EFFECTS OF BUFFER ZONE AND INORGANIC FERTILIZER APPLICATION ON TRANSMISSION OF BANANA BUNCHY TOP VIRUS (*Babuvirus nanofarads)* IN BANANA FIELDS IN NORTHERN MALAWI

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DECLARATION

This thesis is my original work with no submissions to other universities for the award of degrees.

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DEDICATION

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
BBTD	Banana Bunchy Top Disease
BBTV	Banana bunchy top virus
BBMV	Banana bract mosaic virus
BSV	Banana streak virus
CGIAR	Consultative Group on International Agricultural Research
CLCuV	Cotton leaf curly virus
DAP	Di-ammonium Phosphate
DRC	Democratic Republic of Congo
ELISA	Enzyme Linked Immuno Sorbent Assay
EPA	Extension Planning Area
FAO	Food and Agriculture Organization of the United Nations
IPGRI	International Plant Genetic Resources Institute
K	Potassium
LSD	Least Significant Difference
MDMV	Maize dwarf mosaic virus
N	Nitrogen
PCR	Polymerase Chain Reaction
RYMV	Rice yellow mottle virus
SA	Sulphate of Ammonia
SEP	Social Economic Profile
SPSS	Statistical Package for Social Scientists

GENERAL ABSTRACT

Banana bunchy top disease causes yield reductions in bananas across the world, Malawi included. Yield losses of over 60% have been observed in Malawi due to banana bunchy top disease. This calls for effective agronomic management practices to manage the disease. A study was conducted in Mulanje and Nkhata-bay districts during the 2016–2017 season with the following objectives: (1) to evaluate the farmers' understanding and opinions regarding the prevalence and management of banana bunchy top disease; and (2) to ascertain the outcome of the effects of buffer zones and the application of inorganic fertilizer on the transmission of banana bunchy top virus (BBTV). In objective 1, in the districts of Mulanje and Nkhata-Bay, 76 randomly selected farmers were given a semi-structured questionnaire. The information gathered covered the five years' top crops, banana planting techniques, fertilizer types, knowledge of the banana bunchy top disease and suggested countermeasures, and difficulties in banana cultivation. The analysis of survey data was done using SPSS, and the Chi-square test was applied to check relationships between some variables. In objective 2, a field trial was set up at Chintheche and Mpamba sites in Nkhata-Bay district in Malawi in the 2016–2017 growing season. The experiment had a split plot layout with four replicates and a randomized complete block design, with a buffer zone as the main plot element and inorganic fertilizer as the subplot. Treatments consisted of four buffer zones based on the distance from the infected plants (2-10 m radius, 50m radius, 100m radius, and planting where the infected banana plants were removed without a resting period) and two levels of inorganic fertilizer (no inorganic fertilizer control and application of 56.6 kg of NPK (23:21:0+4S) per ha plus 46 kg of urea per ha. Plant height, the number of leaves per plant, the number of suckers per plant, the prevalence of illness, the length, and width of the leaves were all recorded. To determine whether BBTV was present in leaf samples, an enzyme-linked immunosorbent assay (ELISA) was performed. GenStat was used to examine the data collected using analysis of variance (ANOVA), and means were separated using the least significant difference (LSD) test at P 0.05. Bananas were the most prevalent crop in Mulanje (30.8%) and Nkhata-bay (50%) over the preceding five years, while crop production was the main source of income for the farmers in Mulanje (65.4%) and Nkhata-bay (94.0%), respectively. According to the survey, the disease, which is one of the main obstacles to banana production, was known to most farmers (55.4% in Mulanje and 63% in Nkhata-bay). Additionally, many farmers (30.7% in Mulanje and 48.0% in Nkhata-bay) claimed to have managed the disease by following the suggested procedures. The survey also showed that banana bunchy top disease had caused a 15–30 ton per hectare yield reduction

in bananas. The survey also revealed that the yield of bananas had been reduced by 15 to 30 tons per hectare due to banana bunchy top disease. Most of the farmers (64.5%) in both Mulanje and Nkhata-bay reported that they lacked alternative sources of clean planting materials. It was also indicated that most farmers (67.4%) both in Mulanje and Nkhata-bay got information on recommended control measures from public extension works. Farmers reported that uprooting infected banana plants was labor-intensive. The buffer zone had a significant effect (P 0.05) on disease incidence at 12 and 28 weeks after planting at the Chintheche site and at 28 weeks after planting at the Mpamba site. Planting banana plants at a radius of 100 m away from the infected plants had a lower disease incidence than planting at a radius of 2 m to 10 m away from the infected banana and planting where the infected banana was uprooted without a resting period. Application of inorganic fertilizer significantly reduced disease incidence at Chintheche 12 weeks after planting. The buffer zone, inorganic fertilizer, and their interaction had an effect (P 0.05) on disease incidence in both sites at 28 weeks after planting. Higher disease incidence (49.5% and 25.4%) in Chintheche and Mpamba, respectively, was observed in plots planted at a radius of 2 to 10 m from infected bananas and not supplied with inorganic fertilizer. Plots located at a radius of 100 m away from the infected banana plants and not supplied with inorganic fertilizer recorded lower disease incidence (0.9% and 0.5%) in Chintheche and Mpamba, respectively. Plant height, number of leaves per plant, number of suckers per plant, leaf length, stem diameter, and leaf width were significantly increased by the application of inorganic fertilizer. The study showed that banana bunchy top disease was a significant barrier to banana output in the Mulanje and Nkhata-bay areas. The farmers perceived the recommended control measure to be labor-intensive. A buffer zone of 100 m away from infected banana plants and the application of inorganic fertilizer increased plant growth and reduced BBTV transmission. Therefore, Malawi can control the banana bunchy top disease by establishing vast buffer zones and using inorganic fertilizer.

CHAPTER 1
INTRODUCTION

1.1 Background

Banana is an edible fruit crop produced by many species of the genus *Musa's* huge herbaceous flowering plants. Clusters of fruits develop and hang from the plant's top (Nelson et al., 2006). The crop is grown in over 130 tropical and subtropical nations. Bananas are one of the most significant fruits in the world, consumed daily by more than 70 million people (Frison and Sharrock, 1998. About 16 million tons of bananas are exported from the banana growing areas to North America, Europe, Japan, and the Arabian Gulf states (Daniells, 2009). The crop is cooked and used as a main meal, and it can also be eaten as a fruit. Bananas for cooking are referred to as plantains. According to Robinson and Sauco (2010), Bananas are cholesterol free, high in fiber and a source of vitamins A, C and B6, and immediate source of energy.

In the context of Malawi, as highlighted by Gondwe (2004) and Laisnez (2005), the cultivation of bananas assumes a crucial significance, especially within the central and southern regions. This activity functions as a primary income generator for small-scale farmers in these areas. The crop ranks fourth in terms of food security and income generation in the country following crops: maize, rice, and cassava (Banana Production Training Manual for Malawi, 2018). Various cultivars of bananas, including giant Cavendish (Williams) and dwarf Cavendish (Kabuthu), AAA bananas, AAB bananas, and ABB bananas, are cultivated in Malawi (Kenyon et al., 1997).

Despite its significance, according to Gondwe and Banda (2002), banana production in Malawi faces numerous challenges, including both biotic and abiotic stresses. One of the major biotic stresses affecting banana cultivation is the banana bunchy top disease (BBTD).

Banana bunchy top disease

The banana bunchy top disease (BBTD) was first identified in Hawaii in 1889 and is caused by the banana bunchy top virus (BBTV), belonging to the *Babuvirus* genus within the *nanovirade* family (Muengula et al., 2014). The disease has spread to various banana-growing regions, including Malawi, where it was first observed in 1994 and later confirmed in 1997 (Kenyon et al., 1997). By 2012, BBTD had become widespread in Malawi, causing significant yield losses, with reports indicating reductions of over 60% (Soko et al., 2012).

Symptoms and transmission

The disease is primarily transmitted by the aphid vector *Pentalonia nigronervosa* (Amin et al., 2008). Infected plants display characteristic symptoms, such as leaf distortion, marginal leaf yellowing, interveinal yellowing, and the formation of a bunch-like appearance of leaves in advanced stages, giving rise to the name "banana bunchy top" disease (Amin et al., 2008). Early-stage infections can lead to total crop failure, while later-stage infections may result in the production of abnormal fruits (Muengula et al., 2014).

Mode of transmission

Banana bunchy top disease BBTD is not soil-borne; rather, *Pentalonia nigronervosa*, a banana aphid, is the main vector for the disease's spread (Amin et al., 2008). When aphids feed on banana plants with the virus, they become infected themselves. These virus-carrying aphids then travel from one plant to another, infecting healthy banana plants with the virus and aiding in the disease's spread (Amin et al., 2008).

Management strategies

Several management strategies have been suggested to control the spread of BBTD, including uprooting infected banana plants, spraying herbicides to eliminate infected plants, using pesticides to control banana aphids, and implementing quarantine measures to prevent infestation in new areas (James, 2011).

1.2 Problem statement and justification

Banana production in Malawi faces significant challenges arising from various biotic and abiotic factors. Among the biotic factors, banana bunchy top disease (BBTD), caused by *Babuvirus nanoviridae*, has emerged as a major threat with a substantial economic impact on banana cultivation (Muengula et al., 2018). The disease is known to cause significant yield losses, and its severity has become a major concern for farmers and the banana industry alike.

The banana industry plays a critical role in Malawi's crop diversification program, contributing significantly to household food sufficiency and poverty reduction. However, the industry is now on the verge of collapse due to the devastating effects of BBTD (Mbewe et al., 2019). In specific regions such as Nkhata-bay and Nkhotakota, BBTD has been estimated to cause a drastic reduction in banana production from 35 tons per hectare to as low as 8 tons per hectare, highlighting the severity of the situation (Mbewe et al., 2019).

According to Chitengula et al., (2019) current management methods for BBTD, including uprooting and destroying infected plants, pesticide spraying to control aphids, herbicide usage to eliminate infected plants, and quarantine measures, have proven to be labor-intensive and costly for smallholder farmers. The need for innovative and effective management strategies is evident to combat the rapid spread of the disease and reduce its devastating impact on banana production.

Recent research has indicated that the banana aphid, *Pentalonia nigronervosa*, serves as the primary vector responsible for the persistent, non-replicative, circulative transmission of the banana bunchy top virus (Rabion et al., 2005). The secondary spread of the virus by aphids can occur within a limited radius of approximately 15.5 m to 17.2 m, with 66% of new infections within 20 m of the nearest source of infection (Allen, 1987). The establishment of buffer zones between new banana crops and infected plants appears to be a potential management strategy to curtail the spread of BBTD effectively.

Furthermore, the role of poor plant nutrition, a common concern among smallholder farmers in Malawi, in exacerbating BBTD requires in-depth investigation. Limited research exists regarding the effects of buffer zones and proper plant nutrition on BBTD transmission.

This study aims to address the knowledge gaps and develop innovative management options to reduce the spread of BBTD in Malawi. By implementing effective control measures, increased banana production can be achieved, leading to improved food and nutritional security as well as poverty alleviation. Given that banana serve as staple food and a vital source of income for farmers in diverse regions of the country, controlling BBTD will have a substantial positive impact on both the agriculture industry and smallholder farmers' means of life.

1.3 Objectives

1.3.1 Main objective

The main objective of research is to develop effective crop management methods and techniques in which banana bunchy top disease (BBTD) is controlled in Malawi to lessen the damage it causes to banana farms.

1.3.2 Specific objectives

i. To evaluate the farmers' understanding and opinions regarding the prevalence and treatment of banana bunchy top disease
ii. To evaluate the impact of implementing buffer zones and the application of inorganic fertilizer on the spread of Banana Bunchy Top Disease in banana farms.

1.4 Study hypotheses

i. Farmers have knowledge about the incidences and management of banana bunchy top disease.
ii. The establishment of a buffer zone and application of inorganic fertilizer significantly reduces the spread of Banana Bunchy Top Disease in banana fields.

CHAPTER 2
LITERATURE REVIEW

2.1 Botany, ecology, and importance of banana

2.1.1 Botany and evolution of banana

Banana (*Musa* species) is a large, perennial monocotyledous herb of 2 to 9 m in height. It grows from a huge rhizome known as a "corm" (Ploetz et al., 2007). Bananas and plantains were believed to grow on a tree, but it was later discovered that they grow from a large herb called a pseudostem (IPGRI-INIBAP/CIRAD, 1996). The flowers of bananas are elongated, plump, purple to green and they are sometimes called "heart". A semicircular layer of female flowers, followed by neutral flowers and little male flowers devoid of viable pollen are visible as the flower stretches out (Ploetz et al., 2007). The core meristem of the growing sucker produces the initial leaves of a banana plant (Robinson et al., 2010). Full sized leaves are produced six months after developing from broader leaves with widening lamina and narrow sword leaves (Robinson, 2010). New banana plants are propagated through corms, suckers, and tissue culture (Robinson, 2010). The corm is called a true stem that lies underground. Before it extends through the pseudostem and appears about 10 to 15 months after planting as a sizable terminal inflorescence, the meristem of the corm's apical bud produces leaves (Price, 1994). Suckers are the vegetative buds that arise from the rhizome during the development of leaves. There are two types of suckers in terms of morphology; sword suckers which have narrow leaves and broad rhizome base and water suckers which have broad leaves and narrow rhizome bases (Robinson et al., 2010). Suckers are dependent on the parent rhizome for their development (Eckstein and Robinson, 1999).

The banana family Musaceae, which includes 25–80 species of bananas and plantains, includes the genus *Musa* (Robinson et al., 2010*).* The edible bananas originated from southern-east Asian and western pacific regions (Robison et al., 2010). Bananas were dispersed out of Asia due to human mobility (Dainiells et al., 2001). The cultivated, wild, and improved breeds of bananas used for human consumption are all mixed together. The edible bananas are a hybrid of wild and domesticated species as well as improved varieties. The diploid clones were grown in the wetter parts of the southern Asia (Pareek and Sharma, 2017). Chromosomes restitution resulted into the development of seedless triploid cultivars (Raboin et al., 2005) and also crossing between edible diploids and wild species (Daniells et al., 2001). The "ploidy," or the number of chromosomal sets and the relative fraction of *Musa acaminata* (A) and *Musa balbisiana* (B) in their genomes, is used to categorize the Musa species into groups (Ploetz et al., 2007). Tetraploids (AAAA, AAAB, AABB, and ABBB) and diploids (AA, AB, and BB) are uncommon (Ploetz et al., 2007). Bananas come in more than a thousand different kinds, thanks to natural somatic mutation and hybridization (Ploetz et al., 2007). In drier regions of Asia, diploid edible Musa balbisiana cultivars underwent a parallel evolution, but due to human migration, cultivars crossed with Musa acuminata, which resulted in the formation of hybrid seeded kinds (Daniells et al., 2001). Hybridization started in India which became the major center of hybridization (Daniells et al., 2001). Parallel evolution and subsequent hybridization resulted into two species with a wide range of genotypes (i.e., homogenomic and heterogenomic diploids, triploids, and tetraploids). According to Simmonds and Shepherd (1995), the two species' genomes provided different features, with *Musa acuminata's* mostly contributing to parthernocapy and sterility and *Musa balbisiana's* primarily contributing to hardiness, drought tolerance, disease resistance, and starchiness. Most of the cultivated types are triploid; AAA are sweet cultivars that are used for desert and the AAB and ABB are starchy cooking types (Gowen, 1995). Arabs who regarded banana as a holy crop brought bananas to Africa (Reynolds, 1922). African-specific variants include AAA in the East African highlands and AAB, which emerged from somatic mutation (Simmonds, 1966).

2.1.2 Ecology of banana

Bananas fall under the umbrella of tropical and subtropical fruits. Commercial banana cultivation extends from the equator to latitudes of at least 30°. There are occasionally a few sizable banana-growing locations outside of these boundaries (Turner and Lahav, 1983). For successful commercial banana production, one of the most crucial things to consider is temperature. The optimum temperature for banana production is 27ºC and poor fruiting is experienced when the temperature lowers to 15ºC (Espino et al., 1992). Williams's (Giant Cavendish) banana cultivar growth was studied by Turner and Lahav (1983), who concluded that plants exhibited heat injury at day and nighttime temperatures of 37°C and 30°C, respectively. An average of 50-100 mm of weekly rainfall or irrigation is required to provide good moisture which is important for optimum growth of the banana crop (DPI & F, 2004). The ideal rainfall is regarded as having a well-distributed annual average of 1500–2500 mm. However, with proper water management, bananas can even thrive in areas with mean annual rainfall of less than 1200 mm (Uganda Government, 2001). Lack of water leads to reduction of shoot growth, fruit number and size and also reduction in yield.

