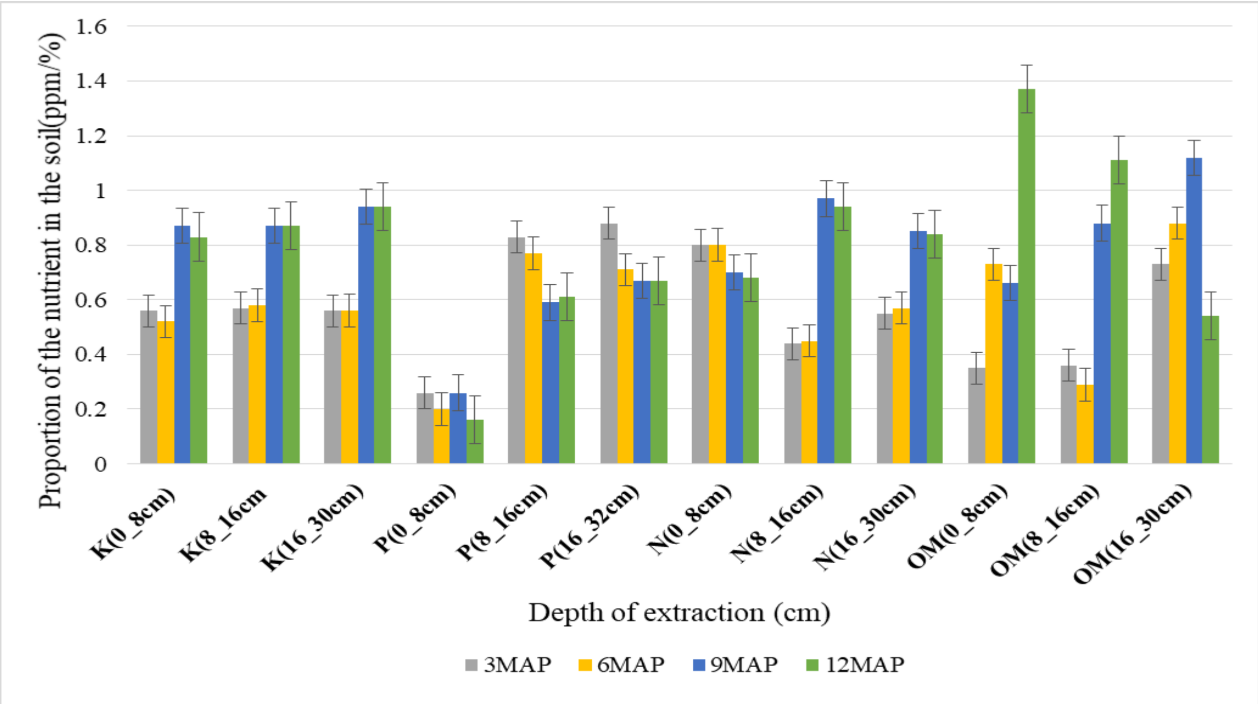

Figure 6. 1: Effect of amendments on the soil nutrient variations in the topsoil (0–30cm) with time after planting

Concentration (ppm) of phosphorus, was low in the 0-8 cm layer but increased in the subsequent layers for a similar period after planting (figure 6.1). Potassium levels increased for the third and fourth quarter i.e. 6MAP and 12MAP, respectively. Percentage nitrogen and organic matter (OM) increased with progression of MAP, with OM reaching the highest percentage at 12MAP in the 0-8 cm depth and progressively declined 16-30 cm depth. The increased concentration of organic matter and other minerals may be the result of accumulated organic materials decomposed arising from weeded plants, and pruned leaves.

The treatments were applied by sub soiling and according to Bakhtiari, *et al*. (2014), the method of application of fertilizer may determine the availability of nutrients in that fertilizer, the concentrations of which may be high in the zone where the fertilizer is applied. Nitrogen accumulated more in the 16-30 cm depths perhaps due to mineralization processes that lead to ammonium ions. These ions are soluble and easily leached into the lower layers of the soil (Manaroinsong *et al*., 2017; Vinícius *et al*., 2018).

The current study established that progression in MAP significantly increased nutrients' availability for banana use. However, with time, the concentrations of phosphorus in the 0-8 cm zone and organic matter in the 0-8, and 8-16 cm zones decreased thus effect for P(ppm) and N (%) in the 0-8 cm, respectively were insignificant (overlapping error bars). Treatments sustainably supplemented the soil nutrient support system significantly for a complete cycle of the banana growth. The results agree with the study hypothesis that integrated soil amendments in TCB production have an effect on potassium, phosphorus, nitrogen and organic matter interactions, which, according to Taulya (2013) and Vinícius *et al*. (2018), their deficiency is a greatly contributes banana orchard degeneration.

6.3.3. Soil chemical variations in the topsoil (0–30cm) within the cultivars

Figure 6.2 shows the variation of nutrients by depth within Mpologoma and Kibuzi cultivars. The proportions of K (ppm), P (ppm), N (%) and OM (%) in the soil varied slightly differently at different depths for the two cultivars. Proportions for K (ppm) were lower in the 0-8 cm and 8-16 cm depths, respectively for the Kibuzi variety. phosphorous proportions were lower for the 0-8cm, for both Mpologoma and Kibuzi cultivars. The percentage of nitrogen progressively increased as the depth increased in the field for Kibuzi cultivars.

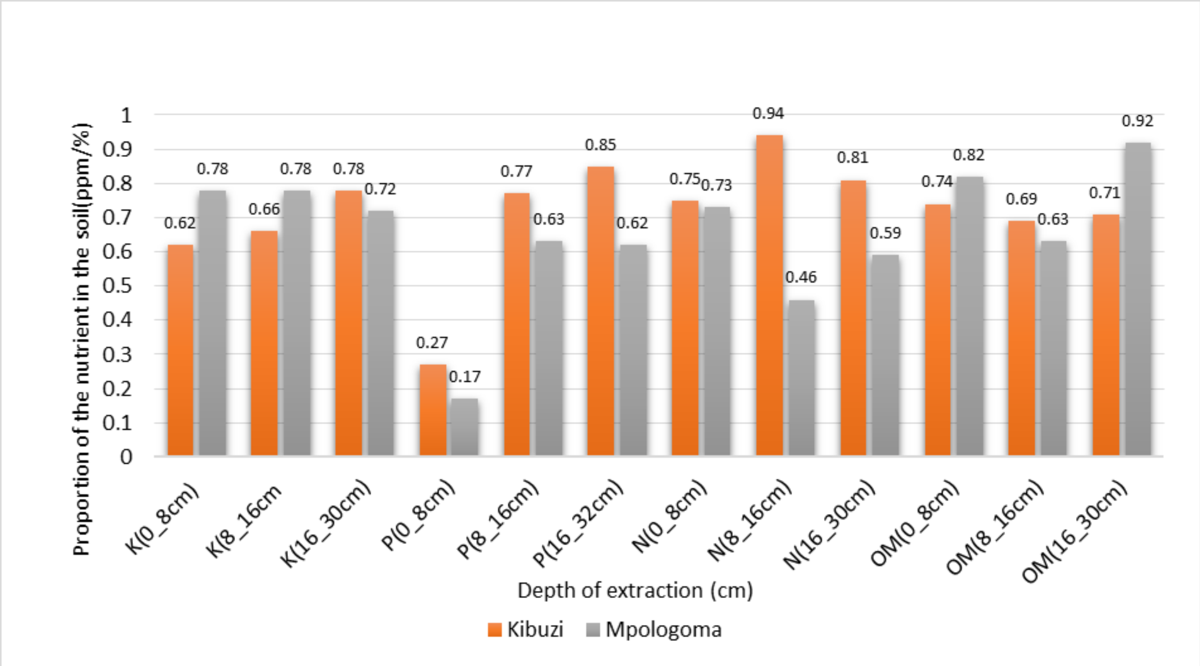

Figure 6. 2: Effect of amendments on the soil nutrient variations in the topsoil (0–30cm) within the cultivars

The nitrogen percentage progressively declined from the 0-8 cm to 16-32 cm depths, with the lowest percentage availability in the 8-16cm depth for Mpologoma. Other than K (ppm) in the 0-8cm, nutrient concentrations for K (ppm), P (ppm), N and OM (%) remained slightly higher in Kibuzi than Mpologoma. According to Wakshum and Sharma (2018), soil depth is essential for the availability of nutrients for plants. The study corroborates findings by Wakshum and Sharma (2018) implying that depths between 0-32 cm is essential for the availability of potassium, phosphorus, nitrogen and organic matter for the growth of Mpologoma and Kibuzi cultivars. The concentration of potassium and phosphorous for both varieties was high in the 0-8 cm, and 8-16 cm zones, however, the 16-32 cm depth was more critical for the availability of phosphorous, nitrogen, and organic matter for the two cultivars. Besides, the study results indicated that Mpologoma cultivar may be a heavy feeder of the nutrients under study compared to Kibuzi. Utilization of K (ppm) in the 0-8cm and 8-16 cm depth was higher for Kibuzi than it was for Mpologoma (Figure 6.2) while the utilization of P (ppm) was higher for Mpologoma for all depths compared to Kibuzi variety. Such differences may be explained by the genetic stature of the tissue culture cultivars. The study results are supported by Khan *et al*. (2011) who found out that TCB processes induce genetic variations, which in the case of this study may be extended to utilization of potassium, phosphorus, nitrogen and products of organic matter decomposition. In another study by Kayongo, *et al.* (2015), the varietal differences were extended beyond the nutrient utilization to drought avoidance and its related mechanisms.