Producing bananas requires soils with a high humus content that are deep and well drained. The ideal pH range is between 5.6 and 7.5 to maintain high yields, bananas need a lot of nitrogen (N) and potassium (K). These can be produced by planting on rich soils or by routinely adding fertilizer (Uganda Government, 2001). According to the Malawian government (1994), producing bananas requires relatively level ground with a slope of at least 2%.

2.1.3 Importance of banana

One of the most significant crops in the world is the banana (Wanitchakorn et al., 2000). It is cultivated in more than 150 nations and is a staple meal for more than 70 million people (Frison and Sharrock, 1998). After rice, wheat, and maize, bananas are the fourth most important crop in the least developed countries (CGIAR, 2011). The fruit banana has the highest export value of all the fruit crops and is the most widely exported worldwide (FAO, 2011). According to Atchédji et al. (2010), households use bananas as a source of both food and income. They offer nutrients like calcium, potassium, and vitamin A along with carbs (Robinson, 2010). Bananas can be cultivated next to established orchards or as a side crop for meals or as a dessert (Dzomeku et al., 2010). Burundi and Rwanda also use the grain to make beer, making it a source of income (Karamura et al., 1998). In Sub-Saharan African countries, banana is mostly grown in high altitude areas hence they provide vegetative cover to control soil erosion and run off (Beed, 2008).

Banana is grown near people's back yard gardens in most of the districts in Malawi. However, the highest producing districts are Thyolo and Mulanje in the Southern Region, Nkhotakota in the central region and Nkhata-bay and Karonga in the Northern region (Soko et al., 2012). In Malawi, bananas are a vital crop for household income and food security, and smallholder farmers cultivate them extensively (Jooste, 2013). According to Banana Production Training Manual for Malawi (2018), Banana is Malawi's fourth-most significant crop, following maize, rice and cassava. It is commonly grown by smallholder farmers in a systematic orchard or uncontrolled number of suckers per station which are called "mats." It provides both food and revenue (Gondwe and Banda, 2002). In Malawi over 100,000 farmers are involved in banana production, of which 40% are women (Gondwe and Banda, 2002). In the northern part of Malawi, banana is used as a staple meal and in southern and central regions banana is used as a dessert hence it is a source of money to most of the smallholder farmers (Gondwe, 2004; Laisnez, 2005). Banana leaves are utilized as animal feed in several regions of the nation, particularly in the districts of Chikwawa and Nsanje (Gondwe and Banda, 2002).

2.2 Constraints to banana production

Despite all its benefits, banana is facing a lot of challenges that affect its production. In Africa, banana production has not improved as compared to other continents like Asia, because there is little research investment in banana production (Beed and Markham, 2008). There is a very big variation in terms of yields of bananas, with a range from 5 to 70 tons per ha (Delvaux, 1995). This huge variation is because of different constraints which can be grouped into biotic, abiotic and social constraints.

Social economic factors that affect banana production in developing countries include low land holding size and lack of access to credit which results in reduced adoption of improved technologies in banana production (Dzomeku et al., 2010). Most East African banana growers don't use fertilizer because to the high cost, unpredictable availability, lack of access to financial options, and lack of information about fertilizer use (IITA, 2010). In Malawi, farmers face the problem of low land holding size. For instance, in Thyolo and Mulanje districts the average land holding size is 0.2 ha because their landscapes are dominated by tea, macadamia and coffee estates (Chinsinga, 2008).

Abiotic variables such as rainfall, temperature, wind, and soil qualities also have an impact on banana production. Strong winds, excessive salinity, and moisture stress are not favorable for growing bananas, especially Cavendish clones (Ravi and Vaganan, 2016). Since the crop is really a humid tropic plant, wet, warm weather without high winds is ideal throughout the entire year (Ravi and Vaganan, 2016). It requires deep, well drained loamy soils with high organic matter content.

Degradation of natural resources has resulted into increased attacks on banana by pests and diseases (Karamura et al., 1998). Pests and illnesses pose a serious threat to the banana industry. (Jain, 2005). Thrips (*Chaetonaphothrips signipennis*), aphids (*Pentalonia nigronervosa*), maize weevils (*Cosmospolites sordidus*), stem weevils/pseudostem borer (*Odoiporus longicollis*), burrowing nematodes (*Radopholus similis*), and hard scales are some of the most problematic pests (*Aspidiotus destructor*). The major diseases of bananas include, banana bunchy top disease (*Babuvirus nanoviridae*), panama disease (*Fusarium oxysporum)*, cigar end rot (*Verticillium theobromae*), black sigatoka (*Mycosphaeralla fijiensis*) and banana bacterial wilt (*Xanthomonas campestris* pv. *Musacearum*). Banana bunchy top disease (BBTD) is one of the most dangerous viral illnesses because it drastically reduces yields in many sub-Saharan African nations (Ploetz, 1998). Yield losses of over 60% were observed due to BBTD in Malawi and Zambia (FAO, 2009). A severe danger to banana productivity in growing regions is the banana bunchy top disease (Niyongere et al., 2013). According to Kumar et al. (2011), BBTD is widespread throughout the Democratic Republic of the Congo (DRC), Malawi, Angola, Gabon, and the south and western regions of Cameroon.

2.3 Description of banana bunchy top disease

According to Kumar et al. (2011), BBTV initially appeared in sub-Saharan Africa in the Democratic Republic of the Congo in the 1950s. The first case of the disease in Malawi was discovered in 1994 in the central Nkhotakota district. And now it is also commonly found in Nkhata-bay district in the north of Malawi (Kenyon et al., 1997). As indicated by Soko et al. (2012), the disease was present throughout all of Malawi's districts. The Banana bunchy top virus *(*BBTV*)* of the genus *Babuvirus* family *Nanoviridae* is the culprit behind banana bunchy top disease (Furuya et al., 2004; 2005). The BBTV is phloem tissue specific, causing various cytopathological effects (Wanitchakorn et al., 2000). The following are some of the symptoms of the disease: leaf distortion, marginal leaf yellowing, interveinal yellowing, bearing small fruits and, at an advanced stage the leaves forming a bunch hence the name banana bunchy top. Total yield loss occurs in plants infected in early stages and those infected in later stages may produce abnormal fruits (Muengula et al., 2014). Banana aphids (*Pentalonia nigronervosa*) and infected vegetative planting materials are the main carriers of the banana bunchy top virus in banana crops (Qazi, 2015). The banana aphid reproduces parthenogenetically (without mating), hence females typically produce live young aphids. The life cycle of a banana aphid nymph usually is 9 to 16 days and the adult 8 to 25 days (Rajan, 1981). Banana bunchy top virus is systematic, symptoms usually appear in new leaves after 20 to 85 days from inoculation (Magee, 1927). The virus is persistently circulatory and does not reproduce itself. (Wanitchakorn et al., 2000). The symptoms that the virus causes in plants can be used to diagnose BBTD in the field, and biochemical and molecular methods like enzyme-linked immunosorbent assay (ELISA) and polymerase chain reaction can be used to find the virus in plant tissue (PCR). ELISA has limited sensitivity especially when the concentration of the virus is low (Wanitchakorn et al., 2000).

2.4 Banana yield losses in Malawi due to BBTD

Banana bunchy top disease (BBTD) has had a significant and far-reaching impact on banana production in Malawi, resulting in substantial yield losses across various regions. A recent study conducted by Mphande et al. (2022) revealed alarming findings, with BBTD leading to yield reductions of up to 78% in affected banana fields. Such extensive losses highlight the severity of the disease and its implications for food security and income generation in the country.

The districts of Nkhata-bay and Nkhotakota have been among the hardest hit by BBTD. Soko et al. (2018) reported that prior to the outbreak of BBTD, farmers in these regions were able to achieve an average yield of 35 tons per hectare. However, following the introduction of the disease, yields drastically declined to as low as 8 tons per hectare. This staggering drop in productivity underscores the urgency in finding effective measures to control and mitigate the spread of BBTD.

The impact of BBTD is not confined to specific regions; it has widespread consequences for banana production throughout Malawi. Muamba et al. (2021) conducted an extensive study covering multiple districts and found that average yield losses due to BBTD ranged from 40% to 50%. This comprehensive assessment highlights the devastating effects of the disease on banana cultivation across the country.

According to Muamba et al. (2021) the yield losses caused by BBTD have far-reaching implications beyond food security. Smallholder farmers, who heavily rely on banana farming as a primary source of income and livelihood, have been disproportionately affected by the disease's detrimental effects. For millions of people in Malawi, bananas are both a primary source of food and a vital source of cash, addressing the BBTD outbreak and its associated yield losses is of paramount importance for the sustainability of the agricultural sector and the overall economic stability of the nation.

Mkandawire (2019) stated that to combat the spread of BBTD and mitigate its impact on banana production, urgent and strategic interventions are needed. Implementing effective crop management practices, such as the establishment of buffer zones and improved plant nutrition through the application of inorganic fertilizers, may play a pivotal role in curbing the disease's progression and restoring banana yields to more sustainable levels. Investing in research, education, and support for smallholder farmers is crucial in developing and disseminating practical and sustainable solutions to safeguard Malawi's vital banana industry.

2.5 Management of banana bunchy top disease (BBTD)

The management of Banana bunchy top disease (BBTD) is critical to mitigate its devastating impact on banana production in Malawi. Currently, various management practices are employed to control the spread of the disease. These procedures include eradication, chemical control, biological control, and isolation measures (Orissa Review, 2007). During quarantine, the movement of banana planting supplies is restricted to prevent the disease from spreading to new areas. Eradication involves the digging and burning of infected plants and suckers in the field, coupled with routine monitoring, to effectively reduce the incidence of banana bunchy top disease (Orissa Review, 2007).

Biological control offers another approach to manage BBTD by reducing the population of banana aphids, which are the primary vectors of the disease. The ladybird beetle (*Coccinella septumpunctata*) is a natural enemy of the banana aphid, *Pentalonia nigronervosa*. Additionally, chemical control involves the use of insecticides to lower the banana aphid population (Orissa Review, 2007). Establishing a buffer zone around banana farms is another essential strategy to curtail the spread of the banana bunchy top virus. Early detection and destruction of infected plants within these buffer zones can prevent disease dissemination (Orissa Review, 2007).

Insights from studies conducted in other regions further inform management strategies for BBTD in Malawi. Niyongere et al. (2013) conducted a study in Uganda, which revealed that the incidence of BBTD varied between banana cultivars and geographic regions. After nine months, plots located between 5 and 30 meters away from affected banana fields exhibited an incidence of BBTD ranging from 0-12.3%, while plots adjacent to infected fields displayed an incidence ranging from 21.8% to 56.4%. This underscores the significance of cultivar and plot location in disease incidence.

Lepoint et al. (2014) emphasized the importance of establishing buffer zones to revamp banana production in BBTD-affected areas, reducing disease spread. In Malawi, Soko et al. (2012) identified various cultivars, including TMBx 582/4, TMBx 5295/1, Natitengwa, Pelipita, Cardiba, and TMBx 1378, that demonstrate the ability to tolerate BBTD. Plant nutrition is crucial for boosting natural disease resistance, in addition to genetic variables controlling disease resistance in plants (Armstrong, 1998). A deficiency of potassium (K) in banana plants weakens their defenses against pathogen invasion, making them more susceptible to BBTD (Armstrong, 1998). Therefore, ensuring good fertility management practices can help strengthen banana plants' resilience against the disease (Armstrong, 1998).

It is essential to acknowledge that no Musa cultivar is known to be completely resistant to BBTV, as highlighted by Daniells (2009). However, some studies have reported variations in susceptibility levels among cultivars. Cultivars containing AA or AAA genotype are said to be more susceptible than those with the B genome (Magee, 1948). Considering these differences in susceptibility levels, the use of resistant or less susceptible cultivars can be explored as part of an integrated approach to control BBTD.

To effectively manage BBTD in Malawi, a comprehensive strategy that combines quarantine measures, eradication, biological and chemical control, buffer zones, cultivar selection, and proper plant nutrition should be adopted. Regular monitoring and research efforts will also be crucial in continuously improving disease management techniques and safeguarding the country's banana production sector. By implementing these recommendations, Malawi can combat BBTD's impact, ensure food security, and support the livelihoods of smallholder farmers who heavily rely on banana cultivation.

2.6 Effects of nitrogen, potassium and phosphorus fertilizers on plant viral diseases

Plant viral diseases can significantly impact crop yield and quality, leading to economic losses in agriculture. While various factors influence the occurrence and severity of viral diseases in plants, the use of fertilizers, specifically nitrogen, potassium, and phosphorus, can have notable effects on disease development.

2.6.1 Evaluation of current fertilizer practices in Malawi

In the evaluation of current fertilizer practices in Malawi's banana cultivation, the study will focus on assessing the actual application rates of nitrogen, potassium, and phosphorus fertilizers being used by banana farmers across different regions. This assessment is crucial to understand how these essential nutrients are being utilized and whether the current application rates align with the recommended guidelines for effectively controlling banana bunchy top disease (BBTD).

According to the Banana Production Manual under the Kutukula Ulimi M'Malawi (KULIMA) Programme (GOM, 2018), banana plants are known to be rapid growers and heavy feeders, requiring a balanced N:P:K fertilizer. However, it is emphasized that the crop has higher demand for nitrogen (N) and potassium (K) compared to phosphorus (P). The recommended fertilizer application rates, as outlined in the manual, include several options:

1. Applying 200 g Calcium Ammonium Nitrate (CAN), 250 g Single Superphosphate, and 175 g Muriate of Potash per mat at the beginning of the rainy season, followed by an additional 200g of CAN per mat in March.
2. Alternatively, using 75g Urea, 200g of 23:10:5+6S+1Zn, and 175g Muriate of Potash per mat at the beginning of the rainy season, followed by 125g Urea in March.

3. Another option is to apply 200g of CAN plus 200g of D-Compound per mat at the beginning of the rainy season, followed by 125g Urea in March. All fertilizers are to be broadcast in the basin, keeping them 30 cm away from the stems.

2.6.2 Effects of nitrogen fertilizers on plant viral diseases

Nitrogen is an essential nutrient for plant growth and is often supplied using fertilizers. While nitrogen promotes vigorous plant growth and enhances crop yield, its excessive application can have detrimental effects on plant health, including an increase in plant susceptibility to viral diseases.

In a study by Xiong et al. (2018), it was demonstrated that excessive nitrogen fertilization has become more common and serious problem than viral diseases in cucumber plants. The researchers found that high nitrogen levels promoted rapid plant growth, leading to an extended period of vulnerability to viral infections. Additionally, the increased vegetative growth facilitated the spread of viruses within the plant population.

Furthermore, the presence of high nitrogen levels in the plant tissues can alter the plant's physiology and biochemistry, making it more attractive to insect vectors that transmit viral diseases. Insects, such as aphids, are known to prefer plants with higher nitrogen content, thereby increasing the likelihood of viral transmission (Blua et al., 2012).

2.6.3 Effects of potassium fertilizers on plant viral diseases

Potassium is essential for various physiological processes in plants, including enzyme activation and osmoregulation. Adequate potassium levels contribute to improved plant health and enhanced resistance to various stresses, including viral infections. However, the influence of potassium on plant viral diseases is complex and can vary depending on the specific plant-virus interaction.

Research by Kang et al. (2015) on tobacco mosaic virus (TMV) in tobacco plants revealed that an appropriate supply of potassium significantly reduced TMV symptoms and viral replication. The study proposed that potassium enhanced the plant's defense responses, activating systemic acquired resistance (SAR) mechanisms against viral pathogens.

Conversely, Kehoe et al. (2019) reported that excessive potassium fertilization in potato plants increased the susceptibility to potato virus Y (PVY) infection. The researchers suggested that the disrupted balance of other nutrients, particularly magnesium and calcium, due to high potassium levels may have weakened the plant's immune system, rendering it more susceptible to viral infections.

2.6.4 Effects of phosphorus fertilizers on plant viral diseases

Phosphorus is crucial for energy transfer in plants and is involved in various metabolic processes. It plays a vital role in plant growth, root development, and flowering. While phosphorus is essential for overall plant health, its direct impact on plant viral diseases is relatively understudied compared to nitrogen and potassium.

However, research by Sun et al. (2021), on tomato spotted wilt virus (TSWV) in tomato plants suggested that adequate phosphorus levels in the soil may confer some degree of resistance against viral infections. The study observed that plants with sufficient phosphorus showed reduced symptom severity and lower viral titers compared to phosphorus-deficient plants. The exact mechanisms of how phosphorus influences viral resistance remain unclear and warrant further investigation.

In summary, the effects of nitrogen, potassium, and phosphorus fertilizers on plant viral diseases are multifaceted and context dependent. While excessive nitrogen and potassium applications can increase plant susceptibility to viral infections, the role of phosphorus in viral disease management requires more research. It is essential for farmers and agricultural practitioners to strike a balance in fertilizer application to maintain optimal plant health and minimize the risk of viral disease outbreaks. Integrated pest management strategies that consider nutrient levels and other factors impacting plant-virus interactions can help mitigate the adverse effects of fertilizers on viral diseases in crops.

CHAPTER 3
EVALUATION OF FARMERS' KNOWLEDGE AND PERSPECTIVES REGARDING THE INCIDENCE AND MANAGEMENT OF THE BANANA BUNCHY TOP DISEASE

3.1 Abstract

Banana bunchy top disease (BBTD) is a highly economically significant disease affecting banana production worldwide, leading to substantial yield losses of over 60%. In Malawi, BBTD has spread across all districts, posing a significant threat to banana cultivation. Current management practices for the disease involve uprooting and destroying infected plants, pesticide spray to control aphids, and quarantine measures. However, the uprooting process has been found to be labor-intensive and met with non-compliance from many farmers.

To address this issue, a study was conducted to assess farmers' perceptions and understanding of BBTD prevalence and treatment in the districts of Mulanje and Nkhata-bay. A total of 76 randomly selected farmers participated in the study, answering a semi-structured questionnaire that covered dominant crops, banana cropping systems, fertilizer usage, understanding of suggested BBTD controls, and problems faced in banana production.

In both districts, most respondents (54.0% in Mulanje and 62.0% in Nkhata-bay) said they had completed primary education. The most common crop grown by farmers over the previous five years was the banana (30.8% in Mulanje and 50.0% in Nkhata-bay), while the majority relied heavily on agricultural production for revenue (65.4% in Mulanje and 94.0% in Nkhata-bay). Majority of farmers, with a considerable fraction having fewer than 20 mats apiece, planted their bananas in mats, the survey found. Most farmers adhered to the prescribed plant spacing of 3 m by 3 m. Even though many farmers were aware of the BBTD, only a small percentage said they have used uprooting as a preventative measure (30.7% in Mulanje and 48.0% in Nkhata-bay), only a fraction reported using uprooting as a control method (30.7% in Mulanje and 48.0% in Nkhata-bay).

The impact of BBTD on banana yield was evident, with a reduction of 30 to 15 tons per hectare reported by farmers. Lack of access to clean planting materials for new orchards was also a significant concern, with most farmers lacking alternative sources. A considerable percentage resorted to purchasing planting materials from other farmers.

Most farmers (67.4%) got their information on BBTD management strategies from extension staff. The poses a significant obstacle to banana production in the research sites, demanding actions to guarantee access to clean planting materials. To address this challenge, the study recommends the establishment of institutions involved in the multiplication of clean banana planting materials. Furthermore, building the capacity of farmers to multiply clean banana planting materials will enhance their ability to combat BBTD effectively and improve banana production in Malawi. These measures are essential for ensuring sustainable banana cultivation and securing the livelihoods of smallholder farmers in the country.

Key words: Banana bunchy top disease, farmers, recommended control measures

3.2 Introduction

Banana (Musa species) serves as a staple food for about 70 million people in Africa (Frison and Sharrock, 1998). According to Gondwe and Banda (2002), it is Malawi's sixth most important crop after maize, rice, groundnuts, vegetables, and beans. The banana industry is a target sector in Malawi's crop diversification program because it is essential to ensuring household food security and reducing poverty. In Malawi, the Musa species of banana is a key food and commercial crop. A study conducted by Gondwe et.al, (2004), found that 50% and 43% of farmers' income in Nkhata Bay and Mulanje, respectively, came from banana. It has a high potential for poverty alleviation and reducing malnutrition. The crop is ranked as fourth staple crop after maize, rice, and cassava in Malawi (Banana Production Training Manual for Malawi, 2018). Production of the crop is mostly done by smallholder farmers mainly in Mulanje, Thyolo, Nkhata Bay, Chitipa and Karonga districts. The crop is a significant source of food and income. It is high in vitamin A and produces fruits throughout the year. However, banana yields have been declining due to the impact of pests, diseases, and poor reproductive issues. Among the devastating viral diseases affecting bananas, banana bunchy top disease (BBTD) has emerged as a significant threat. Reports by Soko et al. (2012) indicate that BBTD has caused drastic reductions in banana yields from 35 tons per hectare to as low as 8 tons per hectare in the districts of Nkhata-bay and Nkhotakota.

The Banana Bunchy Top Virus (BBTV), a member of the Nanovirade family in the Babuvirus genus, is responsible for BBTD. The virus is transmitted by the banana aphid (Pentalonia nigronervosa Coq) and through infected plant materials used for vegetative planting (Qazi, 2015). Additionally, the issue of land degradation and poor soil fertility contributes to low crop output in Malawi (Njoloma et al., 2016). As the fertility rate rises, the nation's heavy dependence on agriculture poses challenges for sustainable productivity (FAO, 2017). Land erosion in Malawi results in an annual loss of over 30 kg of nitrogen and 20 kg of phosphorus per hectare (Njoloma et al., 2016). Poor plant nutrition due to limited fertilizer application by smallholder farmers may accelerate the spread of BBTD.

Banana plants that are infected with the disease are pulled up and burned, insecticides are used to suppress aphids, and quarantine regulations are in place to limit the spread of the disease (James, 2011). However, farmers have found that removing sick plants requires a lot of labor (Kumwenda, 2013).

Despite the significant challenges that BBTD poses to the banana production industry in Malawi, limited information exists regarding the farmers' knowledge and perceptions of the disease's incidence. Therefore, this study aims to assess farmers' understanding, perceptions, and management practices related to Banana Bunchy Top Disease. The findings will contribute to the development of effective management strategies to reduce the spread of the disease and enhance banana production in Malawi.

3.3 Materials and methods

3.3.1 Study site

In the Mulanje district's Milonde extension planning area (EPA), as well as the Nkhata-bay district's Mpamba and Chintheche EPAs, a survey was undertaken. The two districts were selected because they are among the most intensive banana growing areas in Malawi and the three EPAs were the two districts' main banana-growing regions. Nkhata-bay district lies on 11.6086°South, 34.2949°East. It is situated 485 m above sea level and has a total land area of 4,071 sq. km. The district receives 1500 mm of rain yearly, with the majority falling between the months of February and April. Clay-loam, sandy-loam, and clay soils make up most of it. According to the SEP for Nkhata-bay (2012), it likewise experiences minimum temperatures of 18 °C and maximum temperatures of 35 °C.

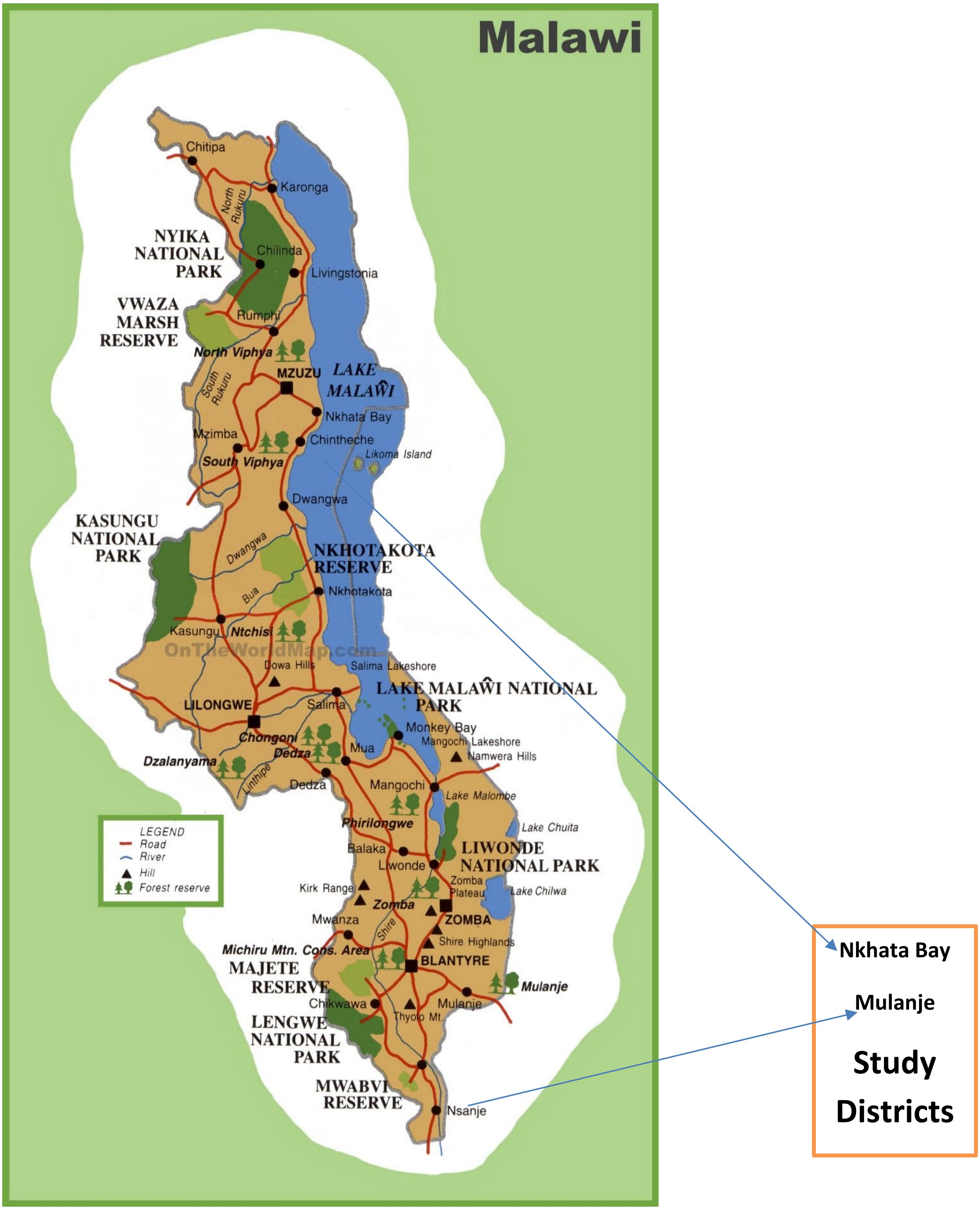

Figure 3.1. Map of Malawi indicating the study sites

Malawi's southern area includes the district of Mulanje. 2056 square kilometers make up the district, which is situated 764 meters above sea level (SEP for Mulanje district, 2014). According to the SEP for Mulanje district from 2014, clay-loam, sandy clay-loamy, sandy-loam, and clay soils are the most common types of soil in the area. The region normally receives temperatures of 27 °C and 1150 millimeters of yearly average rainfall. It is located at 15.9346° South and 34.35° East.

3.3.2 Population of the study

The term "population" describes the total group of people, things, or factors that have something in common and are of interest to the researcher. In a research setting, it symbolizes the larger group from which a sample is taken to draw conclusions or inferences about that group. The population is essential in research because it helps define the scope and generalizability of the study's findings. Understanding the population allows researchers to draw accurate and meaningful conclusions about the group of interest based on the data collected from the sample. Therefore, this research had a population of 200 people, comprising of 80 participants from Mulanje in Milonde EPA, 70 from Nkhata-bay in Mpamba EPA,
And 50 from Nkhata-bay in Chintheche EPA. Below is the table providing details of the population and sample size for the study. Extension planning area (EPA) is an agriculture zone within a district where planning of agriculture extension services is conducted and the zoning is based on agro-ecological zones.

Table 3.1 The population and sample size for the study

District	**Extension Planning Area (EPA)**	**Population Size (N)**	**Sample Size (n)**
Mulanje	Milonde EPA	80	26
Nkhata-bay	Mpamba EPA	70	25
Nkhata-bay	Chitheche EPA	50	25
Total		200	76

sample size= 76

Source: Author (2023)

3.3.3. Sample size and sampling method

The sample of banana growers was chosen for the study using a systematic random sampling procedure from the three Extension Planning Areas (EPAs). The EPAs chosen for the study were those that were well-known for growing bananas in the Nkhata-bay and Mulanje districts. The sample size was calculated using the Slovin formula with a 95% degree of precision. (Slovin, 1960).

Banana growers in three separate Extension Planning Areas (EPA) in the districts of Nkhata-bay and Mulanje were the focus of the study. The sample size was established using the formula below. (Slovin, 1960);

$$n=\frac{N}{1+N(e)^2}$$

The population size is N, the sample size is N, and the level of precision is E. In this poll, a level of precision of ninety-five percent (95%) was employed.

Because a sample created using this technique tends to be more representative, systematic random sampling was used (Bellhouse, 2005). Because bananas are farmed in the four extension planning regions in the two districts, they were selected. The sampling ratio (Kth) for each EPA was calculated by dividing the population size (N) by the sample size (n). Each EPA's Kth farmer was chosen first, and all Kth farmers were chosen to participate in the survey. A total of 76 farmers were chosen, including 26 farmers from Mulanje district and 50 from Nkhata-bay district. The research was conducted in November 2016.

3.3.4 Data collection

A semi structured questionnaire (Appendix 1) was developed and pretested by the support of 10 farmers. Demographics, dominating crops over the previous five years, banana cropping patterns, type of fertilizer used, knowledge of banana bunchy top disease and its recommended control measures, severity of the illness, and difficulties encountered in the cultivation of bananas were among the information gathered. According to the degree of infection, the banana bunchy top disease seriousness was graded on a scale of 0 to 5, with 0 denoting symptomless, 1 representing dark green streaks on leaf veins, 2 representing dark green streaks on leaf midribs and petioles, 3 denoting marginal leaf chlorosis, 4 denoting dwarfing of leaves, and 5 denoting the "bunchy top" aspect, which is represented by upright, crowded, and brittle leaves at the. Four enumerators were recruited to conduct the survey. After being hired, the four enumerators received training on how to interview the chosen farmers. The questionnaire was first presented to the enumerators for them to get familiarized with the questions. The survey used both closed and open-ended questions to avoid limiting responses from respondents. Open-ended questions helped to probe people's ideas on BBTD.

3.3.5 Data Analysis

Data cleaning and coding were done before generating descriptive statistics with the Statistical Package for Social Scientists (SPSS). Chi-square test was applied to test the relationships between age and cropping systems and gender and cropping systems.

3.4 Results

3.4.1 Demographic and social-economic data

In Nkhata-bay, the majority (52.0%) of respondents were male, while the majority (76.9%) of respondents in Mulanje were female (Table 3.2). Most respondents were married (72.0% in Mulanje and 68.0% in Nkhata-bay). Although there were minor differences in the respondents' ages, the majority (38.0% in Nkhata-bay) were between the ages of 32 and 40. The respondents' level of education also varied, with the majority having completed primary school (54.0% in Mulanje and 62.0% in Nkhata-bay). In Mulanje and Nkhata-bay, respectively, only 15.0% and 14.0% of respondents had not received any formal schooling.

Table 3.2 Gender, marital status, age, and education level of respondents (%) in Mulanje and Nkhata-bay districts of Malawi

	District	
	Mulanje	**Nkhata-bay**
Gender		
Male	23.1	52.0
Female	76.9	48.0
Marital Status		
Single	12.0	4.0
Married	72.0	68.0
Divorced	8.0	6.0
Windowed	8.0	22.0
Never married	0.0	0.0
Age		
Below 20	3.8	4.0
21-30	30.8	24.0
32-40	38.5	38.0
Above 40	26.9	34.0
Education level		
Primary	54.0	62
Secondary	31.0	22.0
Tertiary	0.0	2.0
No formal education	15.0	14.0

sample size =76

3.4.2 Dominant crops over the previous five years (2010-2015) and farmers' source of income in Mulanje and Nkhata-bay districts of Malawi

Banana, maize, and sweet potatoes were the top three crops in the Mulanje district over the preceding five years, while rice, bananas, and maize were the top three in the Nkhata-bay district (Table 3.3). Bananas dominated the agricultural landscape in both areas (50.0% in Nkhata-bay and 30.8% in Mulanje). The majority of farmers in Mulanje (65.4%) and Nkhata-bay (94.0%) stated that crop cultivation was their main source of income, followed by part-time labor and small businesses.