6.3.4. Treatments' effect on the variation of plant-parasitic nematodes within the cultivars

Figure 6.3 shows the variations in nematode infestation by the four genera (*H. multicinctus*, *Meloidogyne spp*, *R. Similis* and *P.goodeyi)* of the nematodes within the cultivars.

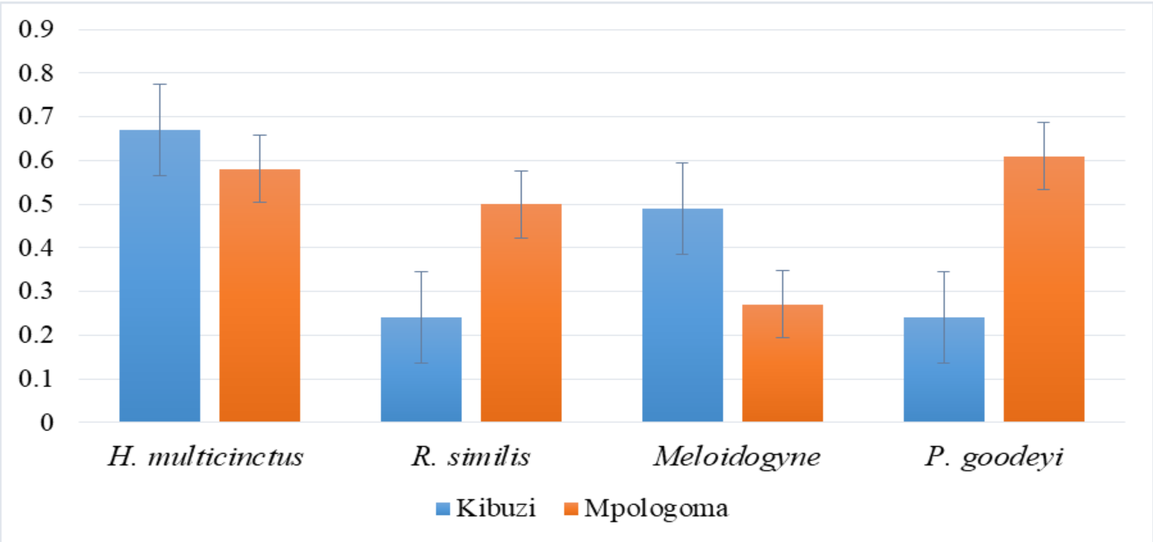

Figure 6.3: Effect of amendments on the relative distribution of parasitic nematodes in two banana cultivars

There were substantial variations for *H. multicinctus, Meloidogyne spp, R. similis and P. goodeyi* within the cultivars (Figure 6.3). Whereas both cultivars were prone to parasitic nematode attack, current results concur with (Tropentag, 1999), that tissue cultured bananas, have been found to be more susceptible to nematode destruction in the first crop cycle. There were, however, existing variations in quantities of the type of nematode that infested the cultivar type. *H. multicinctus* and *Meloidogyne spp* were found more prevalent in Kibuzi cultivar. *P. goodeyi* and *R. similis* were found more prevalent in Mpologoma cultivar. The Mpologoma cultivar was more infected with *H. multicinctus*, *Meloidogyne spp*, *R. similis* and *P. goodeyi* than Kibuzi (Figure 6.3). Studies by Gaidashova *et al.* (2009), indicated similar trends of distribution of the nematodes, although, they were not conclusive on whether specific cultivars are more resistant to nematode attack and multiplication. Pre-existing and /or passive structural features such as root thickness, waxiness of the cuticle, , degree of secondary wall thickenings, and vascular structure, have been reported to contribute to plant resistance to pathogens including plant-parasitic nematodes (Doughari,2009; Hutcheson, 1998). In the current study, the response of the cultivar to applied amendments probably explained the differences in the nematode variations.

6.3.5. Nematode variation by Type of treatment application

All treatment types at various rates significantly ($p < 0.001$) reduced the nematode population compared to the control (Table 6.2). *H.multicinctus* and *P.goodeyi* had a higher mean value for the total population, with the highest counts arising from the control plots. Mean values for *R.similis* and *Meloidogyne* were lower than *P.goodeyi* and *H.multicinctus* (Table 6.2). The mean population for *H.multincictus* from the 100 g of NPK in 5L of banana brew bio-slurry (0.76), 300 g of NPK in10L of the banana brew bio-slurry (0.81) and 300 g of NPK (0.84) were high. Similarly, for cow dung bio-slurry, the high populations were recorded for the 300g of NPK in 10L of cow dung and 300g of NPK (0.84), respectively. The treatments did not have a strong controlling effect on *H.multinctus*. In fact, application of 300g of NPK increased the population of *R.similis* to (2.12) up from the control value (0.22). There was an increase in population of *P.goodeyi* where 500g of NPK in 15L of Banana brew bio-slurry (1.18).

Table 6.2: Variation in numbers of different nematode species in plots treated with banana brew bio-slurry and the cow dung bio-slurry at different rates

Nematode genus	H.multicinctus		R. similis		P.goodeyi		Meloidogyne spp	
Treatment Source	**BBS**	**CDBS**	**BBS**	**CDBS**	**BBS**	**CDBS**	**BBS**	**CDBS**
Control	2.03	1.2	0.22	0.21	0.76	0.78	0.26	0.25
100g of NPK in 5L of soil organic amendment	0.76	0.45	0.46	0.22	0.86	0.26	0.26	0.22
300g of NPK in10Lsoil organic amendment	0.81	0.84	0.23	0.22	0.25	0.26	0.26	0.21
500g of NPK in 15L soil organic amendment	0.4	0.34	0.69	0.45	1.18	0.22	0.22	0.21
100g of NPK	0.35	0.35	0.25	0.25	0.26	0.26	0.21	0.21
300g of NPK	0.84	0.84	2.12	2.12	0.23	0.23	0.31	0.31
500g of NPK	0.37	0.37	0.2	0.42	0.23	0.23	0.26	0.26
5L of soil organic amendment	0.31	0.4	0.18	0.23	0.24	0.26	0.25	0.84
10L of soil organic amendment	0.24	0.23	0.23	0.23	0.26	0.26	0.26	0.48
15Lof soil organic amendment	1.57	0.58	0.22	0.17	1.73	0.29	0.16	2.01
Grand mean	0.778	0.57	0.48	0.43	0.6	0.305	0.245	0.51
F pr.	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Key: BBS-banana brew bio-slurry, CDBS-cow dung bio-slurry, F pr; Fisher's probability

Application of sole 15L of banana bio-slurry increased the population of *Meloidogyne* (2.01), *P.goodeyi* (1.73) and *H.multicinctus* (1.57). Banana bio-slurry performed better in reducing the *Meloidogyne*, and *R.similis populations,* while cow dung bio-slurry performed better in minimizing the population of *H.multicinctus* and *P.goodeyi.* The influence of the treatments was observed from the reduced number of the mean nematode population for all organic amendments. These results agree with Nico, *et al.* (2004), where organic industrial wastes reduced the population of nematodes in potting mixtures. In another study by Farahat, *et al*.

(2012), concoctions of cow dung and neem reduced the populations of *Meloidogyne incognita* in tomato.

The results indicated that the numbers of nematodes were significantly higher in plants treated with the addition of 300g NPK than the control. This may be attributed to the alterations in the ecosystem within and around the root of the plant. For instance applications of nitrogen-rich fertilizer may alter soil nematode food webs in a continuous cropping system (Pan *et al*., 2015), and the alterations can significantly increase nematode diversity (Farahat *et al*., 2012).