Table 3.3: Dominant crops over the previous five years (2010-2015) and farmers' source of income in Mulanje and Nkhata-bay districts of Malawi (% respondents)

Dominant crops over the five years	District	
	Mulanje	**Nkhata-bay**
Banana	30.8	50.0
Oranges	3.8	0.0
Avocado	3.8	2.0
Maize	30.7	16.0
Cassava	3.8	8.0
Tea	3.8	0.0
Sweet potato	19.5	6.0
Rice	0.0	18.0
Groundnuts	3.8	0.0
Source of Income		
Crop production	65.4	94.0
Casual labor	30.8	0.0
Small scale business	3.8	6.0

Sample size= 76

3.4.3 Banana cropping systems in Mulanje and Nkhata-bay districts of Malawi in 2016

Bananas were farmed in orchards or mats in the Mulanje and Nkhata-bay districts (Table 3.4). Bananas were primarily planted on mats by farmers in the Mulanje (88.5%) and Nkhata-bay (80.0%) districts. Few farmers reported planting bananas in orchards in Mulanje (11.5%) and Nkhata-bay (20.0%). Less than 20 mats were planted by most farmers in Mulanje (88.5%) and Nkhata-bay (50.0%) who used mats. In Mulanje (76.9%) and Nkhata-bay (82.0%), many respondents had 0.1-0.25 acres of land planted in bananas.

No farmer in the two districts had more than 240 mats or 0.4 acres of bananas planted. Plant spacings of 3 m by 3 m (76.9%), 4 m by 4 m (15.5%), 2 m by 4 m (3.8%), and 2 m by 2 m (3.8%) were employed by Mulanje farmers. Farmers in Nkhata-bay employed plant spacing of 3 by 3 meters (50%) and 3 by 2 meters (2%), 6 by 2 meters (2%) and 4 by 4 meters (2%). There was no set plant spacing for 44% of the farmers in Nkhata-bay. In the Mulanje and Nkhata-bay district, six different banana types were farmed, including Zambia, Mpama, Mulanje, Grandnaine, Mzeru, and Kabuthu. Grandnaine was among the top three cultivars planted in the Mulanje district. (42.3%), Kabuthu (30.8%) and Zambia (15.3%). In Nkhata-bay, the top three grown varieties were Kabuthu (36.0%), Zambia (34.0%) and Grandnaine (24.0%). Mzeru was the least (2%) grown variety in Nkhata-bay district

Table 3.4: Banana cropping systems in Mulanje and Nkhata-bay districts of Malawi in 2016 (% respondents).

	District	
	Mulanje	**Nkhata-bay**
Banana cropping system		
Mats	88.5	80.0
Orchard	11.5	20.0
Number of mats per farmer		
≤ 20	88.5	50.0
21-121	7.7	40.0
122-240	3.8	10.0
≥ 241	0.0	0.0
Acreage under banana orchards		
≤0.09	11.5	10.0
0.1-0.25	76.9	82.0
0.26-0.4	3.8	8.0
≥0.4	0.0	0.0
Plant spacing		
2 m* 2 m	3.8	2.0
2 m*4 m	3.8	2.0
3 m* 2 m	0.0	2.0
3 m *3 m	76.9	50.0
4 m* 4 m	15.5	2.0
5 m* 5 m	0.0	0.0
6 m* 3 m	0.0	2.0
No specific spacing	0.0	40.0
Banana varieties being grown		
Kabunthu	30.8	36.0
Mpama	7.7	2.0
Zambia	15.3	34.0
Mulanje	3.9	2.0
Grandnaine	42.3	24.0
Mzeru	0.0	2.0

sample size= 76

3.4.4 Agronomic management of banana fields in Mulanje and Nkhata-bay districts of Malawi

Mulanje (69.2%) and Nkhata-bay (64%) farmers in Mulanje claimed that they did not apply fertilizer to their banana crops, respectively (Table 3.5). In both areas, most farmers (90.0% in Nkhata-bay and 80.8% in Mulanje) employed organic fertilizers. Most farmers weeded their orchards or banana mats twice or three times annually.

Table 3.5: Agronomic management of banana fields in Mulanje and Nkhata-bay districts of Malawi (% respondents).

	District	
	Mulanje	**Nkhata-bay**
Fertilizer application		
Applied	30.8	36.0
Did not apply	69.2	64.0
Type of fertilizer used		
Organic	80.8	90.0
Inorganic	19.2	10.0
Frequency of weeding		
Once a year	7.7	10.0
Twice a year	46.2	44.0
Three times a year	42.3	46.0
Four times a year	3.8	0.0

sample size =76

3.4.5 Challenges farmers face in banana production in Mulanje and Nkhata-bay districts of Malawi

BBTV (100%) was the biggest obstacle for the farmers in both districts who were interviewed (Table 3.6). Farmers in Mulanje also listed inadequate soil fertility (15.3% pests, 7.7% theft, 61.5% lack of expertise about banana cultivation, 40.8% lack of improved varieties, and 30.7% uncertain markets as key obstacles. Farmers in Nkhata-bay identified several difficulties in producing bananas, including a lack of improved kinds (42.0%), theft (32.0%), ignorance of banana cultivation (24.0%), uncertain markets (16.0%), low soil fertility (8%), and pests (8%).

Table 3.6: Challenges experienced by farmers in production of banana in Mulanje and Nkhata-bay districts of Malawi (% respondents)

	District	
Constraints to banana production	**Mulanje**	**Nkhata-bay**
BBTD	100.0	100.0
Lack of improved varieties	80.1	42.0
Theft	61.5	32.0
Lack of knowledge in banana production	40.8	24.0
Unreliable markets	30.7	16.0
Poor soil fertility	15.3	8.0
Pests	7.7	8.0

BBTD- Banana bunchy top disease, Sample size-76

3.4.6 Knowledge of farmers on strategies for improving the management of banana bunchy top disease in Mulanje and Nkhata-bay regions of Malawi

In both districts, the majority of respondents (55.4% in Mulanje and 63.0% in Nkhata-bay) stated that they were aware of the control measures that the BBTD recommended (Table 3.7). The sharing of suckers (96.0% in Mulanje and 83.0% in Nkhata-bay) and insects (46.0% in Mulanje and 56.0% in Nkhata-bay) was cited by the majority of farmers in both districts as a means of BBTV dissemination. The majority of farmers (80.0% in Mulanje and 54.0% in Nkhata-bay) got their information on suggested BBTD management strategies from extension personnel. The two most popular methods for enhancing BBTD management were uprooting and burning infected plants (30.7% in Mulanje and 48.0% in Nkhata-bay), which was mentioned by the majority of respondents (46.2% in Mulanje and 36.0% in Nkhata-bay).

Table 3.7: Farmers' knowledge of banana bunchy top disease (BBTD) recommended control measures and strategies for improving the management of the disease in Mulanje and Nkhata-bay districts of Malawi (% respondents)

	District	
	Mulanje	**Nkhata-bay**
Knowledge on BBTD recommended control measures		
Had knowledge	55.4	63.0
Didn't have knowledge	44.6	37.0
Knowledge on how BBTV spread		
Sharing of suckers	96.0	83.0
Insects	46.0	56.0
Farm equipment	3.0	5.0
Soil contamination	1.0	2.0
Sources of information on the recommended BBTD measures		
Radio	7.7	6.0
Friends	11.5	4.0
Extension workers	80.8	54.0
Research scientist	0.0	30.0
Other farmers	0.0	6.0
Strategy		
Uprooting and burning of infected plants	30.7	48.0
Training on best practices	46.2	36.0
Introduction of improved varieties	2.0	6.0
Provision of chemicals to control aphids	0.0	2.0

BBTV- banana bunchy top virus, BBTD- Banana bunchy top disease, sample size-76

3.4.7 The magnitude of the banana bunchy top disease and bunchy top virus impact on banana production

After recognizing BBTV symptoms, most of the farmers (80.6% in Mulanje and 80% in Nkhata-bay) reported a decrease in banana yield (Table 3.8). Most respondents in Mulanje (75.8%) and Nkhata-bay (60%) predicted that BBTD will cause banana production losses of 16–30 tons per ha. Many of the respondents classified the BBTD severity as mild (50.6% in Mulanje and 42.0% in Nkhata-bay) or severe (40.6% in Mulanje and 34.0% in Nkhata-bay). Few farmers (8.8% in Mulanje and 24% in Nkhata-bay) claimed that their mats and orchards were free of illness. Most farmers cited low-income rates (100 percent in Mulanje and 75 percent in Nkhata-bay) and yield reductions (96.2% in Mulanje and 100 percent in Nkhata-bay) as BBTD's effects.

Table 3.8: Severity of the banana bunchy top disease, bunchy top virus impact on banana yield production in Mulanje and Nkhata-bay districts of Malawi (% respondents)

	District	
	Mulanje	**Nkhata-bay**
Yield reduced after noticing BBTD symptoms		
Reduction	80.6	80
No reduction	19.4	20
Quantities of yield reduction		
0-15 tons/ha	24.2	32
16-30 tons/ha	75.8	68
BBTD severity		
Mild	50.6	42
Severe	40.6	34
None	8.8	24
Impacts of BBTD		
Low rate of income	100	76
Yield reduction	96.2	100
Lack of quality suckers	7.9	0

BBTD- Banana bunchy top disease, sample size- 76

3.4.8 Availability of alternative sources of BBTV-free suckers and preferred banana varieties in Mulanje and Nkhata-bay districts of Malawi

The majority of Mulanje's farmers (80.0%) stated that they had no other place to get suckers free of BBTV (Table 3.9). Most people in the Nkhata-bay district (81.0%) claimed to have another source of BBTV free suckers. The majority (38.0%) of those who said they obtained their BBTV free suckers in Nkhata-bay from a different source said they obtained the planting supplies from academic organizations. While Williams (30.0%), Mpama (24.0%), Zambia (24.0%), and Grandnaine (22.0%) were the most popular banana types in Nkhata-bay, Kabunthu (45.6%), Zanda (23.6%), and Sukali (14.0%) were the most popular in Mulanje.

Table 3.9: Availability of alternative sources of BBTV-free suckers and preferred banana varieties in Mulanje and Nkhata-bay districts of Malawi (% respondents)

	District	
	Mulanje	**Nkhata-bay**
Availability of alternative source of BBTV-free banana suckers		
Available	20.0	81.0
Not available	80.0	19.0
Sources of BBTV-free planting materials		
Research institutions	0.0	38.0
Government extension workers	48.2	22.0
Other farmers	30.2	35.0
Own source	21.6	5.0
Preferred banana varieties in Mulanje and Nkhata-bay		
Kabuthu	45.6	0.0
Kholobowa	6.3	0.0
Sukali	14.0	0.0
Zanda	23.6	0.0
Ngerezi	7.0	0.0
Kashunga	3.5	0.0
Mpama	0.0	24.0
Zambia	0.0	24.0
Grandnaine	0.0	22.0
Williams	0.0	30.0
Mzeru	0.0	4.0
Mbingidola	0.0	2.0
Gweru	0.0	2.0
Tondiamu	0.0	2.0

BBTV- *Banana bunchy top virus*, sample size =76

3.4.9 Challenges faced by farmers in controlling banana bunchy top disease in Mulanje and Nkhata-bay districts of Malawi

For the Mulanje district farmers who were interviewed, labor-intensive uprooting and burning of the diseased plants was the biggest obstacle to BBTD control (32.0%), followed by weak management abilities (28.6%) (Table 3.10). The greatest challenge in Nkhata Bay was labor intensity (40%) followed by other farmers' resistance to uprooting and burning sick plants (28%).

Table 3.10: Challenges faced by farmers in controlling banana bunchy top disease in Mulanje and Nkhata-bay districts of Malawi (% respondents)

	District	
	Mulanje	**Nkhata-bay**
Challenges in controlling BBTD		
Labour intensive to uproot and burn infected plants	32.0	40.0
Resistance by other farmers to uproot and burn infected plants	20.4	28.0
Poor management skills	28.6	18.0
Lack of improved varieties	19.0	14.0

BBTV- Banana bunchy top disease, sample size =76

3.4.10 Relationship between level of education and cropping system

There was no correlation between the farmers' farming systems and their degree of schooling. (Chi-square table 3.11).

Table 3.11: Relationship between level of education and cropping system

		Cropping system			
		In mats	**Orchard**	**Total**	**Chi-square P Value**
Level of education	Primary school	39	6	45	0.614**
	Secondary school	14	5	19	
	Tertiary School	1	0	1	
	No formal education	9	2	11	
	Total	63	13	76	

**- Not significant

3.5 Discussion

The majority (58%) of the farmers who were interviewed for the survey had completed their elementary education, enabling them to understand the issues posed by the banana bunchy top disease. All the respondents (14.5%) who did not pursue formal education were female. Women and young people make up most Malawians working in the agricultural industry, but they face several disadvantages, including limited access to education and ownership of financial and productive assets (Malawi National Agriculture Policy, 2016). In both districts, most responders (62.5%) were women, demonstrating the dominance of women in the two districts' banana production industries. According to a comparable survey done in the Thyolo district, female farmers dominated the production of bananas (Kumwenda, 2013). The findings are in line with the Malawi Population and Housing Census report from 2018, which noted that females make up 51% of Malawi's population. According to Kumwenda (2013), around 71% of all agricultural labor was performed by women, 70% of whom worked as full-time farmers. The survey results reveal that farmers with a primary education demonstrated better understanding and comprehension of the challenges posed by Banana bunchy top disease (BBTD). This underscores the importance of education in empowering farmers to effectively tackle the disease. However, a significant proportion (14.5%) of respondents who lacked any formal education were all women. This observation highlights a critical link between gender and education in the context of BBTD. Previous research has already demonstrated that education significantly influences farmers' knowledge and adoption of disease management practices (Addai et al., 2020).

Furthermore, the dominance of women (62.5%) among the respondents in both Mulanje and Nkhata-bay districts suggests that the banana production sector in these regions is predominantly led by women. This gender disparity in banana farming aligns with findings from studies conducted in other parts of Malawi, indicating that female farmers play a major role in the sector (Kumwenda, 2013). The substantial presence of women in the banana farming sector is especially noteworthy, given that the majority of the agricultural workforce in Malawi consists of women and youth. According to the Malawi National Agriculture Policy, women frequently experience several disadvantages despite their major involvement in agriculture, including limited access to education, ownership, control of funds, and productive assets.

Bananas (40.4%) were the most common crop planted in Mulanje and Nkhata-bay districts over the preceding five years, according to the survey. Sweet potato (12.6%) and maize (23.4%) came next. These findings suggest that both areas' most important crop is the banana. According to Gondwe and Banda (2002), one of Malawi's six most important crops is the banana. In central and southern Malawi, the crop is consumed as a fruit and is also a source of income (Laisnez, 2005). The main source of income for farmers in Mulanje and Nkhata Bay was crop production, which was followed by casual work (15.4%) and small-scale companies (4.9%). According to earlier research by Kumwenda (2013), the main source of revenue for farmers in the Thyolo district was from the production of bananas. Along with Thyolo, the Malawian districts of Mulanje and Nkhata-bay also cultivate bananas. According to Gondwe (2004), farmers in the Nkhata-bay and Mulanje districts made 50% and 43% of their money from bananas, respectively. Therefore, increasing banana production should be a consideration for any help given to these areas since it can significantly increase smallholder farmers' income. The study's discovery that bananas are the main crop in Mulanje and Nkhata-bay districts highlights the crop's importance to these areas. While it may have been known before, this specific data highlights its importance for food security and income generation among smallholder farmers. Crop production, especially banana, emerged as the highest income source, suggesting the potential impact of upscaling banana production on farmers' livelihoods. Despite being previously known, presenting this data strengthens the study's implications and highlights the importance of supporting banana production for smallholder farmers in the region.

The majority of the farmers in the districts of Mulanje and Nkhata-bay who were interviewed did not adhere to the suggested management techniques. This could be one of the factors making Banana bunchy top disease (BBTD) so challenging to treat. This was demonstrated by the statistic that 84.3% of farmers said their bananas weren't grown in a formal orchard. As a result, when the banana bunchy top disease (BBTD) appears in a field, it is exceedingly challenging to remove the affected plants because they develop into large mats. The study also revealed that 36.5% of farmers did not use the advised 3 m by 3 m spacing. Thus, there is insufficient use of the land or plant overcrowding, which leads to low production. Additionally, it was shown that 66.6% of the smallholder farmers didn't fertilize their banana crops. According to the Orissa Review (2007), the current management techniques for BBTD include chemical control, biological control, eradication, and quarantine measures. These BBTD management strategies are ineffective in areas where farmers use subpar agronomic techniques, as the survey found. Plant nutrition plays a role in enhancing natural resistance of crops (Armstrong, 1998). Lack of fertilizer application as revealed in the study might be one of the factors accelerating the spread and adverse effects of BBTV.

The high percentage of farmers not following recommended management practices in banana cultivation, such as not growing in organized orchards, not maintaining proper spacing, and not applying fertilizer, can be attributed to several factors. One possible reason is limited access to information and knowledge about best agricultural practices. Lack of awareness or training on proper banana farming techniques may lead to suboptimal practices.

Additionally, smallholder farmers often face resource constraints, including limited access to inputs like fertilizers, which can hinder their ability to implement recommended practices. Financial limitations may also prevent them from establishing organized orchards or adopting proper spacing.

Furthermore, traditional farming practices and cultural norms may play a role in farmers' reluctance to adopt modern management techniques. If farmers have been practicing traditional methods for generations, they might be resistant to change or unaware of the benefits of adopting new practices.

A combination of these factors, including limited knowledge, resource constraints, and traditional practices, could be contributing to the high percentage of farmers not following recommended management practices for banana cultivation. Therefore, addressing these issues through targeted education, access to resources, and awareness campaigns may help improve the adoption of effective management practices and contribute to better control of Banana Bunchy Top Disease (BBTD).

According to the survey, BBTD was the main problem for the smallholder farmers in the districts of Mulanje and Nkhata-bay who were questioned (100%). According to Kumwenda (2012), the major problem facing the district of Thyolo's banana producers is BBTV. The results back up Ploetz's (1998) assertion that BBTD is the worst banana illness. The results of the study demonstrated that most smallholder farmers in the Mulanje and Nkhata-bay regions were knowledgeable about the banana bunchy top disease. The farmers said that other farmers and government extension agents provided them with the knowledge. These findings demonstrate the effectiveness of the extension systems in the two districts since farmers may obtain information from both extension agents and other farmers. According to Masangano et al. (2012), government extension services in Malawi provide the most coverage for farmers.

The findings demonstrate that most smallholder farmers were aware of the disease's symptoms since they could name some of them, including small-sized bunches and stunted growth. This demonstrates the capability of smallholder farmers to recognize a sick banana plant. This discovery is like that made by Kumwenda (2013), who discovered that 95% of farmers in the Thyolo district were aware of the symptoms of BBTD. By pulling up the diseased plants, most smallholder farmers (76.63%) in the two districts of Mulanje and Nkhata-bay managed the disease. This demonstrates that farmers in the two districts are aware of the value of bananas to their day-to-day existence. The fact that the farmers were aware of the advised control measures further demonstrated the success of the extension system in the two districts.
Most the research sites' smallholder farmers were familiar with how the disease propagated. Aphids are the disease's vector, as explained by most farmers (70.8%). Understanding how the virus spreads could make the sickness easier to control. It is possible to treat illnesses and increase productivity by providing farmers with better information about banana production and disease management (Beed and Markham, 2008). Most of the farmers who were interviewed said that BBTD had decreased their household income because of inadequate yields. According to Atchédji et al. (2010), bananas are a food supply for families and a source of generation. Banana yields significantly decrease because of the BBTV. According to studies, BBTV might result in yield losses of more than 60% (Muengula et al., 2014). According to the study, banana production has significantly decreased because of the spread of banana bunchy top disease. Banana bunchy top disease, according to Soko et al. (2012), caused Malawi's banana production to drop from 35 t/ha to 8 t/ha. Therefore, to save the industry, agronomic techniques must be used to control the banana bunchy top.

The study also revealed that most smallholder farmers (64.5%) did not have alternative sources of clean planting materials rather than sourcing from fellow farmers. This shows that most farmers access planting materials from fellow farmers which could also be infected. This system of sharing planting materials among farmers could encourage spreading of the virus. Report by FAO (2009) indicate that BBTV continues to spread across Malawi due to sharing of planting materials between farmers. Jooste (2013) reported that most horticultural crops in Plants that reproduce vegetative, like those grown in Malawi such as banana, potato, sweet potato, and pineapple, provide a significant pest and disease risk to succeeding crops. Access to disease free banana planting material is limited in Malawi but South Africa is the closest source of clean banana planting materials. However, the cost of importing planting materials from South Africa is prohibitive to most smallholder farmers (Jooste, 2013). Jooste (2013) reported that there are quality concerns about the imported planting materials as some are not free from diseases.

Most farmers in Mulanje and Nkhata-bay preferred Kabunthu, Zambia and Mulanje and Williams. The varieties were preferred because of their sweetness and high yielding capacity. Similarly, Kumwenda (2013) also found the same varieties as the preferred varieties in Thyolo district. Banda and Mwenebanda (2000) reported giant Cavendish (Mulanje) and dwarf Cavendish varieties (Kabunthu and Zambia) showed the highest yields among the six local banana varieties which were collected country wide.

The survey findings highlighted that poor management skills and labor intensiveness of the current practices were significant challenges faced by farmers when controlling Banana Bunchy Top Disease (BBTD). Farmers reported various poor skills and practices contributing to the ineffective control of the disease, such as improper disease identification, lack of sanitation and hygiene, inadequate quarantine measures, incorrect uprooting techniques, limited knowledge of resistant varieties, poor crop rotation practices, negligence in nutrition management, inadequate record-keeping, lack of early detection and reporting, and limited awareness of Integrated Pest Management (IPM) strategies.

Addressing these challenges through education, training, and extension services could enhance farmers' ability to manage BBTD effectively and protect their banana crops. By empowering farmers with the necessary knowledge and skills, the overall disease control measures can be improved, leading to better outcomes in banana production.

Furthermore, the labor intensiveness of the current management practices was a major obstacle for farmers in controlling BBTD. Tasks such as uprooting infected plants, establishing buffer zones, practicing hygienic measures, implementing quarantine measures, adopting IPM strategies, managing nutrition and soil health, and monitoring early detection demanded considerable labor efforts and resources. This labor-intensive nature of the practices may deter some farmers from fully adopting them, contributing to the ongoing spread of the disease.

To address this challenge, alternative, more practical approaches to disease control should be explored, and the adoption of less labor-intensive methods should be encouraged. For instance, establishing buffer zones between infected and healthy plants could be a more manageable option for farmers to adopt. This way, the disease's spread can be curtailed while minimizing labor requirements.

The findings concur with those of Kumwenda (2013), who noted that the present suggested control techniques in the Thyolo district require a significant amount of labor. Because the present recommended management strategies are labor-intensive, farmers may adopt them less and the disease will continue to spread. According to Ajzen (1991), the ease or difficulty of implementation of a technology has an impact on whether farmers choose to use it. Farmers may find it simple to implement an alternative management strategy that entails creating a buffer zone between the diseased banana and a new area. According to this assessment, the output of bananas in the two districts of Mulanje and Nkhata-bay was severely hampered by banana bunchy top. The disease's suggested control measures, which include removing the diseased plants, were known to most farmers in the two areas. The recommended control measures were viewed as labor-intensive by the farmers.

CHAPTER 4

EFFECTS OF BUFFER ZONES AND APPLICATION OF INORGANIC FERTILIZER ON BANANA BUNCHY TOP VIRUS TRANSIMISSION IN BANANA FIELDS

4.1 Abstract

Banana is fourth most vital crop in Malawi, it comes after maize, rice, groundnuts, vegetables and beans. However, its production has been greatly reduced by Banana bunchy top virus (BBTV) which has spread across the country. The study was done to determine the effect of buffer zone and inorganic fertilizer application on transmission of BBTV in Mpamba and Chintheche sites in Nkhata-bay district in Malawi growing season of 2016/2017. In the trial, buffer zone served as the main plot factor while inorganic fertilizer served as the sub-plot component in a randomized block design with split plots. Buffer zone treatments comprised planting banana at 2-10 m radius from infected banana plants, planting banana at 50 m radius from infected banana plants, planting banana at 100 m radius from infected banana plants and planting where infected banana plants were removed without a resting period. Inorganic fertilizer treatments comprised no fertilizer application (control) and application of 56.6 kg of NPK (23:21:0+4S) plus 46 kg of urea (46% N) per ha. The following information was gathered: plant height, number of leaves per plant, number of suckers per plant, prevalence of disease, length, width, and stem of the leaves. To check for the presence of BBTV in leaf samples, an enzyme-linked immunosorbent assay (ELISA) was performed. Results demonstrated that buffer zone had a significant effect ($P \leq 0.05$) on the disease occurrence at 12 and 28 weeks after planting at Chintheche site and at 28 weeks after planting at Mpamba site. Plots located at a radius of 100 m from infected plants had lower disease incidence while plots located at 2 m to 10 m radius from infected plants and plots established where infected banana was uprooted without resting period had higher disease incidence. Application of inorganic fertilizer significantly reduced disease incidence at Chintheche at 12 weeks after planting. Buffer zone, inorganic fertilizer and interaction of the two factors had an effect ($P \leq 0.05$) on disease incidence in both sites at 28 weeks after planting. In both sites, the highest disease incidence (49.5% and 25.4%) in Chintheche and Mpamba sites respectively was observed in plots planted at a radius of 2 m to 10 m from infected bananas and not supplied with inorganic fertilizer. The lowest disease incidence (0.9% and 0.5%) in Chintheche and Mpamba, respectively was observed at a plot located at a radius of 100 m away from diseased plants and

supplied with inorganic fertilizer. Inorganic fertilizer application dramatically accelerated plant growth (plant height, number of leaves per plant, number of suckers per plant, leaf length, stem diameter and leaf width). ELISA test confirmed presence of BBTV in all the leaf samples collected. A buffer zone of 100 m radius away from infected banana plants and application of inorganic fertilizer increased plant growth and reduced BBTV transmission.
Key words: disease incidence, infected plants, management options, resting period.

4.2 Introduction

Over 400 million people worldwide rely on the banana (Musa sp.), an important crop. After maize, rice, groundnuts, vegetables, and beans, bananas are the sixth most important crop in Malawi (Gondwe and Banda, 2002). However, banana production faces challenges, with one of the most devastating diseases being Banana Bunchy Top Disease (BBTD). BBTD has significantly reduced banana yields, affecting production in Nkhata-bay and Nkhotakota districts, where yields decreased from 35 t/ha to 8 t/ha (Soko et al., 2012). The disease is caused by the Banana Bunchy Top Virus (BBTV), transmitted by aphids (Pentalonia nigronervosa Coq) and sharing of infected planting materials (Qazi, 2015).

Currently, there are no reported banana cultivars with resistance to BBTV. The available management options involve uprooting infected plants and using virus-free planting materials. However, uprooting can be labor-intensive, and many farmers face challenges accessing virus-free planting materials due to cost constraints (Jootse, 2013). The susceptibility of plants to BBTV can be influenced by their nutritional status. Nutrient stress, especially nitrogen, phosphorus, and sulfur deficiencies, can increase a plant's susceptibility to diseases (Magee, 1948; Spann and Schumann, 2010). For instance, the presence of phosphorus in plant tissue can reduce virus concentration (Merret et al., 1994).

Making buffer zones could be a feasible management method to stop the spread of BBTD. By creating buffer zones, it may be possible to stop the spread of the virus, which is spread from plant to plant by aphids (Niyongere et al., 2013). As a result, the purpose of this study is to assess how buffer zones and inorganic fertilizer affect BBTV transmission. This study's goal is to find out how buffer zones and inorganic fertilizer affect the spread of BBTD, or banana bunchy top disease. The findings of this study will contribute to better disease management strategies for banana production in Mulanje and Nkhata-bay districts. By understanding the role of buffer zones and inorganic fertilizers in controlling BBTD, farmers can adopt more effective practices to protect their banana crops and improve yields. This study seeks to address the current knowledge gap on the effectiveness of buffer zones and inorganic fertilizers in managing BBTD, providing valuable insights for sustainable banana production in Malawi.

4.2 Materials and methods

4.2.1 Study area

Field trials were conducted in Mpamba and Chintheche locations in Nkhata-bay district during the 2016/17 growing season, which spans from October 2016 to November 2017. The district experiences average yearly maximum and minimum temperatures of 30°C and 18°C, respectively and annual rainfall of 1,500 mm. The highest and heaviest rainfalls are experienced between February and April (Nkhata-bay Social Economic Profile, 2014). The district has relatively high humidity. Several factors contribute to this relative high humidity (72%) in the district including water bodies (Lake Malawi and several rivers), high vegetation cover and high temperatures. Nkhata-bay experiences light to moderate winds, mainly South-easterlies. Heavy gusts are also experienced from May through to September because of South-east trade winds locally referred to as *Mwera.* These bring with them *Chiperoni* weather conditions resulting in patches of drizzle especially in the highlands. The average wind speed has been within 1 m/s. The soils in Nkhata-bay district are generally good and fertile for growing most food and cash crops. The common soils in the district are lithosols which are usually shallow and stony (Table 4.1). The experiment was conducted in 2016/2017 growing season but in two locations of Mpamba and Chintheche in Nkhata-bay district of Malawi.

Table 4.1: Mean rainfall and temperature during the study period (January, 2017 to November, 2017)

	Chintheche site		Mpamba site	
Month	**Temperature (°C)**	**Rainfall (mm)**	**Temperature (°C)**	**Rainfall (mm)**
January	30.0	158.9	28.0	160.2
February	30.0	141.4	27.0	130.8
March	29.0	283.4	26.0	375.4
April	28.0	109.8	27.0	282.1
May	27.0	30.7	26.0	92.5
June	25.0	17.7	24.0	8.2
July	26.0	6.9	25.0	15.5
August	27.0	19.4	26.0	5.1
September	28.0	2.0	26.0	0.0
November	29.0	36.0	27.0	21.1

4.2.1.1 Soil sampling and analysis

Soil samples were collected to assess the basic attributes of the soil. All the plots in the two locations had their soil samples taken. The soil samples were taken to Chitedze research station soil laboratory where the following analysis were conducted: analysis for pH, % organic carbon (OC), % organic matter (OM), % N, P (µg/g) and K (centimoles/Kg) (Table 4.2)

Table 4.2: Soil Analysis results for Mpamba and Chintheche study sites

	Site	
	Mpamba	**Chintheche**
Ph	5.9	6.19
% OC	0.6	0.28
%OM	1.0	0.38
%N	0.1	0.03
P(µg/g)	25.5	12.84
K (cmol/Kg	1.1	1.02

4.2.2 The design of the experiment and its treatments

Buffer zone and inorganic fertilizer application factors were assigned to main plots and sub-plot respectively. The main plot measured 12 m by 12 m and the subplot measured 12 m by 6 m. The buffer zone treatments comprised planting at 2 m-10 m radius from infected banana plants, planting at 50 m radius from infected banana plants, planting at 100 m radius from infected banana plants and planting where infected banana plants were removed without a resting period. Inorganic fertilizer treatments comprised no fertilizer application (control) and application of 56.6 kg NPK (23:21:0+4S) plus 46 kg of urea (46% N) per hectare. Application of NPK (23:21:0 +4S) was done one month after planting and application of 46 kg/ ha of Urea 46% of nitrogen) was done two months after planting. The land was prepared by clearing and planting holes spaced at 3 m by 3 m and holes measured 40 cm by 40 cm by 40 cm. A buffer zone in this study is the distance from an infected banana plant to the site where a new banana orchard is to be established. The experiment was repeated four times using a split plot layout and a randomized complete block design.

4.2.3 Crop husbandry

Tissue cultured virus free banana variety *Williams,* sourced from Bvumbwe agricultural research station, was used as the planting material as it was the preferred variety in the area. The planting holes were created to be 40 cm by 40 cm by 40 cm, and the bananas were planted in straight rows using a rectangular system with 3 m by 3 m. One tissue cultured planting material was planted per planting station. Weeds compete with bananas for moisture and nutrients during the early phases of crop establishment, so weeds were eliminated using a hoe. Weeding was done three times in the space of two, four and six months after planting.

4.2.4 Data collection

Data Collection and Leaf Sampling: Data collection commenced one month after planting and continued for seven months. To test for the presence of the Banana Bunchy Top Virus (BBTV) at the seventh month following planting, leaf samples from each plot were collected. For this analysis, ELISA kits from Agdia (EMEA France) were used. **Leaf Selection and Measurements:** For growth parameter measurements, four randomly chosen plants were selected from each plot. These plants were tagged for quick identification and monitored throughout the study period. The selected leaves for measurement were the most mature and representative leaves on each plant.

Uniformity of Planting Materials: The data of suckers at planting was considered crucial for evaluating the initial plant size and uniformity. In this study, the uniformity of planting materials was ensured to ensure the best results. The planting materials (suckers) were all uniform in size, which helped provide valuable insights into the initial conditions of the banana plants used in the experiment.