6.3.6. Banana weevil variation with Type of treatment application

The treatments significantly ($p<0.001$) lowered banana weevil prevalence compared to the control. The banana weevil population in 300g of NPK sole application (1. 10), and in 500g of NPK in 15L of organic amendment (1.23) were above the control counts captured under Split Pseudo stem, for the banana brew bio-slurry (Table 6.3). Similarly, for the same method of weevil capture, the banana weevil population were high for the cow dung bio-slurry (0.84, and 0.74) for the same treatments, respectively. The banana weevil population (3.76) under the 5L of cow dung bio-slurry treatment was the highest capture under Disc on Stamp traps. Compared to other treatments under the banana brew bio-slurry, the 300g of NPK sole application had a high weevil capture (0.74) under the DOS traps. Both banana weevil traps captured a significant amount of weevils and can be used concurrently in banana weevil management in TCB production. Studies earlier conducted by Murongo *et al*. (2019), corroborate these results that for young plantations, the Split Pseudo Stem is a better approach while for harvested, broken or older plantations, the Disc on Stamp is a better approach. The average number of weevils captured under banana brew bio-slurry (0.60, 0.57) for the split Pseudo stem and disc on stamp, respectively, was lower than those for the cow dung (0.65,0.77) for the respective weevil traps (Table 6.3).

Table 6. 3: Variation in numbers of banana weevil in plots treated with banana brew bio-slurry and the cow dung bio-slurry at different rates

	Mean Weevil density by split pseudo stem		Mean Weevil density disc on stump	
Treatment Source	**BBS**	**CDBS**	**BBS**	**CDBS**
Control	0.85	1.17	0.94	0.64
100g of NPK in 5L of soil organic amendment	0.58	0.9	0.47	0.24
300g of NPK in10Lsoil organic amendment	0.38	0.42	0.47	0.47
500g of NPK in 15L soil organic amendment	1.23	0.74	0.47	0.47
100g of NPK	0.38	0.35	0.67	0.47
300g of NPK	1.1	0.84	0.74	0.47
500g of NPK	0.38	0.37	0.57	0.47
5L of soil organic amendment	0.38	0.94	0.47	3.76
10L of soil organic amendment	0.38	0.38	0.47	0.43
15Lof soil organic amendment	0.38	0.42	0.47	0.24
Grand mean	0.6	0.65	0.57	0.77
F pr	<.001	<.001	<.001	<.001

Key: BBS-banana brew bio-slurry, CDBS-cow dung bio-slurry, F pr; Fisher's probability

The study has further established that when compared to the cow dung bio-slurry, the banana brew bio-slurry significantly lowered the banana weevil populations in TCB production for the first cycle of banana growth. The pesticidal action of the organic amendments in this study were largely not known, however, the amendments may have enhanced development of natural enemies against the banana weevil at the egg and larval stages. In a study by Graaf, *et al.* (2008), application of "*machicha*" another product of banana brewing process enhanced the multiplication of *Bauveria bassiana* that was found to be highly infective to banana weevil. Although the pesticidal effects of the bio-slurries and their inorganic mixtures were largely not known Graaf *et al.* (2008), gives an idea on the contribution of the bio slurries in the reduction of banana weevils in TCB production.

6.4. Treatment effect on cultivar growth and yield

6.4.1. Growth progression with time after planting

Application of the integrated treatments resulted in the normal growth of the tissue culture cultivars from the time of planting to first cycle harvest. The growth behaviour for the middle leaf lengths and widths in (cm), pseudo-stem girth and height in (cm), the total number of leaves and total number of suckers at MAP are shown in figure 6.4. Small amount of the treatments did not impede growth for the two cultivars for the first twelve months of plant growth. Leaf lengths and widths responded positively to the treatments. The pseudo stem girth and height progressively increased up to the 12MAP. However, the cultivars produced a large number of suckers as early as the 3MAP.

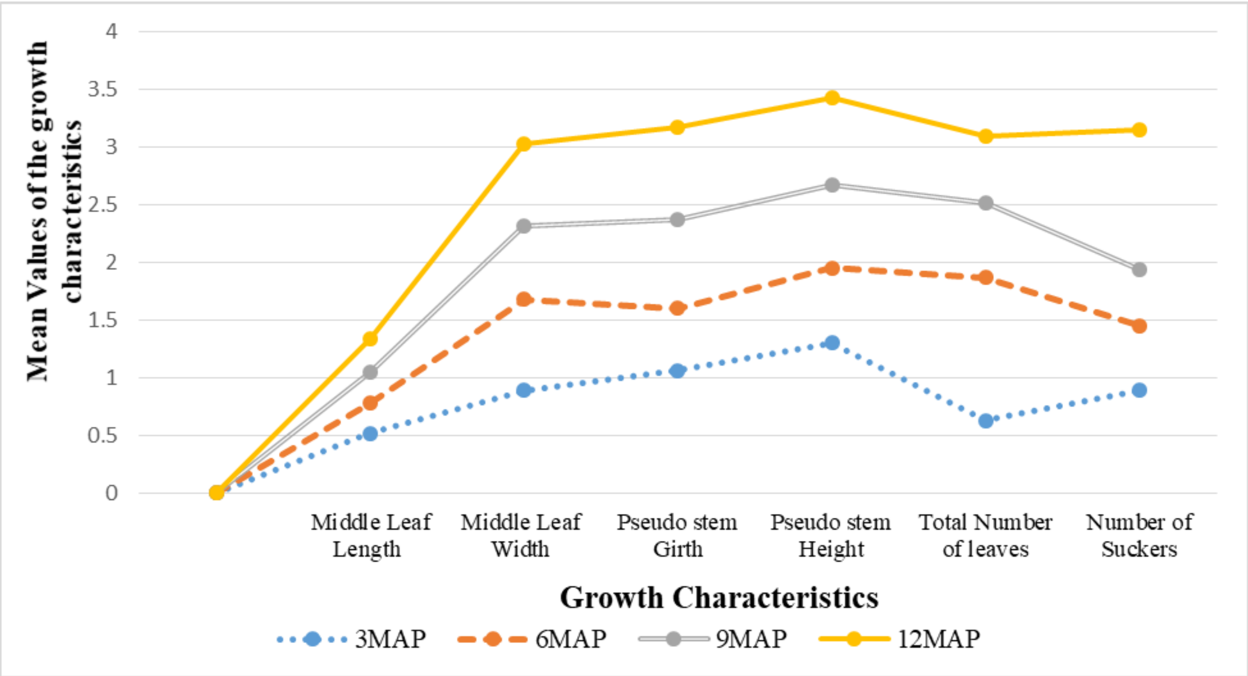

Figure 6. 4: Effect of amendments on the growth parameters of cultivars for 3, 6, 9 and 12 months after planting

The results of the study imply that integrated soil amendments in TCB production have a positive effect on the biotic and abiotic interactions that promote TCB growth and productivity. Studies by Pan *et al*. (2015), and Zhang *et al*. (2018) found that external inputs into the crop production system may be a source of pests such as nematodes, that reduce bananas growth with losses as high as 90% due to toppling Chitamba *et al.* (2013; and Speijer (2017), others have chemical substances that inhibit growth (Pan *et al*., 2015), and yet others are adulterated with plant herbicides which may cause total destruction (Allison, 1973). This was not the case for the treatments used by the study.

6.4.2. Variation of growth parameters by cultivar

The leaf lengths and widths, pseudo stem girth and height, total number of leaves and the total suckers produced varied considerably within the cultivars as shown in (Figure 6.5). Pseudo stem girth responded more differently between the cultivars with Mpologoma producing bigger stems than Kibuzi. Leaves for cv. Mpologoma were narrow and longer than those of cv. Kibuzi. Pseudo stem height was taller for cv. Kibuzi than cv. Mpologoma. The sucker population was high in both varieties with Kibuzi cultivar producing a higher number of suckers per mat. Growth characteristics of the banana are largely attributed the genetic differences, although, the environment within which the crop is grown may moderate the parameters (Khan *et al.*, 2011; Ocan *et al*., 2008; Majid *et al*., 2011). In this study, treatments form part of the environment whose role on growth differences cannot be overruled. Where farmers rely on suckers from their own orchards for propagation of banana (Murongo *et al*., 2018), cv. Kibuzi would be the best alternative due to its capacity to produce many suckers which are essential for propagation of the orchards.

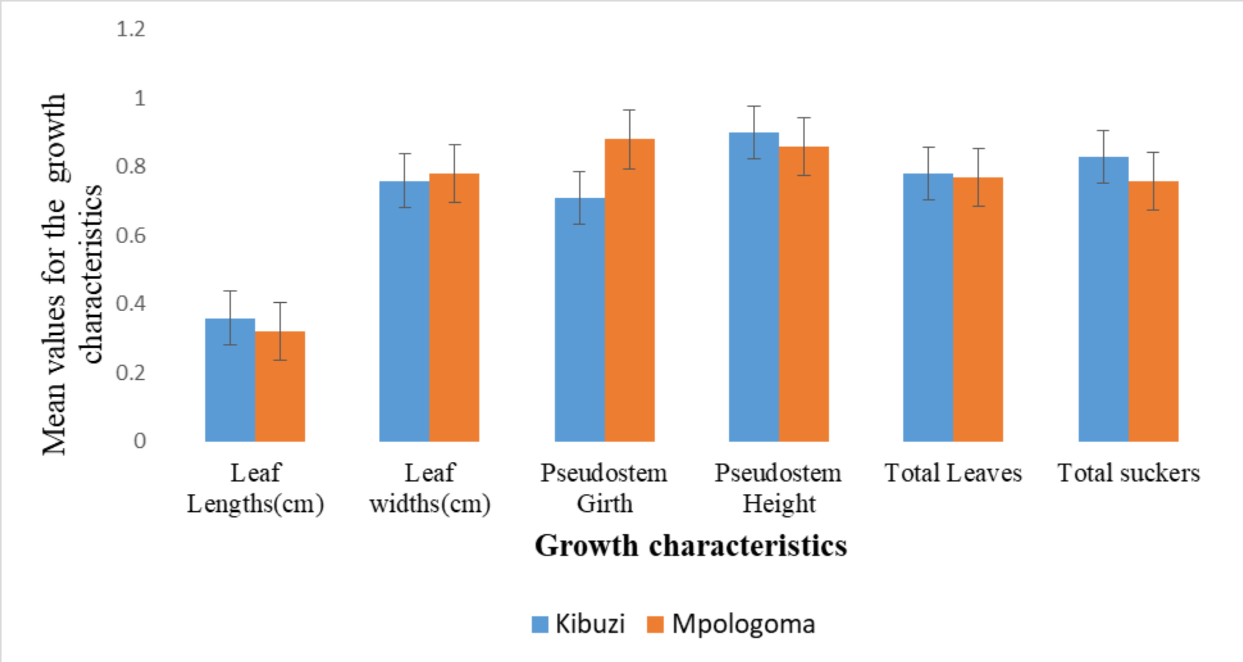

Figure 6. 5: Effect of the amendments on the variations of of growth parameters for two cultivars

The study established that above-ground vegetative growth parameters (leaf lengths, leaf widths, and stem girth) of both cultivars did not vary greatly except the pseudo stem height. Hence, both cultivars can be recommended to the small-scale farmers to be produced under similar treatments used by this study.

6.4.3. Relative growth rate for cv. Kibuzi and cv. Mpologoma

The Relative Growth Rate (RGR) was measured, specifically on leaves other than the whole plant. Growth rate of the banana cultivar Kibuzi under banana brew bio-slurry and its inorganic concoctions slowed down from the 9MAP to the 12MAP (Table 6.4). RGR of the two cultivars ranged from -0.68 to 0.54 mg g^{-1} d^{-1}, with 100g of sole NPK, 5L of banana brew bio-slurry and 100g of NPK in 5L of cow dung bio-slurry producing the highest RGR (0.64, 0.49, and 0.34 mg g^{-1} d^{-1}), respectively at 9 MAP for the Kibuzi cultivar. The lowest (-0.46

mg g^{-1} d^{-1}) RGR at 9MAP was observed under a 300g in 10L banana brew bio-slurry amendment.

Table 6. 4: Relative growth rate for banana cultivars Kibuzi and Mpologoma at the 9th and 12th month after planting

Relative Growth Rate (RGR mg g^{-1}/day^{-1})	KIBUZI CULTIVAR				MPOLOGOMA CULTIVAR			
	RGR-9MAP		RGR-12MAP		RGR-9MAP		RGR-12MAP	
	BBS	CDBS	BBS	CDBS	BBS	CDBS	BBS	CDBS
Control	0.38	0.00	0.05	0.00	-0.43	0.00	0.43	-0.31
100g of NPK in 5L organic amendment	0.03	0.34	-0.49	0.00	-0.07	0.00	0.00	0.00
300g of NPK in10L organic amendment	-0.46	0.24	0.00	-0.03	-0.04	0.00	0.09	0.05
500g of NPK in 15L organic amendment	-0.27	-0.11	-0.33	0.11	-0.04	0.05	0.04	-0.05
100g of NPK	0.64	0.08	-0.68	-0.08	0.32	0.32	0.00	0.00
300g of NPK	0.40	0.22	0.00	0.40	0.17	-0.13	0.06	0.36
500g of NPK	0.00	0.24	0.10	0.10	0.00	0.10	0.00	-0.10
5L organic amendment	0.49	0.18	0.17	-0.23	-0.37	0.00	0.00	0.00
10L organic amendment	-0.29	-0.08	0.52	0.14	0.37	0.54	0.00	-0.54
15L organic amendment	0.17	0.24	0.00	0.11	-0.10	0.00	0.00	-0.14

Key: BBS-banana brew bio-slurry, CDBS-cow dung bio-slurry, RGR-Relative growth rate RGR-9MAP; refers to relative growth rate at nine months after planting, RGR-12MAP; relative growth rate at 12 months after planting; BBS, refers to the Banana brew bio-slurry, CDBS; cow dung bio-slurry.

The banana brew bio-slurry treatments caused relatively higher growth at 9MAP compared to the cow dung bio-slurry for the same period and cultivar. The highest RGR (0.34 mg g^{-1} d^{-1}) under cow dung bio-slurry, resulted from a 100 g of NPK in 5L of fermented cow dung bio-slurry.

The average RGR at 12 MAP in Kibuzi cultivar, was high and positive for a 10L banana brew bio-slurry (0.52 mg g^{-1} d^{-1}) and 5L of the slurry (0.17 mg g^{-1} d^{-1}), respectively (Table 7.4). The cow dung bio-slurry did not result in significant growth rates at the 12MAP, as much of the treatments resulted in negative growth rates at 12MAP. Mpologoma cultivar responded better to the cow dung bio-slurry at 9MAP than banana brew bio-slurry. Treatment of the cultivar with 10L of banana brew bio-slurry and the same rate for cow dung bio-slurry resulted in Higher RGR (0.37 mg g^{-1} d^{-1} and 0.54 mg g^{-1} d^{-1}), respectively. At 12MAP, Mpologoma growth rates declined to zero except for the control (0.43 mg g^{-1} d^{-1}) and 300g of sole NPK (0.36 mg g^{-1} d^{-1}), respectively. RGR has been reported to play a fundamental part in the identification of pathways of evolutionary specialty in herbaceous species (Hunt, *et al*., 2019), an aspect that corroborates the findings of this study with respect to the cultivars under investigation.

6.5. Yield Parameters

The data on the effect of treatments on the total number of clusters per bunch, total number of fingers per cluster, weight (kg) of the first cluster per bunch, weight (kg) the bunch are presented in (Table 6.5).

There were significant (P<0.001) differences on total number of clusters per bunch, fingers per cluster, cluster weight of the first cluster, and total bunch weight for both cultivars (Table 6.5). Results from this study showed that cv. Kibuzi and cv. Mpologoma grown under integrated amendments and varying rates of application resulted in numerically high yield for the first harvest. The effect of integrated treatments on number of clusters per bunch for Mpologoma (Table 6.5) significantly (P<0.001) varied among the treatments, with the mean total maximum number of hands (1.015) per bunch recorded in 100g NPK in 5L organic amendment for the banana brew bio-slurry source, which was followed by 0.903 in 300g NPK in10L banana brew bio-slurry amendment. However, the minimum number of clusters (0.27) per bunch was recorded in treatment 15L of soil organic amendment of banana brew bio-slurry. The effect of integrated treatments on number of clusters per bunch (Table 6.5) also significantly (P<0.001) varied among the treatments.

The maximum number of clusters (1.466) per bunch recorded in 100g NPK in 5L organic amendment for the CDR organic source, which was followed by (1.015), in 300g NPK in10L Banana bio-slurry Banana bio-slurry organic amendment. However, the minimum number of clusters (0.27), per bunch recorded in treatment 15L of soil organic amendment of banana brew bio-slurry.

The weight of the first cluster per bunch differed significantly (P<0.001) among the different treatments for Mpologoma cultivar. The maximum weight of first cluster per bunch (1.378) and (1.299) for treatments; 5L of soil organic amendment and 500g of NPK in 15L organic amendment of the banana brew bio-slurry source, respectively. Similarly, 15L of soil organic amendment of the CDR source resulted in high weight (1.013) of the first cluster. The minimum weight of the premier cluster per bunch (0.123) was recorded for the 500g NPK under banana brew bio-slurry source.