In this study, a variety of growth characteristics were evaluated to determine how well the banana plants performed. The following growth parameters were measured using specific instruments and techniques:

1. Plant Height, Number of Leaves, and Number of Suckers: Plant height, number of leaves per plant, and number of suckers per plant were measured at multiple time points: 4, 6, 8, and 12 weeks after planting. A measuring tape or ruler was used to determine the plant height from the base to the tip of the highest leaf. The number of leaves and suckers were counted directly on each plant.

2. Leaf Diameter, Leaf Length, and Leaf Width: At the 16th week after planting, leaf diameter, leaf length, and leaf width were measured to assess the leaf morphology. The diameter of the leaf, which was determined as the width across the leaf, was measured using a Vernier caliper or ruler. A randomly chosen adult leaf's length was measured from the base to the tip, and the same leaf's breadth was gauged at its widest point.

3. Stem Diameter: A measuring tape was used to calculate the stem's diameter. The measurement was made at the thickest part of the main stem, which is normally at a standard height above the ground.

4. Disease Incidence: Disease incidence, particularly Banana Bunchy Top Disease (BBTD), was assessed at different time intervals: 4, 6, 8, 12, and 28 weeks after planting. The proportion of plants displaying BBTD symptoms was calculated by dividing the number of symptomatic plants by the total number of plants in the plot and then multiplying the result by 100.

4.2.6 Detection of banana bunchy top virus in banana leaf samples using enzyme-linked immunosorbent assay (ELISA)

During the seventh month after plot establishment, leaf samples were collected for BBTV detection using ELISA test. Two plants were sampled from each plot and the third leaf from the top of each plant was collected for detection. The samples were kept in a cool and dry plastic bag and taken to Chancellor College Biotechnology Laboratory for ELISA test. The ELISA kit was sourced from Agdia (EMEA France). Five buffers were prepared using the reagents provided in the kit. The reagents were dissolved in 100 cc of distilled water, then the buffer's pH was adjusted to 9.6 by adding sodium carbonate (1.59 g), sodium bicarbonate (2.93 g), and sodium azide (0.2 g). Phosphate buffered saline tween (PBST) buffer was prepared by dissolving in distilled water to 1000 ml and adding the following chemicals; sodium chloride (8.0 g) Sodium phosphate, diabasic (1.15 g), Potassium phosphate, monobasic (0.2 g), Potassium Chloride (0.2 g) and Tween-20 (0.5 g). Then it was adjusted to pH of 7.4. ECI buffer was prepared by adding to 1000 ml of PBST buffer and adding the following Bovine serum albumin (2.0 g), Polyvinlypyrrolidone (20.0 g) Sodium azide (0.2 g) and adjusting to a pH of 7.4. PNP buffer was prepared by dissolving in 1000 ml of water; Magnesium chloride hexahydrate (0.1 g), Sodium azide (0.2 g), Diethanolamine (97 ml) and adjusting to a pH of 9.8. General extract buffer was prepared by dissolving in 1000 ml of PSBT; sodium sulfite (1.3 g) Polyvinlypyrrolidone (20.0 g), sodium azide (0.2 g) Powdered egg (2.0 g) Tween-20 (20.0 g) and adjusting the pH to 7.4. Samples were prepared by grinding the plant tissues in a sample extraction buffer at a 1:10 ratio of tissue weight in grams to buffer volume in ml. Mortor and pestle were used and were washed thoroughly between samples. Prepared samples of 100 µl were dispensed in the wells, 100 microlitre of positive control wells were dispensed in positive control wells and 100 microlitre of sample extraction buffer was dispensed into buffer wells. The plates were refrigerated overnight while being incubated in a humid box. The plates were cleaned after incubation. Next, 1X PBST was added to the plates, which were then promptly drained (this was repeated 7 times). Per well, 100 microliters of enzyme conjugate solution was distributed, and the plates were incubated for two hours at room temperature in a humid box. For each PNP tablet included in the kit, 5 ml of room temperature 1X PNP buffer was added to the buffer at around 15 minutes left in the aforementioned incubation. The plates were washed again for 8 times using 1X PBST. PNP substrate (100 microplitre) was dispensed into each well and the plates incubated for 60 minutes. After the 60 minutes elapsed, the plates were examined by eye. Wells which developed color indicated positive results and wells with no significant color development indicated negative results.

4.3 Data analysis

GenStat software 14.2 version was used to perform an analysis of variance (ANOVA) on the collected data. The Fisher's Protected least significant difference test was used to look at the differences between the treatment means at the 5% level of probability.

4.4 Results

In both sites, the interaction between buffer zone and inorganic fertilizer did not show statistically significant effects at the $P \leq 0.05$ level for most of the parameters, except for disease incidence. However, in the Mpamba site, the buffer zone exhibited significant effects on stem diameter, leaf length, and leaf diameter after 16 weeks following planting. On the other hand, in the Chintheche site, the buffer zone had a significant impact on the number of suckers per plant at eight weeks after planting ($P \leq 0.05$). Additionally, the application of inorganic fertilizer showed significant effects on all measured parameters.

The significant effects observed in the buffer zone at eight weeks in the Chintheche site indicate that this specific zone had a considerable influence on the growth and development of banana plants during this early stage. The specific parameters impacted by the buffer zone at this time point were the number of suckers per plant. This finding suggests that the buffer zone played a vital role in promoting sucker formation, potentially leading to increased plant multiplication and overall plant population.

Practical Implications: The significant impact of the buffer zone on the number of suckers per plant implies that the selection and management of the buffer zone can significantly influence sucker production and subsequent banana plant propagation. Proper planning and maintenance of the buffer zone can be utilized as a strategic approach to enhance the establishment and growth of banana plants in the early stages of planting. By ensuring favorable conditions within the buffer zone, such as suitable soil conditions and microclimatic factors, farmers and researchers can foster optimal sucker development, which may result in higher plant yields and improved productivity.

By understanding the specific parameters affected by the buffer zone, this study provides valuable insights for banana growers and agricultural practitioners to tailor their management practices accordingly. Implementing targeted interventions to optimize the buffer zone's conditions at critical growth stages can lead to improved plant performance and overall success in banana cultivation.

4.4.1 Effects of buffer zone on plant height (cm) at 4, 6, 8 and 12th weeks after planting in Mpamba and Chintheche sites in Nkhata-bay district

The height of banana plants in the buffer zones between the two sites did differ significantly. (P≤0.05) throughout any of the sampling period (Table 4.3) Plant height at 12 weeks following planting ranged from 105.7 cm to 152.2 cm at Mpamba and 104.3 cm to 139.4 cm at Chintheche.

Table 4.3: Effects of buffer zone on banana plant height (cm) at 4, 6, 8 and 12th weeks after planting at Mpamba and Chintheche sites in during 2016/2017 season.

	Weeks after planting			
Buffer Zone	**4**	**6**	**8**	**12**
Mpamba				
Infected plots	108.6	111.2	113.7	120.0
2m-10 m	108.8	110.9	113.5	119.3
50 m	94.9	97.0	99.7	105.7
100 m	143.6	146.2	152.1	152.2
P-value	0.345	0.341	0.309	0.392
LSD (≤0.05)	NS	NS	NS	NS
CV%	15.3	14.6	15.4	12.2
Chintheche				
Infected plots	60.1	64.4	65.8	126.3
2 m-10 m	47.6	53.4	59.9	113.8
50 m	62.3	66.8	59.8	139.4
100 m	40.2	45.6	52.3	104.3
P-value	0.172	0.210	0.748	0.311
LSD (≤0.05)	NS	NS	NS	NS
CV%	22.0	20.7	37.7	22.0

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, NS- Not significant at P≤0.05

4.4.2 Effects of buffer zone on number of leaves per plant at Mpamba and Chintheche sites

Buffer zone did not significantly impact (P≤0.05) on the number of leaves per plant in both sites at all the sampling periods (Table 4.4). At 12 weeks following planting, the number of leaves per plant varied between 10 and 12 at the Mpamba site and between 18 and 21 at the Chintheche location.

Table 4.4: Effects of buffer zone on number of leaves per plant at Mpamba and Chintheche sites during 2016/2017 season.

	Weeks after planting			
Buffer Zone	**4**	**6**	**8**	**12**
Mpamba				
Infected plots	8	10	10	10
2 m-10 m	10	11	12	12
50 m	9	10	11	11
100 m	10	11	12	12
P-value	0.449	0.465	0.369	0.2
LSD (≤0.05)	NS	NS	NS	NS
CV%	15.4	13.9	10.700	12.0
Chintheche				
Infected plots	9	11	12	18
2 m-10 m	8	9	11	18
50 m	9	11	13	21
100 m	8	10	12	19
P-value	0.454	0.428	0.452	0.28
LSD (≤0.05)	NS	NS	NS	NS
CV%	20.3	15.000	14.4	10.2

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, NS- Not significant at P≤0.05

4.4.3 Effects of buffer zone on number of suckers per plant at Mpamba and Chintheche sites

Buffer zone significantly affected (P≤0.05) the number of suckers per plant only at 8 weeks following planting in Chintheche site (Table 4.5). Plots located at 100 m from the infected banana plants had higher number of suckers per plant than plots located at 50 m from infected banana plants, plots located at 2 m to 10 m radius from infected banana plants and plots from which infected banana plants were uprooted. At Mpamba, the number of suckers per plant at 12 weeks following planting varied from 0.5 to 1.4, and at Chintheche, it ranged from 4.6 to 5.5.

Table 4.5: Effects of buffer zone on number of suckers per plant at Mpamba and Chintheche sites during 2016/2017 season.

	Weeks after planting			
Buffer Zone	**4**	**6**	**8**	**12**
Mpamba				
Infected plots	0.3	0.5	0.4	0.5
2 m-10 m	1.1	1.8	1.8	1.8
50 m	0.6	0.9	0.9	0.9
100 m	0.8	1.3	1.3	1.4
P-value	0.212	0.416	0.330	0.383
LSD (≤0.05)	NS	NS	NS	NS
CV%	86.6	78.6	82.6	75.9
Chintheche				
Infected plots	0.6	0.8	0.9	4.6
2 m-10 m	0.3	1.0	1.1	5.1
50 m	0.3	0.8	0.8	5.3
100 m	0.1	0.3	0.3	5.5
P-value	0.174	0.088	0.049	0.873
LSD (≤0.05)	NS	NS	0.596*	NS
CV%	153.2	84.0	83.9	15.2

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, NS- Not significant at P≤0.05, *- Significant at P≤0.05

4.4.4: Effects of buffer zone on disease incidence at 4, 6,8 and 12 weeks after planting in Mpamba and Chintheche sites

At Mpamba site buffer zone did not significantly (P≤0.05) affect disease incidence at 4, 6, 8 and 12 weeks after planting (Table 4.6). However, banana plants grown in plots from which infected banana plants were uprooted and plots located at 2 m to 10 m from infected banana plants had significantly higher disease incidences than plots located at 100 m from the infected banana plants. Disease incidence at 12 weeks after planting ranged from 0 to 14.8 at Mpamba. In Chintheche, buffer zone did not significantly (P≤0.05) affect disease incidence at 4, 6 and 12 weeks after planting but significantly affected this parameter at 12 weeks after planting. Disease incidence at 12 weeks following planting ranged from 1.6 % to 22.6 % at Chintheche site.

Table 4.6: Effects of buffer zone on disease incidence (%) at 4, 6, 8 and 12 weeks after planting at Mpamba and Chintheche sites during 2016/2017 season

	Weeks after planting			
Buffer Zone	**4**	**6**	**8**	**12**
Mpamba				
Infected plots	9.4	9.4	14.8	14.8

2 m-10 m	3.1	3.1	3.1	3.1
50 m	3.1	3.1	6.2	6.2
100 m	0.0	0.0	0.0	0.0
P-value	0.376	0.376	0.320	0.32
LSD (≤0.05)	NS	NS	NS	NS
CV%	196.0	200.0	140.5	200.0
Chintheche				
Infected plots	7.8	7.8	9.4	10.0
2 m-10 m	12.5	12.5	18.8	22.6
50 m	6.3	6.3	7.8	8.3
100 m	1.6	1.6	1.6	1.6
P-value	0.181	0.18	0.060	0.004
LSD (≤0.05)	NS	NS	NS	8*
CV%	118.8	111.8	83.9	36.6

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, NS- Not significant at P≤0.05, *- Significant at P≤0.05

4.4.5: Effects of buffer zone on leaf length (cm), leaf diameter (cm) and leaf width (cm) at 16 weeks after planting at Mpamba and Chintheche sites during 2016/2017 season

Buffer zone did not significantly (P≤0.05) affect leaf length, stem diameter and leaf diameter at Chintheche site (Table 4.7). At the Mpamba site, however, the buffer zone had a substantial impact on leaf length, stem diameter, and leaf diameter. In comparison to plants growing in plots where diseased banana plants were uprooted and those planted at 2 to 10 m and 50 m away from infected plants, plots located at 100 m away from infected plants showed the highest leaf length, stem diameter, and leaf diameter. Leaf length ranged from 100.9 cm to 164.1 cm, stem diameter ranged from 33.5 cm to 59.3 cm and leaf diameter ranged from 40.4 cm to 62.6 cm at Mpamba site.

Table 4.7: Effects of buffer zone on leaf length (cm), leaf diameter (cm) and leaf width (cm) at 16 weeks after planting at Mpamba and Chintheche during 2016/2017 season

	Stem Diameter		**Leaf length**		**Leaf diameter**	
Buffer zone	**Mpamba**	**Chintheche**	**Mpamba**	**Chintheche**	**Mpamba**	**Chintheche**
Infected plots	38.4	25.4	101.2	75.7	43.3	32.3
2 m-10 m	39.1	23.1	115.5	67.3	44.1	26.0
50 m	33.5	28.2	100.9	83.3	40.4	33.8
100 m	59.3	21.3	164.1	64.0	62.6	24.4
P-value	0.009	0.292	0.032	0.291	0.05	0.163
LSD (≤0.05)	13.6*	NS	44.58*	NS	16.82*	NS
CV%	18.6	18.6	9.4	18.2	8.8	19.4

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, NS- Not significant at P≤0.05, *- Significant at P≤0.05

4.4.6 Effects of inorganic fertilizer application on banana plant height (cm) at Mpamba and Chintheche sites

Inorganic fertilizer significantly (P≤0.05) affected plant height in both sites at all sampling periods (Table 4.8). Application of inorganic fertilizer significantly improved plant height at all sampling periods. Plant height at 12 weeks after planting ranged from 104.6 cm to 143.9 cm in Mpamba and 76.4 cm to 165.5 cm in Chintheche.

Table 4.8: Effects of inorganic fertilizer application on plant height (cm) at Mpamba and Chintheche sites during 201/2017 season

	Weeks after planting			
Inorganic fertilizer	**4**	**6**	**8**	**12**
Mpamba				
No fertilizer applied	93.4	95.8	100.7	104.6
Fertilizer applied	134.5	136.8	137.7	143.9
P-value	<0.001	<0.001	<0.001	<0.001
LSD (≤0.05)	12.42*	13.1*	14.18*	11.69*
CV%	15.3	14.6	15.4	12.2
Chintheche				
No fertilizer applied	37.2	42.4	46.3	76.4
Fertilizer applied	67.8	72.6	72.6	165.5
P-value	<0.001	<0.001	0.006	<0.001
LSD (≤0.05)	8.9*	9.2*	17.3*	20.5*
CV%	22.0	20.7	37.7	22.0

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, *- Significant at P≤0.05, Fertilizer applied: 46 kg urea (46% N) and 56.6 kg (23:21:0+4S) per hectare

4.4.7: Effects of inorganic fertilizer on number of leaves per plant at Mpamba and Chintheche locations in the 2016–2017 season

Inorganic fertilizer had a significantly effects on the number of leaves per plant at P≤0.05 at both sites across all sample intervals (Table 4.9). After applying inorganic fertilizer at both locations over the course of all test intervals, the number of leaves per plant increased dramatically. The fertilizer applied increased number of leaves per plant by 25%, 11%, 9% and 20% at 4, 6, 8 and 12 weeks respectively in Mpamba and 43%, 33%, 30% and 38% at 4, 6, 8 and 12 weeks after planting respectively at Chintheche site.