The weight of the bunch differed significantly (P<0.001) among the different treatments. The maximum weight of bunch (1.33) was recorded in plots where plants were treated with 500g of NPK in 15L organic amendment of banana brew bio-slurry. The treatments with 15L of soil organic amendment produced considerably high bunch weight (0.92) and (0.89) for banana brew bio-slurry and CDR, respectively (Table 6.5).

Table 6. 5: Effect of treatments on the yield of Mpologoma (A) and Kibuzi (B)

Yield parameters (A)	Clusters/Bunch		Fingers/Cluster		Cluster weight		Bunch Weight	
Treatment Source	BBS	CDBS	BBS	CDBS	BBS	CDBS	BBS	CDBS
Control	0.65	0.256	0.231	0.381	0.992	0.404	0.24	0.25
100g of NPK in 5L organic amendment	1.015	1.466	1.045	0.83	0.627	0.806	0.91	0.73
300g of NPK in10Lorganic amendment	0.903	0.692	0.858	0.659	0.695	0.865	0.65	0.71
500g of NPK in 15L organic amendment	0.467	0.917	0.797	0.858	1.299	0.606	1.33	0.38
100g of NPK	0.354	0.354	1.029	1.029	0.218	0.216	0.46	0.46
300g of NPK	0.284	0.284	0.511	0.511	0.405	0.405	0.31	0.31
500g of NPK	0.345	0.345	0.259	0.459	0.123	0.23	0.55	0.27
5L of soil organic amendment	0.692	1.015	1.2	0.716	1.378	0.833	0.58	0.73
10L of soil organic amendment	0.467	0.481	0.783	0.739	0.884	0.734	0.72	0.73
15Lof soil organic amendment	0.27	1.015	0.71	0.721	0.688	1.013	0.92	0.89
Grand mean	0.5447	0.6825	0.7423	0.6903	0.7309	0.6304	0.667	0.546
F pr.	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Yield parameters (B)	**Clusters/Bunch**		**Fingers/Cluster**		**Cluster weight**		**Bunch Weight**	
Control	0.75	0.256	0.291	0.321	0.916	0.514	0.01	0.216
100g of NPK in 5L organic amendment	2.05	1.466	1.105	0.77	0.551	0.906	0.68	0.696
300g of NPK in10Lorganic amendment	1.403	0.952	0.918	0.599	0.619	0.835	0.42	0.676
500g of NPK in 15L organic amendment	0.667	1.177	0.857	0.798	1.223	0.616	1.1	0.346
100g of NPK	0.454	0.614	1.089	0.969	0.142	0.218	0.23	0.426
300g of NPK	0.384	0.544	0.571	0.451	0.329	0.405	0.08	0.275
500g of NPK	0.45	0.605	0.319	0.399	0.047	0.23	0.32	0.236
5L of soil organic amendment	1.021	1.275	1.26	0.656	1.302	0.833	0.35	0.696
10L of soil organic amendment	0.467	0.741	0.843	0.679	0.808	0.734	0.49	0.696
15Lof soil organic amendment	0.27	1.275	0.77	0.661	0.612	1.013	0.69	0.856
Grand mean	0.7916	0.8905	0.8023	0.6303	0.6549	0.6304	0.437	0.512
F pr.	<.001	<.001	<.001	<.001	<.001	<.001	<.007	<.006

The minimum weight of the bunch (0.24) recorded from the control treatment under banana brew bio-slurry source. The study results do not differ from those of (Al-Harthi and Al-Yahyai 2009), although, the treatment rates on the banana were only for NPK. The residual effects of the application of the amendments in soil and plants as well as its interaction with other factors such as weeding, de-suckering and management practices, were beyond the scope of this study, and therefore, long term studies to determine the residual effect of the bio-slurry amendments is recommended.

The yield (number of clusters per bunch and hands per cluster) for cv. Kibuzi was higher compared to cv. Mpologoma. Table 6.5, further shows that for Kibuzi cultivar, the mean total maximum number of hands (2.015) per bunch was recorded for 100g NPK in 5L organic amendment for the banana brew bio-slurry source, which was followed by (1.403), in 300g NPK in10L banana brew bio-slurry amendment. Number of clusters (0.27) per bunch was recorded lowest in treatment 15L of soil organic amendment of banana brew bio-slurry. The mean weight of the first cluster and the mean weight of the bunch were lower for Kibuzi than Mpologoma in similar treatments. The maximum weight of the bunch (1.10) was recorded in plots where plants were treated with 500g NPK in 15L organic amendment of banana brew bio-slurry. The maximum weight of bunch (1.10) was recorded in plots where plants were treated with 500g NPK in 15L organic amendment of banana brew bio-slurry. The treatments with 15Lof soil organic amendment resulted in high bunch weight (0.69) and (0.86) for cv. Kibuzi for banana brew bio-slurry and Cow dung bio-slurry, respectively (Table 6.5). The minimum weight of the bunch (0.01) recorded in the control under banana brew bio-slurry. The genetic composition of the cultivars may contribute to the yield differences in terms of number of clusters per punch and number of hands per cluster of the banana (Okech, *et al*., 2004), although, the cluster weight and total weight of the bunch may be as a result of the soil environment. The nutrients and water extracted from the soil are responsible for the proper filling of the hands. Well filled hands produce higher bunch weight.

6.6. Profiling of secondary metabolites

The different phytochemical constituents present in the roots of the banana cultivars are shown in (table 6.6). The study has established that at least twenty-seven volatile oils extracted in n-hexane exist in the banana roots. The volatile oils vary in their presence within the different treatments in terms of retention time, percentage area covered and percentage height of the phytochemical in the gas column. The ability of the roots to exude the volatile oils may be attributed to the amendments given to the cultivars. According to (Ndiege *et al.* (1991), Ndiege *et al.* (1996), Zhang *et al.* (2014), and Yuan *et al*. (2015), some of the volatiles play a contributory role in the control of pathogens that are detrimental to banana production.

The analysis (table 6.5) indicated substantial absence of some phytochemical compounds in roots samples that received treatments at different rates. The phytochemicals that were absent in samples obtained from treatments were however detected in the control samples. Table 6.6 indicates that 1,1,6-trimethyl-3-methylene-,17.alfa,21.beta-28,30-bisnorhopane, 1-Naphthalenamine,N-phenyl, Phenanthrene,2,3,5-trimethyl-, Oxirane,2,2-dimethyl-3-, 3-Buten-2-one, 3-methyl-4-(1,3,3-trime were present in the control sample root sample. The results presented in Table 6.2 indicated that there were high nematode population counts in the control samples of the banana cultivars. Though not conclusive, the presence of the phytochemicals in the control sample that absent in the treatment samples probably explains the high nematode densities that were detected in the control samples. The phytochemicals present in the control may thus be suspected to be nematode attractants. The effect of many of the phytochemicals analyzed on banana by this study as having nematicidal effect is not widely known according to literature, however, some of the similar classes of volatiles from *P. putida* were found to have strong nematicidal activity against *M. incognita* J2 larvae by direct-contact, and inhibited egg hatching of *M. incognita* both by direct contact and by fumigation. (Zhai *et al*., 2018). The study has established that phenanthrene, 2,5-dimethyl-, was absent in the control sample, and according to Amellal *et al*. (2006), phenanthrene, 2,5-dimethyl-, adsorbed in[especially] sandy loam soils, degrades under natural conditions to yield 2,5-*Furandione, 3-dodecyl*- [which is only in treatments sample that received 10L of the organic amendment] (table 6.6) and 9,10-phenanthrenedione, both of which are toxic degradation products.

Table 6. 6: Chemical components detected in banana roots obtained from samples treated with amendments

Phytochemical Identification				Treatments									
	RT	A (%)	H (%)	1	2	3	4	5	6	7	8	9	10
1,1,6-trimethyl-3-methylene-2-(3,6,9,1	26.0	0.8	0.6	*	x	x	x	x	x	x	x	x	x
17.alfa,21.beta.-28,30-Bisnorhopane	29.0	1.3	1.2	*	x	x	x	x	x	x	x	x	x
1-Naphthalenamine,N-phenyl	18.0	1.0	0.8	*	x	x	x	x	x	x	x	x	x
2,2,4-Trimethyl-1,3-Pentanediol diisob	9.2	1.2	1.9	*	x	x	x	*	*	*	*	*	*
2,5-Furandione, 3-dodecyl-	12.2	0.6	0.7	*	x	x	x	x	x	x		□	□
2-Buten-1-0ne,1-(2,6,6-trimethyl-1-cy	27.8	1.1	0.7	x	*	*	*	*	*	*	*	*	*
3-Buten-2-one, 3-methyl-4-(1,3,3-trime	27.0	1.1	0.8	*	x	x	x	x	x	x	x	x	*
3-Methyl-5-(1,4,4-trimethylcyclohex-2	27.2	0.6	0.8	x	*	*	*	*	*	*	*	*	*
hexadecanoic acid, methyl ester	8.2	1.1	1.9	x	*	*	*	*	*	x	*	*	*
4,4-((p-phenylene)diisopropylidene)di	25.0	0.5	0.7	x	*	*	x	*	*	*	*	*	x
5.alpha-cholestane	7.1	1.2	1.3	x	*	*	*	*	*	*	*	*	*
9 H-Fluorene,9-methylene-	12.0	1.0	1.0	x	*	*	*	*	*	*	*	*	*
9-octadecenoic acid, ester methyl	27.0	1.0	0.0	x	x	x	x	*	*	*	x	x	x
Cholest-5-en-3ol(3 beta)-,carbonoch	9.1	0.2	0.9	x	*	*	*	*	*	*	*	*	x
Docasane,2,22-dibromo	26.0	1.0	0.0	x	*	*	*	*	*	*	*	*	*
Dodecanoic acid,octadecyl ester	11.0	1.2	0.1	x	*	*	*	*	x	*	*	*	*
Dotriacontane	26.0	5.0	6.5	x	*	*	*	*	*	*	*	*	x
Eicosane	20.0	3.0	3.3	x	*	x	*	*	*	*	*	*	*
Hexacontane	5.0	6.5	0.5	x	*	*	*	*	*	*	*	*	x
Nonadecane, 23-demerhyl-	27.0	1.1	0.8	x	*	*	*	*	x	*	*	*	*
octadecanoic acid	9.1	1.2	0.9	x	*	*	*	*	*	*	*	*	*
Oxirane,2,2-dimethyl-3-	27.0	1.0	1.0	*	*	*	*	*	*	*	*	*	*
Phenanthrene,2,3,5-trimethyl-	18.0	1.0	1.0	x	*	x	*	x	x	x	*	*	x
Phenanthrene,2,5-dimethyl-	18.0	1.0	0.5	x	*	*	*	*	*	*	*	*	x
Phenanthrene,4-methyl-	14.0	1.0	0.0	x	*	*	*	*	x	x	*	*	*
Pyrene	17.0	2.0	1.0	x	*	*	*	*	*	*	*	x	*
Tetrapentacontane	27.0	4.0	6.3	x	*	*	*	*	*	*	*	x	*

Key: RT = retention time, A(%)= percentage area covered by the eluent, H(%)= the percentage height covered by the eluent; treatments; 1=Control 2=100g of NPK in 5L organic amendment 3=300g of NPK in10Lorganic amendment 4=500g of NPK in 15L organic amendment 5=100g of NPK 6=300g of NPK 7=500g of NPK 8=5L of soil organic amendment 9=10L of soil organic amendment 10=15Lof soil organic amendment. * denotes the presence of the phytochemical; x denotes absence of the phytochemical

The results presented in table 6.2 further indicated that 10L of soil organic amendment for both banana brew bio-slurry, and the cow dung bio-slurry, recorded the lowest nematode populations for all genera. The contribution of phenanthrene, 2, 5-dimethyl-, to the reduction in the nematode population, may not be ruled out by the current study. This toxicity may have a negative effect on the growth and development of nematode.

The n-hexane root extracts contained fatty acid esters such as *hexadecanoic acid, methyl ester,* and *Dodecanoic acid*, *octadecyl ester*, *9-octadecenoic acid, methyl ester*, and a carboxylic acid *hexadecanoic acid*. Studies have indicated that esters and carboxylic acids have various bioactivities (Irawan, *et al.* 2018). The activities according to Sabu (2016) are antifungal and antioxidant bioactivities. According to Pradhan and Deo (2019), the root extracts contain nematicide, pesticide bioactivities, and potent antimicrobial activity.. Phytochemical compound of *9-octadecenoic acid, methyl ester* have been reported as Antibacterial and antifungal (Nwankwo and Osaro, 2014). Therefore, their presence in the control sample could suggest inhibition of antagonistic fungi against nematodes (Pan *et al.,* 2015). The potent antioxidant and antimicrobial activity bioactivity against the nematodes could have occurred in most treatment samples due to the presence of the phytochemical compounds, as *hexadecanoic acids* and octadecanoic acids. Further studies are recommended to determine the actual bioactivity effects of the identified phytochemicals against the nematodes.

6.7. Conclusions

The study observations were focused on the variations of soil components of nitrogen, potassium, phosphorus and organic matter as abiotic factors. Further observations focused on the response of banana weevils and parasitic nematodes towards the treatments as well as the cultivar response in producing phytochemicals that could be essential for defence against the nematodes. This study established that; generally, application of inorganic, sole organic and combinations of the amendments reduced nematodes and banana weevil populations. The application of small amounts up to 15 litres of banana brew bio-slurry and cow dung bio-slurry soil amendments significantly provided nutrients at variable depths and equally caused normal TCB growth up to the 12^{th} month after planting. The nutrient content of the soil improves when small amounts of NPK are mixed in the bio-slurry to make soil amendment. In fact application of 300g NPK in 5 liters of bio-slurry increased K nutrient proportions more than other amendments, especially in the 8-16 cm depth, a region where most banana roots draw soil nutrients. Banana cultivar Mpologoma was found to be more prone to all the plant parasitic nematodes in the study site than Kibuzi with the exception of *H. Multicinctus.*The occurrence of phytochemicals in the root of the banana of different cultivars did not differ significantly for all treatments but the application of 10 litres of the banana bio-slurry and cow dung bio-slurry significantly resulted in the lowest parasitic root nematodes. In the control root samples where the nematode counts were high, a significant number of phytochemicals were absent while they were present in roots that received treatments at different rates which could be contributing factors to the high nematode densities and so maybe suspected as nematode attractants.

The study associates the reduced nematode population with the variations in the occurrence of phytochemical compounds in the root of banana of different cultivars elicited by the treatments some of which may act in defence against the nematode attack. Investigation through the present study revealed that the integrated treatments could stimulate TCB cultivars to produce is a reliable source of bioactive compounds like fatty acid esters, alcohols, hydrocarbons, alkanes, amines, terpenes, and sugars, some of which may be essential in controlling banana weevil and nematodes in banana production systems. However, the antioxidant, antimicrobial, nematicidal and pesticide properties of the phytochemicals extracted from banana roots against the banana weevil, and the nematodes are recommended for further study.

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1. Introduction

Banana production has nearly replaced most traditional cash crops as an income-generating crop and is gradually providing an alternative to many perishable unprocessed products. In Uganda, TCB technology was introduced to solve the “Pest and Disease” problem in the banana production industry however, levels of adoption of the technology has remained low among smallholder farmers. The adoption has been low even when the technology has the potential for high yield. Farmer perceptions play an important role in the adoption of a new technology. Chapter three of this study assessed the farmer perceptions linked to adoption of TCB technology and the key highlights are discussed under section 7.2

The environment within which Banana orchards grow is important for interactions between the banana plants and banana weevils and nematodes. These are biotic factors of economic importance to banana production. Their action on the banana orchards is rather detrimental. Variations in soil pH, nitrogen, potassium, phosphorus and organic matter in orchards cause variations in the growth and productivity of the banana in the field, and their effects may reduce the adoption of the banana production technology. Chapter four and five of this study focused on the biophysical interactions in the banana orchards, and the key highlights are discussed under section 7.3

Whereas nematodes and banana weevils are a nuisance in TCB production, and soil nutrient sources wobble, appropriate, simple, and affordable amendments to control pests while supplying nutrients for sustainable banana growth appear elusive to the smallholder farmers.

Chapter six of this study focused on designing local integrated soil amendments to enable growth and sustainable production of TCB at smallholder production while providing a solution to biotic and abiotic factors associated with TCB orchard degeneration. Section 7.4 highlights the key findings on this objective.

7.2. Factors that influence on TCB technology adoption

Several factors affect farmers' attitudes towards the adoption of a given technology (Sjakir *et al.,* 2015). Farmer perceptions and orientations towards technology are often reflected in the attention given to the practices pertaining to that technology. The study established that the levels of adoption of tissue culture technology are still low, with 83% of the farmers growing NTCB. The production of NTCB type was high due to the perception of the smallholder farmers that its yield is sustainable and productivity last longer. For the TCB technology to be fully adopted by smallholder farmers, it must be convincing enough to overcome the perceived mind-set of smallholder farmers. Therefore, smallholder farmers are solely responsible for the decision to adopt or reject TCB technology. Actually, factors affecting the TCB technology adoption at smallholder farm level are largely linked to farmers' perceptions, contrary to the study hypothesis (section 1.4.3). This study considered the adoption of the tissue culture plantlets by smallholder farmers as a factor dependent on the motivations, and interests of the farmers themselves (section 1.6). Therefore, any factor that motivate and stimulate interests of the smallholder farmer for the technologies, directly and indirectly, will enhance their adoption.