Table 4.9: Effects of organic fertilizer on number of leaves per plant in Mpamba and Chintheche in the 2016–2017 growing season

	Weeks after planting			
Inorganic fertilizer	**4**	**6**	**8**	**12**
Mpamba				
No fertilizer applied	8.0	10.0	11.0	10.0
Fertilizer applied	10.0	11.1	12.0	12.0
P-value	0.002	0.007	0.003	0.001
LSD (≤0.05)	1.2*	1.1*	0.9*	1.0*
CV%	15.4	13.9	10.7	12.0
Chintheche				
No fertilizer applied	7.0	9.0	10.0	16.0
Fertilizer applied	10.0	12.0	13.0	22.0
P-value	<0.001	<0.001	<0.001	<0.001
LSD (≤0.05)	1.3*	1.2*	1.3*	1.5*
CV%	20.3	15.0	14.4	10.2

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, *- Significant at P≤0.05, Fertilizer applied: 46 kg urea (46% N) and 56.6 kg (23:21:0+4S) per hectare

4.4.8 Effects of inorganic fertilizer on number of suckers per plant

Inorganic fertilizer has a significant impact on the number of suckers per plant at P≤0.05 in both sites at all sampling periods (Table 4.10). Application of inorganic fertilizer increased the number of suckers per plant from 0.1 to 1.3, 0.4 to 1.8, 0.4 to 1.7 and 0.4 to 1.9 at 4, 6, 8 and 12 weeks after planting respectively at Mpamba site and 0 to 0.6, 0.1 to 1.3, 0.1 to 1.4 and 4.0 to 6.0 at 4, 6, 8 and 12 weeks after planting respectively at Chintheche site.

Table 4.10: Effects of inorganic fertilizer on number of suckers per plant at Mpamba and Chintheche sites during 2016/2017 season

	Weeks after planting			
Inorganic fertilizer	**4**	**6**	**8**	**12**
Mpamba				
No fertilizer applied	0.1	0.4	0.4	0.4
Fertilizer applied	1.3	1.8	1.7	1.9
P-value	<0.001	<0.001	0.002	<0.001
LSD (≤0.05)	0.5*	0.7*	0.7*	0.7*
CV%	86.6	78.6	82.6	75.9
Chintheche				
No fertilizer applied	0.0	0.1	0.1	4.0
Fertilizer applied	0.6	1.3	1.4	6.0
P-value	0.003	<0.001	<0.001	<0.001
LSD (≤0.05)	0.4*	0.5*	0.5*	0.6*
CV%	153.2	84.0	83.9	15.2

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, NS-Significant at P≤0.05, *-Significant at P≤0.05, Fertilizer applied: 46 kg urea (46% N) and 56.6 kg (23:21:0+4S) per hectare

4.4.9 Effects of inorganic fertilizer on disease incidence

Inorganic fertilizer did not have a significant effect (P≤0.05) on disease incidence at Mpamba site at all the sampling periods and Chintheche at 4 and 6 weeks after planting (Table 4.11). Inorganic fertilizer had a significant effect on the disease incidence (P≤0.05) application at 8 and 12 weeks after planting at Chintheche site. At the Chintheche location, the use of inorganic fertilizer at the appropriate times after planting reduced the disease incidence by 50% and 57%, respectively.

Table 4.11: Effects of inorganic fertilizer on disease incidence at 4, 6, 8 and 12 weeks after planting at Mpamba and Chintheche sites during 2016/2017 season

	Weeks after planting			
Inorganic fertilizer	**4**	**6**	**8**	**12**
Mpamba				
No fertilizer applied	4.70	4.70	7.80	7.80
Fertilizer applied	3.10	3.10	6.20	6.20
P-value	0.574	0.574	0.205	0.21
LSD (≤0.05)	NS	NS	NS	NS
CV%	196.00	196.00	140.50	200.00
Chintheche				
No fertilizer applied	1.00	8.75	12.50	16.67
Fertilizer applied	0.00	5.00	6.25	7.14
P-value	0.483	0.28	0.05	<0.001
LSD (≤0.05)	NS	NS	3.8*	5.75*
CV%	118.80	111.80	83.90	36.60

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, NS-Significant at P≤0.05, *- Significant at P≤0.05, Fertilizer applied: 46 kg urea (46% N) and 56.6 kg (23:21:0+4S) per hectare

4.4.10 Effects of inorganic fertilizer on stem diameter in Mpamba and Chintheche

Inorganic fertilizer had a substantial impact on stem diameter at both sites at P≤ 0.05. (Table 4.12). Application of inorganic fertilizer increased stem diameter by 23% and 101% in Mpamba and Chintheche respectively.

Table 4.12: Effects of inorganic fertilizer on stem diameter (cm) at Mpamba and Chintheche sites during 2016/2017 season

	Stem diameter(cm)	
Inorganic Fertilizer	**Mpamba**	**Chintheche**
No fertilizer applied	38.2	16.2
Fertilizer applied	47.0	32.7
P-value	<0.001	<0.001
LSD (≤0.05)	3.5*	3.5*
CV%	18.6	18.6

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, *- Significant at P≤0.05, Fertilizer applied: 46 kg urea (46% N) and 56.6 kg (23:21:0+4S) per hectare

4.4.11 Effects of inorganic fertilizer on leaf length (cm) and diameter (cm) of banana plants in Mpamba and Chintheche

Inorganic fertilizer had a significant (P≤0.05) effect on both leaf diameter and leaf length in both sites (Table 4.13). Application of inorganic fertilizer increased leaf length and leaf diameter by 19% and 20% respectively at Mpamba and by 98% and 103% respectively at Chintheche.

Table 4.13: Effects of inorganic fertilizer on leaf length (cm) and leaf diameter (cm) of banana plants in Mpamba and Chintheche sites during 2016/2017 season

	Leaf length(cm)		Leaf diameter(cm)	
Inorganic Fertilizer	**Mpamba**	**Chintheche**	**Mpamba**	**Chintheche**
No fertilizer applied	110.0	48.7	43.3	19.2
Fertilizer applied	130.8	96.4	51.9	39.0
P-value	<0.001	<0.001	<0.001	<0.001
LSD (≤0.05)	8.7*	10.2*	3.2*	4.3*
CV%	9.4	18.2	8.8	19.4

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, *- Significant at P≤0.05, Fertilizer applied: 46 kg urea (46% N) and 56.6 kg (23:21:0+4S) per hectare

4.4.12 Effect of the interaction between buffer zone and inorganic fertilizer application on disease incidence at 28 weeks after planting at Mpamba site during 2016/2017 season

At 28 weeks following planting at the Mpamba site, the buffer zone, use of inorganic fertilizer, and interaction all had a significant (P≤0.05) impact on disease incidence (Table 4.14). Plots which were supplied with inorganic fertilizer had lower disease incidence than those that were not supplied with inorganic fertilizer in all buffer zones. Plots located at a radius of 100 m from the infected banana plants had the lowest disease incidence (3.8%) while plots from which infected banana plants were uprooted without a resting period had the highest disease incidence (16.1%).

Table 4.14: Effect of the interaction between buffer zone and inorganic fertilizer application on disease incidence (%) at 28 weeks after planting at Mpamba site during 2016/2017 season

Buffer zone	No fertilizer	Fertilizer applied	Mean
Infected plots	20.9	11.3	16.1
2 m-10 m	25.4	4.8	15.1
50 m	18.1	4.8	11.5
100 m	7.1	0.5	3.8
Mean	17.9	5.4	
P-buffer zone	<0.001		
P-inorganic fertilizer	<0.001		
P- buffer zone* inorganic fertilizer	<0.001		
LSD-buffer zone	1.9		
LSD-inorganic fertilizer	1.1		
LSD-buffer zone*inorganic fertilizer	2.3		
CV%	12.1		

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, *- Significant at P≤0.05, Fertilizer applied: 46 kg urea (46% N) and 56.6 kg (23:21:0+4S) per hectare

4.4.13 Effects of buffer zone and inorganic fertilizer on disease incidence at Chintheche site

Disease incidence at 28 weeks after planting at the Chintheche site was significantly (P≤0.05) influenced by the buffer zone, inorganic fertilizer, and their interaction (Table 4.15). Plots which were supplied with inorganic fertilizer had lower disease incidence than those that were not supplied with inorganic fertilizer. Plots located at a radius of 100 m from the infected banana plants had the lowest disease incidence (3.7%) and plots located at a radius of 2 m to 10 m from infected banana plants had the highest disease incidence (35.3%).

Table 4.15: Effects of buffer zone and inorganic fertilizer on disease incidence (%) at 28 weeks after planting at Chintheche site

Buffer zone	**No fertilizer**	**Fertilizer applied**	**Mean**
Infected plots	40.0	12.2	26.1
2 m-10 m	49.5	21.2	35.3
50 m	20.9	9.6	15.3
100 m	6.4	0.9	3.7
Mean	29.2	10.9	
P-buffer zone	<0.001		
P-inorganic fertilizer	<0.001		
P- buffer zone* inorganic fertilizer	<0.001		
LSD-buffer zone	4.1*		
LSD-inorganic fertilizer	4.1*		
LSD-buffer zone*inorganic fertilizer	6.7*		
CV%	8.8		

LSD- Least significant difference at P≤0.05, CV- Co-efficient of variation, *- Significant at P≤0.05, Fertilizer applied: 46 kg urea (46% N) and 56.6 kg (23:21:0+4S) per hectare, buffer zone*inorganic fertilizer- interaction between buffer zone and inorganic fertilizer

4.4.14 ELISA test of banana leaf samples

All the four buffer zones showed the presence of BBTV (Table 4.16). In both sites after 7 months of plot establishment, the plots located at a radius 100 m away from the infected plants showed 12.5% of samples were positive for BBTV in Mpamba and 37.5% in Chintheche. Plots located 50 m away from infected plants had 50% of the plants being positive for BBTV in Mpamba site and 75% detected with the virus at Chintheche site. There was 100% presence of BBTV in plots located 2 to 10 meters radius from the infected bananas in both sites. Plots planted where infected banana was uprooted showed 75% BBTV positive in both sites.

Samples collected from plants acting as source of infection confirmed 100% presence of BBTV.

Table 4.16: ELISA results for banana leaf samples from Mpamba and Chintheche sites

Mpamba	**Samples collected and tested**	**Samples with positive results**	**Percentage of positive samples**
Infected plots	8	6	75.0
2 m-10 m	8	8	100.0
50 m	8	4	50.0
100 m	8	1	12.5
Chintheche			
Infected plots	8	6	75.0
2 m-10 m	8	8	100.0
50 m	8	6	75.0
100 m	8	3	37.5
Host plants			
2 m-10 m	6	6	100.0
50 m	6	6	100.0
100 m	6	6	100.0

4.5 Discussion

This study aimed to investigate the impact of buffer zones and inorganic fertilizer application on banana plant health and disease incidence. The findings revealed significant positive effects of both buffer zones and inorganic fertilizer on various plant health parameters, including plant height, number of leaves per plant, number of suckers per plant, leaf diameter, leaf width, and stem diameter.

Effects of Inorganic Fertilizer on Banana Plant Health: The application of inorganic fertilizer has shown significant positive effects on various aspects of banana plant health. The inclusion of essential nutrients, such as nitrogen and phosphorus, in the inorganic fertilizer contributed to favorable responses in banana plants, leading to improvements in several plant health parameters (Kumar et al., 2003; Nobrega et al., 2010). Nitrogen and phosphorus availability from the applied inorganic fertilizer played a crucial role in promoting robust growth in banana plants. This resulted in increased plant height, a greater number of leaves per plant, and the development of more suckers per plant. Adequate supplies of nitrogen, phosphorus, and sulfur facilitated vigorous vegetative growth, preventing issues like yellowing of the plant and slow growth. The findings of Kumar et al. (2003) corroborate these positive effects, as they reported that nitrogen fertilizer application increased the number of leaves and plant height in bananas. Additionally, Nobrega et al. (2010) found that the supply of nitrogen and proper pruning of the mother plant enhanced sucker production in banana plants. Furthermore, the availability of essential nutrients in the inorganic fertilizer, such as potassium, phosphorus, and nitrogen, proved critical for the healthy development and growth of banana plants. As heavy feeders, bananas require an ample supply of these nutrients for optimal growth and development (Srivastava, 1963). The application of inorganic fertilizer replenished the nutrients required by the banana plants, ensuring they were adequately nourished and promoting their overall health. In areas where soil fertility is compromised due to land degradation, as observed in some regions of Malawi (Njoloma et al., 2016), the positive effects of inorganic fertilizer become even more pronounced. By providing the necessary nutrients, the inorganic fertilizer addressed the deficiencies in the soil, enabling the banana plants to thrive and exhibit healthier growth.

Effects of Buffer Zones on Disease Incidence: The establishment of a buffer zone at 100 meters from infected banana plants resulted in a significant reduction in disease incidences at both the Chintheche and Mpamba sites. This positive outcome can be attributed to the physical isolation of healthy plants from infected ones, effectively limiting the transmission of the Banana bunchy top virus (BBTV) carried by the banana aphid (Pentalonia nigronervosa). These findings are in line with previous research conducted by Rajan (1981), who stated that the life cycle of a banana aphid is completed in approximately 29 days on average. As a result, a generation of banana aphids may produce winged adults after 203 days. Although banana aphids are not known for their strong flying abilities, they can still be carried by breezes over considerable distances (Rajan, 1981). Furthermore, studies by Young and Wright (2005) have shown that banana aphids prefer newly planted banana plants. When new banana plants are established at a shorter distance from infected ones, the aphids tend to migrate from the older plants to the newly established ones, leading to higher disease incidences in plots located within a 2 to 10-meter radius from the infected plants. Niyongere (2013) also reported lower disease incidences in plots located 30 meters away from infected plants compared to plots located at 5 meters. This suggests that increasing the distance between infected banana fields and newly established banana fields can effectively reduce the chances of BBTV transmission. It is important to note that the banana aphid is highly host-specific and primarily infests banana plants, but in the absence of bananas, it may also infest other ornamental plants like Alpinia purpurata (Rajan, 1981). The transmission of BBTV by the banana aphid occurs in a persistent circulative manner, and it is non-propagative (Wanitchakorn et al., 2000). This explains the high disease incidence in plots where infected plants were uprooted. The aphids present in the area infested the newly established banana plants, facilitating the transmission of the virus.

Interactions between Inorganic Fertilizer and Buffer Zones: The interaction between inorganic fertilizer application and buffer zones had significant impacts on disease incidence. The highest disease incidences were observed in buffer zones within a radius of 2 to 10 meters without fertilizer application, while the lowest incidences occurred with a buffer zone of 100 meters combined with inorganic fertilizer application. This outcome can be attributed to the reduced ability of the banana aphid to fly to a distance of 100 meters, thus limiting disease spread. Additionally, the positive influence of inorganic fertilizer on plant growth attributes further contributed to disease reduction. These findings are consistent with the study conducted by Niyongere (2013), which found that the lowest BBTV disease incidence was observed at a radius of about 30 meters away from infected banana plants, compared to plots located at 5 meters. As noted by Dordas (2008), plant nutrition plays a crucial role in the effective management of plant diseases and is an essential component of sustainable agriculture. Proper nutrient supply can reduce the severity of certain conditions and enhance the effectiveness of other care techniques in disease management. It's crucial to note that in this study, buffer zones had no discernible impact on plant height, the number of leaves per plant, the number of suckers per plant, leaf diameter, stem diameter, or leaf width. This lack of significant influence may be attributed to the occurrence of Banana Bunchy Top Disease (BBTD) in some plots, resulting in stunted growth and leaf distortion, as reported by Wanitchakorn et al. (2000). The presence of BBTD could have masked the potential positive effects of buffer zones on these plant growth attributes in this specific context.