The study indicated that the general orientation to adopting TCB production is positive but slow, with different variances towards materials planted in the production process as animated by household leadership, gender, and other factors surrounding the farmer. It is upon such variables that NARO, (2017) showed that the adoption of different agriculture technologies in a locality is based on different household individuals and small group farmers who maintain the management by attending agriculture extension services about adopted technology. Adoption to new agriculture technologies remains difficult in a farm management structure of communities farming for subsistence.

Land ownership in banana production is a key factor in the adoption of TCB technology. Actually Tessema *et al.* (2016), argued that adoption and dissemination of new technology is difficult on customary property since individual or single household decision is hard to arrive at.

Social networks and learning are fundamental factors to the adoption of the new technology. Social networks hinge on gender, occupational and religious aspects (Conole and Alevizou 2010). The majority of the households (55%) were male-headed. Such a distribution attracts the adoption of new or improved technology since it is the males who have control over land and they are most influential in the households' decision making. Females have limited access to information and hardily control land (fixed assets to production). However, the disaggregation between men and women has not been well captured in this study. Besides, this study did not show how the religious social network influences the tissue banana culture production yet religion is one of the social networks in the study area. These, therefore, are gaps that further studies can address in the near future.

Labour was found to be an important factor influencing TCB technology adoption at the smallholder farm level. It may be illogical for smallholder farmers to adopt the technology that requires expensive labour and leave the one that uses available and cheap labour. Most households depend on family for subsistence and small-scale commercial production. Although this study did not disaggregate labour in a household setting as per gender relations in TCB production, it clearly showed that majority of households depended on family labour. The decision to use family labour dependents on the number of persons in a family and the size of labour needed to be accomplished (Watcharaanantapong 2012).

Studies have also identified various limitations in the adoption of new or improved agriculture technology. According to Sulo *et al.* (2012), the cost of adopting a new technology right from agriculture extension services, farm inputs, costs of labour, transportation, and mechanization are limiting factors to adoption. Importantly, agriculture in Western Uganda is dominated by women but the scope of this study never assessed the voices of women towards such costs. Whilst adoption is a practice for the general farmers, the information about women's attitude towards costs and the extent to which it limits them in the production process of the banana tissue culture remains another gap to be studied in the future.

7.3. Biotic and abiotic factors influencing TCB orchard production

The extent to which biotic and abiotic factors interact to influence adoption of the TCB production is presented within the confines of farmer location, seasonal banana weevil, nematode, and nutrient distributions within a type of banana. High banana weevil population increases the rate of TCB degeneration. In fact, the response of a type of banana to banana weevil infestation cannot be dissociated from the effect attributed to high banana weevil density. Whilst Wairegi *et al*. (2010), and Sabiiti *et al.* (2016), argued that the choice to plantain production is due to prevailing climatic conditions, their studies show that the banana weevil supersedes other factors in contributing to crop degeneration. The effect of the banana weevil on the banana influences the decision of the farmer to adopt the type of banana technology (chapter four).

Regardless of location and season, this study showed that parasitic nematodes negatively affected TCB plantations more than they affected NTCB plantations. Speijer (2017), established that both banana weevil and nematode prevalence affect the general cycle of the plantain. According to prior findings by (Grant 2012), banana weevil and nematodes' incidence in banana plantations under smallholder farms can cause between 20-90% destruction. However, variations in plant survival, according to Gunawardena and Dissanayake (2000), may arise from plants' inherent ability to resist harmful interactions with the biotic factors, hence, smallholder farmers are most likely to adopt the cultivars types with inherent ability to co-exist with banana weevil and the nematode. The different banana cultivars can show similar characteristics during growth but hardily similar resistance towards the weevil or the nematode.

The biophysical interactions affected TCB production under heterogeneous on-farm conditions among Ugandan smallholder farms. Banana weevil and total nematode populations densities independently but negatively limited the distribution[7] of TCB, although adoption of NTCB was largely influenced by the banana weevil than it was by nematodes in the same farmers' fields. In other words, nematodes and weevils do not need to interact, but the presence of any one of the two above the threshold will cause considerable damage to banana. According to Singh and Kumar (2015), high densities of the pests reverse the yield and subsequently limit the acceptability of the affected crop by the farmers. Variations in soil pH and N positively influenced TCB distribution. Nitrogen was adequate although, an

[7] In the context of this study it refers to the abundance of tissue culture and non-tissue culture banana with in the area of study.

increase in nitrogen would lower pH probably due to accumulation of NO_2^- and NO_3^- anions that eventually acidify the soils within which the banana grows.

7.4. Integrated soil amendments and their effects on selected biotic and abiotic factors for TCB growth and productivity

Soil amendments are presented in relation to TCB growth and productivity and the findings in chapter seven focus on soil components of, nitrogen, potassium, phosphorus, and organic matter as well as banana weevil and nematodes. The findings showed that the integrated soil amendments have an influence on both biotic and abiotic factors in lieu of TCB growth and productivity. The application small amounts of banana brew bio-slurry and cow dung bio-slurry and NPK significantly provided nutrients at variable depths, resulted into normal TCB growth, and reduced nematodes and banana weevil populations in all treatment plots except in the control. The study further established that there were variations in the susceptibility to nematode infestation of the cultivars. For instance, cv. Mpologoma was prone to all nematode infestation. Additionally, cv. Kibuzi was more susceptible to *H. Multicinctus* than cv. Mpologoma, which in turn was more susceptible to *P. goodey*i. The occurrence of phytochemicals in the root of the banana of different cultivars did not differ significantly for all treatments but the application of 10 litres of the banana bio-slurry and cow dung bio-slurry significantly resulted in the lowest parasitic root nematodes' populations.

This study established that the application of small amounts of banana brew bio-slurry and cow dung bio-slurry soil amendments provided nutrients and enhanced TCB growth. The scope of the study did not capture the actual composition of the bio-slurries in terms of the nutrient contents, further studies to confirm that bio-slurries as already pre-digested products of a process, add nitrogen to the soil are recommended. The nutrient content of the soil improves when small amounts of NPK are mixed in the bio-slurry as a soil amendment (Forster *et al*., 2013). In fact application of 300g NPK in 5 litres of bio-slurry increased K (ppm) more than other amendments. According to Kagoda (2005), Banana plantations that receive manure have a long period of productivity because organic matter alters the micro-environment thus negatively affecting both the nematode and the banana weevil

The variations in the occurrence of phytochemical compounds in the roots of banana of different cultivars are most likely attributed to the treatments [described under sections 6.4.1 and 6.4.3]. The nematode population in treatment samples was lower than the control and it likely that this was due to the effect of some phytochemicals. The study manipulated the environment with integrated treatments which probably contributed to the phytochemical exudation. The quality and quantity of phytochemicals in the plant roots depend on the environment within which it is growing (Pan *et al.*, 2015; Solomou and Martinos, 2018). The phytochemicals form an intricate network of defences and counter-defences for the plant to fight and survive (Lämke and Unsicker, 2018).

The analysis of the n-hexane extracted root exudates showed absence in the control sample of phytochemicals with positive bioactivity against nematodes. Carboxylic acids and esters that were absent in the control (Table 6.6) suggested the absence of bioactivities such as antifeedant (Irawan *et al.,* 2018), anti-oxidant (Mena *et al.*, 2016), and repellent bioactivity (Koul, 2008). Similarly, there were phytochemicals present in the control sample but generally absent from the rest of the treatment samples. Some of the phytochemicals particularly present in the control and absent in the treatment samples probably are nematode attractants and this could explain the high nematode densities recorded in the control plots. The biotic stress exposed to the control plants may have induced the production of the phytochemical compounds (Yugandhar and Savithramma, 2017) most likely attractants of nematodes and weevils. This likelihood assumption contravenes Lämke and Unsicker (2018), and Adesina and Rajashekar (2018), who opine that trees are specifically challenged to resist the plethora of abiotic and biotic stresses due to their dimension and longevity. In this case, the banana trees by nature have developed survival mechanisms to co-exist with the nematode and the weevils within their environment.

7.5. Conclusions and recommendations

The adoption rates for TCB in smallholder banana farms in western Uganda have been found to be low. The result runs counter to the widely expressed perception that TCB technology is largely accepted among smallholder farmers in Uganda. Smallholder farmers' perceptions on user attributes, and performance of TCB technologies must carefully be compared to the conventional traditional banana production technologies to give farmers options for production by context. There should be a deliberate effort to respond to TCB adoption problems such as subjective impressions about the TCB technology that limit land, labour, and time resource allocation to the production of the technology. Further studies need to be done to disaggregate gender based subjective versus objective orientations, religious versus social networks in influencing tissue banana culture production.

This study has shown that under natural conditions when smallholder banana farms are exposed to weevil and nematode pests both TCB and non TCB are susceptible to banana weevil and nematode infestation. Spatio-temporal interaction of the banana orchards with banana weevils and nematodes influences the adoption of tissue culture and NTCB. Therefore, failure to adopt TCB and/ or fall back into production of NTCB by smallholder cannot be ring-fenced to the smallholder farmers' perception only.

The study further established that under heterogeneous conditions in smallholder banana farms, high banana weevil and nematode population densities, and variations in pH, phosphorous, potassium, nitrogen and organic matter influence the adoption and distribution of banana types in smallholder banana orchards. The awareness about the effect of interactions between biotic (nematodes, banana weevils) and abiotic (phosphorous, nitrogen, potassium, and pH) factors determine the level of banana production and productivity is important in shaping the adoption and production of the adopted banana technology. The awareness should be a basis for formulating soil nutrient amendments and field practices for controlling the banana weevil and nematodes below the threshold while supplying nutrients to improve banana productivity amongst smallholder farmers in Uganda.

Application of small amounts of banana brew bio-slurry and cow dung bio-slurry and NPK leads to normal banana plant growth. The amendments supplied nutrients [phosphorous, potassium, nitrogen, organic matter] moderated pH, and minimised population and negative effects of banana weevil and nematodes to the lowest during TCB production. In fact, the application of 10 liters of sole banana brew bio-slurry and cow dung bio-slurry gave good results. The bio-slurries could have stimulated the TCB cultivars to produce a reliable source of bioactive compounds essential in controlling the banana weevil and the nematodes in banana production. The study associates the reduced nematode population with the variations in the occurrence of phytochemical compounds in the root of banana of different cultivars elicited by the treatments some of which may act in defence against the nematode attack. However, the antioxidant, antimicrobial, nematicidal and pesticide properties of the phytochemicals extracted from banana roots against the banana weevil, and the nematodes are recommended for further study.

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APPENDICES

Appendix 1: Study tool for field survey

Dear Farmer,

I have the honour and privilege to work with you as an experienced farmer in the field of banana production. Due to your experience, I***, MURONGO MARIUS FLARIAN,*** [a student of Doctor of philosophy in Dry Land Resources Management, University of Nairobi] hereby request to work with you as a respondent on a study aimed at increasing adoption of new agricultural technologies by smallholder farmers in the field of TCB production. Responses obtainable from your participation are meant solely for academic analysis and publication. Thank you dearly for your response**.**

FIELD LOCATION

Field Number	**Sub-County**	**District**	**Altitude**	**GPS reading**

PART A: factors influencing tissue culture banana technology adoption at smallholder farm level.

A_1 HOUSEHOLD DETAILS (tick as appropriate to your choice)

Gender of respondent	[1] =Male	[2] =Female		
Age of the farmer	[1] = >18<30	[2] = >30<50	[3] = >50<75	[4] = >75
Level of education	[1] = Non formal level	[2] = Primary level	[3] =Secondary level	[4]=Tertiary level
Household board	[1] = husband is the head	[2] = wife is the head	[3] = children are head	[4] = the guardian

A_2 FARMER'S PLOT DATA

Gender of respondent	[1] =Male	[2] =Female		
Age of the farmer	[1] = >18<30	[2] = >30<50	[3] = >50<75	[4] = >75
Level of education	[1] = Non formal level	[2] = Primary level	[3] =Secondary level	[4]=Tertiary level
Household board	[1] = husband is the head	[2] = wife is the head	[3] = children are head	[4] = the guardian

Parameter	**1**	**2**	**3**	**4**
Total size (acres) proportion covered by TCB	1-25%,	26-50%,	51=75%,	75-100%
Total size (acres) covered by NTCB	1-25%,	26-50%,	51=75%,	75-100%

Parameter	**1**	**2**	**3**	**4**
Total size (acres) proportion covered by TCB	1-25%,	26-50%,	51=75%,	75-100%
Total size (acres) covered by NTCB	1-25%,	26-50%,	51=75%,	75-100%

07; Land tenure; [1] = land Inherited from parents [2] = Leased land [3] = freehold land

08; Land rights, [1] Female farmers have access to titled land, [2] Female farmers are entitled to untitled land, [3] Male farmers have access to titled land, [4] Male farmers are entitled to untitled land

09; Type of banana grown; [1] = TCB, [2] = NTCB

10; Variety of TCB grown; [1] Tissue culture cooking banana, [2] Non-tissue culture cooking banana, [3] Tissue culture brewing banana,[4] Non-tissue culture brewing banana, [5] Tissue culture dessert banana, [6] Non- tissue culture dessert banana,[8]. Others (specify)

11. Proportion of the variety selected above; [1] 1-25%, [2] = 26-50%, [3] = 51-75%, [4] = 75-100%.

SECTION A_3; SOURCE OF PLANTING MATERIALS AND LABOUR REQUIREMENTS

12. Type Propagation materials; [1] = Plantlets, [2] = Conventional suckers

13. Source of the materials; [1] = From the research outlet center, [2] = Supplied by government projects such as APEP, OWC, [3] = Farmers own suckers from the previous/existing crop, [4] = From the neighbourhood.

14. Management of the materials; [1] = Treated for pest and disease control, [2] = No treatment is done for pest and disease control

15. Labour for the value chain; [1] = Hired/profesional labour, [2] = Family labour, [3] = Community labour, [4] = Extension work force

16. Cost of production; [1] =Costs of labour are largely limiting, [2] = Cost of TCB planting materials are largely limiting, [3] = Field hygiene in TCB production is more expensive and lagrely limiting, [4] = Land acquisition costs are high and largely limiting, [5] = Transportation costs are largely limiting

17. Farmers' source of incomes; [1] = Permanent and pensionable employment, [2] = Wage employment, [3] = Sales from subsistence production, [4] = Agricultural loans, [5] = Gifts and donations

SECTION A_4; CROP YIELDS FOR THE DIFFERENT TYPES OF BANANA/CYCLE						
18	Approximate Number of bunches of cooking banana for cycle (specify units)	**1**	**2**	**3**	**4**	**5**
19	Approximate Number of bunches of beer banana for cycle (specify units)					
20	Approximate Number of bunches of dessert banana for cycle (specify units)					

SECTION A_5; MARKET POTENTIAL, CONSUMPTION AND COMMUNICATION PREFERENCES

21; Has a High market demand with attractive prices; [1] = Check all that apply. [2] = Tissue culture cooking banana [3] = Non-tissue culture cooking banana [4] = Tissue culture brewing banana [5] = Non-tissue culture brewing banana [6] = Tissue culture dessert banana [7] = Non- tissue culture dessert banana.

22 Low market demand with low prices; [1] = Check all that apply. [2] = Tissue culture cooking banana [3] = Non-tissue culture cooking banana [4] = Tissue culture brewing banana [5] = Non-tissue culture brewing banana [6] = Tissue culture dessert banana [7] = Non- tissue culture dessert banana.

23; highly preferred for consumption; [1] = Check all that apply. [2] = Tissue culture cooking banana [3] = Non-tissue culture cooking banana [4] = Tissue culture brewing banana [5] = Non-tissue culture brewing banana [6] = Tissue culture dessert banana [7] = Non- tissue culture dessert banana.

24; Less preferred for consumption; [1] = Check all that apply. [2] = Tissue culture cooking banana [3] = Non-tissue culture cooking banana [4] = Tissue culture brewing banana

[5] = Non-tissue culture brewing banana [6] = Tissue culture dessert banana [7] = Non- tissue culture dessert banana.

25; Not preferred by consumers; [1] = Check all that apply. [2] = Tissue culture cooking banana [3] = Non-tissue culture cooking banana [4] = Tissue culture brewing banana [5] = Non-tissue culture brewing banana [6] = Tissue culture dessert banana [7] = Non- tissue culture dessert banana.

26; Farmers get feedback for their communication in time; [1] = through use of the mobile phone technology, [2] = through face to face interaction with extension staff, [3] = No communication is made to these effects

27. Symptoms of TCB degeneration are communicated promptly [1] =through use of the mobile phone technology, [2] = through face to face interaction with extension staff, [3] = No communication is made to these effects.

28; Diseases and pest disturbances are immediately communicated; [1] = through use of the mobile phone technology, [2] = through face to face interaction with extension staff, [3] = No communication is made to these effects.

Thank You