Effects of Inorganic Fertilizer and Buffer Zones on Plant Growth: The application of inorganic fertilizer had a positive impact on various plant growth attributes in banana plants, including plant height, number of leaves per plant, number of suckers per plant, leaf diameter, leaf width, and stem diameter. The availability of crucial nutrients including nitrogen, phosphorus, and sulfur, which were provided through the application of 23:21:0+ 8 4S and urea fertilizers, might be credited for this favorable response. These nutrients played a crucial role in promoting vegetative growth and preventing issues like yellowing of the plant and slow growth that can occur due to nutrient deficiency. Previous studies support these findings, as Kumar et al. (2003) reported that nitrogen fertilizer application in bananas led to an increase in the number of leaves and plant height. Similarly, Nobrega et al. (2010) found that the supply of nitrogen to banana plants, combined with pruning, enhanced the production of suckers. Bananas are heavy feeders and require significant amounts of potassium, phosphorus, and nitrogen for healthy growth and development (Srivastava, 1963). In both study sites, the application of inorganic fertilizer significantly reduced disease incidence. This reduction can be explained by the role of plant nutrition, particularly potassium (K) and phosphorus (P), in conferring natural resistance to diseases. Magero et al. (2018) also observed reduced severity of Maize lethal necrosis (MLN) when maize plants were supplied with macronutrients, secondary elements, and micronutrients. Nutrient inadequacy can lead to symptoms such as thin and weak cell walls, flimsy stalks and stems, short and weak roots, and sugar buildup in the leaves, all of which promote disease infection. Maintaining good fertility management practices ensures that nutrient deficiency stress is not a factor in banana production (Armstrong, 1998). Additionally, the establishment of a buffer zone of 100 meters away from infected banana plants significantly reduced disease incidences at both the Chintheche and Mpamba sites. This spatial isolation effectively limits the transmission of the Banana bunchy top virus (BBTV) carried by the banana aphid (*Pentalonia nigronervosa*). The life cycle of the banana aphid takes about 29 days on average, and although they are not strong fliers, they can travel considerable distances, favoring newly planted banana plants. By maintaining a buffer zone, the banana aphid's ability to transmit the virus to newly established plants is restricted, resulting in lower disease incidences. The interaction between inorganic fertilizer and buffer zones also influenced disease incidence. High disease incidences were observed in buffer zones within a radius of 2 to 10 meters without fertilizer application, while the lowest incidences occurred with a buffer zone of 100 meters combined with inorganic fertilizer application. This can be attributed to the reduced ability of the banana aphid to fly to a distance of 100 meters, limiting disease spread. Additionally, inorganic fertilizer's positive impact on plant growth attributes further contributed to disease reduction.

ELISA Test Results and Disease Presence: The ELISA test confirmed the presence of the Banana bunchy top virus (BBTV) in all samples collected from both the buffer zones and the plots, irrespective of whether inorganic fertilizer was applied or not. However, the percentages of positive samples varied depending on the location and management practices. Higher percentages of positive samples were observed in plots located at a radius of 2 to 10 meters from the infected banana plants and in plots where uprooting was performed. This higher incidence of positive samples can be attributed to the proximity to infected plants and the presence of the banana aphid (*Pentalonia nigronervosa*). According to Rajan (1981), the banana aphid, although not a strong flier, can transmit the virus over short distances, facilitating the spread of BBTV in plots located closer to infected plants. Maintaining a buffer zone of 100 meters from infected banana plants significantly reduced the disease incidences at 12 and 28 weeks after planting in both Chintheche and Mpamba sites. This reduction can be explained by the physical distance covered by the banana aphid to transmit the virus from the infected banana plants to the newly established ones. Furthermore, Young and Wright (2005) stated that the life cycle of the banana aphid spans approximately 29 days on average, and the aphids may produce winged adults after approximately 203 days. While they can be carried by breezes and travel some distance, maintaining a buffer zone of 100 meters limits their ability to transmit the virus to newly planted banana plants. The ELISA test results demonstrate that the combination of inorganic fertilizer and buffer zones played a significant role in reducing disease incidence. Plots with buffer zones of 2 to 10 meters radius and no application of inorganic fertilizer showed the highest disease incidences, which could be attributed to the reduced ability of the banana aphid to fly to a distance of 100 meters, as it is not a strong flier (Niyongere, 2013). In contrast, plots with a buffer zone of 100 meters and inorganic fertilizer application had the lowest disease incidence, highlighting the beneficial effects of both disease management strategies in tandem. It is important to note that buffer zones did not significantly influence specific plant growth attributes, such as plant height, number of leaves per plant, number of suckers per plant, leaf diameter, stem diameter, and leaf width. This lack of significant impact may be attributed to some plots being attacked by the Banana Bunchy Top Virus, leading to stunted growth and leaf distortion (Wanitchakorn et al., 2000).

Mechanisms of Inorganic Fertilizer and Buffer Zone Effects: The positive effects of both inorganic fertilizer and buffer zones on banana plant health can be attributed to their respective mechanisms of action.

Mechanisms of Inorganic Fertilizer Effects: The application of inorganic fertilizer provides essential nutrients, such as nitrogen, phosphorus, and potassium, which are crucial for optimal plant growth and development. Nitrogen is known to promote vegetative growth, leading to increased plant height and the number of leaves and suckers per plant (Kumar et al., 2003). The availability of phosphorus also contributes to healthier plant growth, preventing yellowing of the plant and slow growth (Srivastava, 1963). Furthermore, the supply of nutrients to the mother banana rhizome through inorganic fertilizer application results in the development of more suckers, supporting overall plant vigor (Bhende and Kurien, 2015). Studies by Nobrega et al. (2010) further support this, as they found that nitrogen supply to banana plants, combined with pruning, enhanced sucker production. Considering the issue of low soil fertility in certain regions of Malawi due to land degradation (Njoloma et al., 2016), the timely and appropriate application of inorganic fertilizers plays a critical role in providing the necessary nutrients for banana plants' optimal growth and development.

Mechanisms of Buffer Zone Effects: The establishment of a buffer zone at a distance of 100 meters from infected banana plants contributes to disease reduction through spatial isolation. This physical isolation effectively limits the transmission of the Banana bunchy top virus (BBTV) carried by the banana aphid (*Pentalonia nigronervosa*) (Rajan, 1981). The life cycle of the banana aphid takes approximately 29 days on average, and it may produce winged adults after approximately 203 days (Rajan, 1981). Although not strong fliers, banana aphids can travel short distances, favoring newly planted banana plants (Young and Wright, 2005). By maintaining a buffer zone of 100 meters, the ability of the banana aphid to transmit the virus to newly established banana plants is significantly reduced.

Replication of Results and Optimal Fertilizer Level: Replicating the positive impacts of buffer zones on disease incidence and optimal inorganic fertilizer levels is crucial for effective banana disease management in various regions. The findings from this study, which demonstrated the significant positive effects of buffer zones and inorganic fertilizer application on banana plant health and disease incidence, can serve as a basis for replication in other banana-growing regions facing similar disease challenges. However, it is essential to consider specific environmental conditions, banana cultivars, and disease prevalence when implementing buffer zones as a management strategy. The success of buffer zones in reducing disease transmission relies on maintaining a spatial separation of at least 100 meters between healthy and infected banana plants. By adopting this approach, farmers can effectively limit the spread of Banana bunchy top virus (BBTV) carried by the banana aphid (*Pentalonia nigronervosa*) and promote healthier banana plants. In terms of inorganic fertilizer application, our study used an optimal level of 46 kg of urea (46% N) and 56.6 kg of (23:21:0+4S) fertilizer. This optimal nutrient supply resulted in improved plant growth and health, promoting increased plant height, leaf production, and sucker development. However, it is essential for farmers to exercise caution and adhere to appropriate fertilizer application rates. Applying excessive fertilizer can lead to nutrient imbalances, increased susceptibility to other pests and diseases, and environmental pollution. Hence, understanding the proper dosage of inorganic fertilizers based on soil conditions and the specific nutrient requirements of banana plants is vital for achieving optimal results in plant growth and health. By replicating these findings and adopting the recommended buffer zone distances and appropriate fertilizer levels, farmers can effectively manage banana diseases and promote sustainable agriculture with healthier banana plants in their respective regions.

In summary, the study demonstrates the significant positive effects of buffer zones and inorganic fertilizer application on banana plant health and disease incidence. Buffer zones contribute to disease reduction by isolating healthy plants from infected ones, limiting pathogen transmission. Inorganic fertilizer application provides essential nutrients for optimal plant growth, promoting increased plant height, leaf production, and sucker development. By implementing buffer zones and adhering to appropriate fertilizer application rates, farmers can effectively manage banana diseases and promote sustainable agriculture with healthier banana plants. Future studies can replicate these findings in different banana-growing regions to further enhance banana disease management practices.

CHAPTER 5
GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

The survey and field experiment results in this study show a strong connection between the two, especially when it comes to the usage of inorganic fertilizer and its effects on the health and incidence of disease in banana plants. The survey revealed that poor agronomic practices, including inadequate fertilizer use, contributed to low banana yields in Mulanje and Nkhata-bay districts. This finding aligns with the field experiment results, which showed that the application of inorganic fertilizer significantly boosted plant growth and the number of suckers produced per plant. Essential nutrients for plant growth and development, including nitrogen, phosphorus, and sulfur, were provided by the inorganic fertilizer. The positive effects of inorganic fertilizer on plant growth attributes observed in the field experiments further support the survey findings, emphasizing the importance of proper nutrient management practices in banana cultivation. The present study establishes a strong nexus between the survey and field experiment findings, complementing and reinforcing each other while shedding light on effective strategies for managing Banana bunchy top disease (BBTD) and improving banana production in Mulanje and Nkhata-bay districts.

The survey findings, in line with earlier research (Kumwenda, 2013; Ploetz, 1998), confirm that women play a crucial role in banana production in the region. However, poor agronomic practices, including inadequate fertilizer use, have contributed to declining banana yields. This observation aligns with the field experiment results, where the application of inorganic fertilizer significantly enhanced plant growth and the number of suckers produced per plant. These results are consistent with previous studies that have emphasized the importance of proper nutrient management in promoting plant growth and health.

The survey and field experiment findings collectively demonstrate the significant impact of buffer zones on disease incidence, with BBTV being identified as a major challenge to banana production, consistent with prior research. The establishment of a 100-meter buffer zone from infected plants drastically reduced disease transmission, limiting the spread of BBTV by the banana aphid. These results corroborate earlier research (Rajan, 1981; Young and Wright, 2005), highlighting the critical role of buffer zones in disease management and the importance of maintaining spatial isolation to prevent disease spread.

The reliance of farmers on fellow farmers for clean planting materials, as revealed in the survey, can facilitate BBTV transmission. This finding aligns with the field experiment results, demonstrating that the combination of a buffer zone and inorganic fertilizer application effectively reduced disease transmission. The interaction of these strategies restricted aphid movement and promoted natural resistance in banana plants, resulting in a substantial reduction in BBTV spread.

The survey also identified the preference for susceptible banana varieties, such as Kabunthu, Zambia, and Mulanje (dwarf Cavendish varieties), due to their taste and high yield capacity. This preference was confirmed by the field experiment findings, which showed that these varieties were susceptible to BBTV, leading to yield losses. These results concur with prior research (Ploetz, 1998), emphasizing the importance of developing and introducing resistant or tolerant banana varieties to mitigate BBTV's impact.

In summary, the present study, along with earlier research (Kumwenda, 2013; Ploetz, 1998; Rajan, 1981; Young and Wright, 2005), underscores the critical role of inorganic fertilizer application and buffer zones in promoting healthy banana plant growth and reducing disease incidence. Proper nutrient management practices, along with the implementation of buffer zones, are essential components of effective disease management and sustainable banana production in the region. By adopting these strategies and incorporating resistant or tolerant banana varieties, farmers in Mulanje and Nkhata-bay districts can enhance their resilience against BBTD and ensure the long-term prosperity of banana cultivation.

5.2 Conclusion

The prevalence of Banana bunchy top disease (BBTD) in Mulanje and Nkhata-bay districts of Malawi has significantly impacted banana production. While uprooting infected banana plants is considered an effective method, it proves labor-intensive for farmers. Despite implementing a 100-meter buffer zone, the disease's spread was not completely halted, but rather delayed.

Nevertheless, establishing a buffer zone at a 100-meter radius from infected plants demonstrated a reduction in the spread of BBTV. Additionally, the application of inorganic fertilizer contributed to a decrease in disease incidence. The combination of a 100-meter buffer zone and inorganic fertilizer application emerged as an effective approach to substantially reduce incidences of BBTD. This study has shed valuable light on disease management strategies and sustainable agricultural practices. By adopting buffer zones and applying inorganic fertilizers, farmers can effectively limit disease transmission and promote robust banana plant growth, thereby enhancing overall productivity. Encouraging the adoption of buffer zones and proper fertilizer application is essential to enhance disease resistance and plant health. Further research should be conducted to explore the period between uprooting infected bananas and planting new ones. Additionally, the development and introduction of resistant or tolerant banana varieties can significantly contribute to disease management efforts. By implementing these recommendations, farmers in Northern Malawi can gain access to disease-free planting materials, efficiently manage BBTV infections, and secure the long-term sustainability and prosperity of banana cultivation in the region.

5.3 Recommendations

I. The establishment of institutions to be involved in the production of disease-free banana planting materials and the development of farmers' capacity for macro propagation of disease-free planting materials to increase access to healthy planting materials because most farmers lack disease-free planting materials.

II. Practice of sharing of banana planting materials between farmers should be discouraged because most of farmer's banana plants were infected by the virus.

III. Farmers should establish at least 100 m buffer zone from infected banana plants when establishing a new banana field and also apply inorganic fertilizer in their banana fields.

IV. Further research on the period from uprooting infected banana to planting new bananas should be conducted.

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APPENDIX 1: QUESTIONNAIRE

Objective 1: To assess farmer's knowledge and perceptions on incidence and management of banana bunchy top disease: Case study of farmers from Milonde Extension planning areas (EPA) in Mulanje district and Chintheche and Mpamba EPAs in Nkhata-bay district.

Introduction

This research is carried out by a Malawian Postgraduate Student, Godfrey Tiwonge Kayira pursuing a Master of Science degree in Agronomy in the department of Plant Science and Crop Protection, University of Nairobi. The survey will assist the student gather information for the compilation of his thesis. The first objective of his research is to assess farmer's knowledge and perceptions on the incidence and management of banana bunchy top disease. Please circle and fill in responses where applicable.

Name of a respondent was also indicted:

A. Socio-economic data

A1. Sex of respondent

1. Male 2. Female

Name of a respondent was also indicated:

A2 Age-range of respondent

1. Below 20 years old 3. 21 to 30 years old
2. 31 to 40 years old 4. More than 41 years old

Actual age was also indicated

A3. Marital status

1. Single 2. Married 3. Divorced 4. Widowed

A4. Level of education

1. Primary School 2. Secondary Education 3. Tertiary Education
4. No formal education

A5. What are the major crops you grow?

1. Bananas 2. Mango 3. Oranges 4. Avocado 4. Maize 5. Other, specify ________________

A6. Which crop has been your predominant source of income for the past 5 years?

____

A7. What are your current sources of income?

____

B. Management practices of banana production

B1. How do you grow bananas?

1. In Mats 2. In orchard

B2. If in mats, how many mats do you have? ______________________________________

B3. If in an orchard, what is the acreage for the orchard?

____

B4. What spacing do you use when planting bananas?

____

B5. What varieties of banana do you grow?

____

____

____

B6. Do you apply fertilizer to your bananas? 1. Yes. 2. No

B7. If yes, what type? 1. Organic 2. Inorganic.

B8. What quantities of fertilizer do you apply?

____

B9. Do you do weeding in your banana field? 1. Yes 2. No

B10. If yes, how many times do you weed in a season?

____

C. Constraints to banana production

C1. List down the challenges you face when producing banana

____

____

____

____

____

____

____

____

C2. Rank the challenges in the order of importance.

D. Farmers' knowledge and perceptions on causes and effects of BBTV disease.

D1. Do you know anything about BBTV disease? 1. Yes 2. No

D2. If yes, where did you get the information? 1. Research scientists

2. Extension workers 3. Friends 4. Other farmers 5.Other, Specify ______________________

D3. What are the signs of BBTV? ____

D4. What are the effects of BBTV disease on yield and income observed over the past five years? ____

D5: How does BBTV spread?____

E. Banana Bunchy Top control measures being practiced by farmers

E1. Do you control BBTV? 1. Yes 2. No

E2. If you do, what measures do you take to control it? ______________________________

F. Farmers' perceptions on recommended BBTV control measures

F1. Do you know any recommended (by research) control measures of BBTV? 1. Yes 2. No

F2. Which recommended BBTV control measures do you know? ___________________

____

F3. Where did you get the information from? 1. Public Research scientists

2. Public Extension workers 3. Private Research scientists/extensionists 4. Friends5. Other farmers. 5. Others, specify ____

F4. What are your opinions about recommended BBTV control measures? _____________

____

____

____

____

F5. How should these recommended BBTV control measures be improved?

____

____

____

G. Yield loses, infection levels and trends of BBTD

G1. Have you noticed any yield reduction after noticing banana bunchy top disease in your yield?

1. Yes. 2. NO

G2. If yes, what quantities? ____

G3. What have been the production trends of banana after noticing BBTD in your field?

____

G4. What are infection levels in your field?

1. Mild. 2. Severe

H. **Availability of alternative disease-free banana planting materials**

H1. . Do you have alternative source of disease-free banana planting materials? 1. Yes 2. No

H2. If yes, where do you get the disease free planting materials?

____

H3. Which banana varieties would you prefer to be multiplied at Agricultural Research?

I. Farmers' challenges in the control of banana bunchy top virus disease

I1. What are the constraints you face in the control of banana bunchy top virus disease?