MANAGEMENT OF PLANT PARASITIC NEMATODES ON SWEET POTATOES USING BIOCHAR AND CHICKEN MANURE IN BUNGOMA COUNTY, KENYA

BY

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DECLARATION

Declaration by the Candidate

I, the undersigned, declare that this Research Thesis submitted to Moi University is my original work and it has not formed previously the basis for the award of any degree in any other University. No part of this project may be reproduced without the prior written permission of the author and/or Moi University.

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DEDICATION

This thesis is dedicated with deep respect and heartfelt appreciation to all those who have supported and guided me throughout this academic journey as follows;

To my family, your constant love patience and sacrifice have been the foundation upon which this endeavor was built. In moments of self-doubt and fatigue, your belief in me remained steadfast. You reminded me of my purpose and inspired me to persevere. Your values and quiet strength have shaped me to whom I am and for that I'm forever grateful.

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ABSTRACT

Sweet potato (*Ipomoea batatas* L.) is a source of food and nutrition in many developing nations. Plant Parasitic Nematodes (PPN) significantly reduce its productivity and yield. Synthetic nematicides used to manage PPN are harmful to the environment, non-target species and humans, and hence the need for safer and effective PPN management options. Thus, the aim of this study was to examine the effect of soil organic amendments on sweet potatoes and plant parasitic nematodes in Bungoma County, Kenya. The specific objectives were to: Assess the impact of drill and ridge farming systems on sweet potato yield; Evaluate the effect of biochar and chicken manure on sweet potato growth and yield; and Determine the effect of biochar and chicken manure on plant parasitic nematode abundance and diversity. A total of eleven treatments consisting of sole and combined soil amendment treatments of biochar and chicken manure were tested on sweet potatoes planted under drill and ridge farming systems on three farms (Ben, Mabanga and Nafula) using a completely randomized design and randomized complete block design in the first and second planting seasons, respectively. Data on plant biomass and yield that included total tuber weight and number, and marketable and non-marketable tuber weight and number were collected at harvest time, while the initial and final population density of PPN in the soil and on plant roots was collected at planting and harvest time, respectively. Data was analyzed using one-way analysis of variance and significant means separated using Tukey test in the R software. Results from each farm showed no significant yield differences (P=0.05) among treatments tested on sweet potatoes planted under drill farming. However, treatments tested under ridge farming produced significantly higher (P≤0.05) total tuber weight when compared to those under the drill farming, indicating that ridges ensured that the sweet potato roots had enough space to grow and develop. While biochar treatment increased plant biomass, co-application of biochar and chicken manure (five tonnes each) and the sole application of ten tonnes of chicken manure significantly increased (P≤0.05) total and marketable tuber weight, which is attributed to the nutrient-rich water released as a result of the decomposition of chicken manure. Economically significant PPN of sweet potatoes belonging to the genera *Pratylenchus, Meloidogyne* and *Rotylenchulus* were more prevalent in the soil than roots. Mabanga farm had significantly higher (P≤0.05) population density of PPN than Ben and Nafula farms. Co-applications of biochar and chicken manure significantly decreased (P≤0.05) the population size of PPN on all farms, but their impact on the different PPN genera was varied. Ridge farming with organic amendments, offers a sustainable strategy for sweet potato production. This study recommends field co-applications of biochar and chicken manure mixture (five tonnes each) under the ridge farming system as practical strategies to boost yield and reduce plant parasitic nematode pressure in sweet potato production.

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ABBREVIATIONS

AEZ	– Agro-ecological Zones
ANOVA	– Analysis of Variance
CLD	– Compact Letter Display
CRD	– Completely Randomized Design
CRU	– Continuous Ridge Use
DMC	– Dry Matter Content
FP	– Farmer Practice
FO	– Frequency of Occurrence
GLM	– General Linear Model
HIV/AIDs	– Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome
HSD	– Honest Significant Difference
IFPRI	– International Food Policy and Research Institute
IPM	– Integrated Pest Management
J2	– Second Stage Juveniles
KALRO	– Kenya Agricultural Livestock and Research Organization
NPK	– Nitrogen:Phosphorus:Potassium ratio
OFSP	– Orange Fleshed Sweet Potato
PD	– Population Density
pH	– Potential of Hydrogen
PPN	– Plant Parasitic Nematodes
PV	– Prominence Values
RKN	– Root Knot Nematodes
SE	– Standard Error

SPN	– Sweet Potato Nematodes
USA	– United States of America
USD	– United States Dollar

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Ipomoea batatas (L.) Lam., also known as sweet potato, is a root vegetable that is endemic to tropical America. It is extensively farmed in developing nations as a subsistence crop, especially in tropical, subtropical, and warm temperate climates. This perennial crop features varied leaf forms and a vine-like growth pattern. As the plant grows, the store roots swell. Sweet potatoes may be produced in moderately infertile soils with minimum inputs as they are vegetatively propagated.

Sweet potatoes contain immense nutritional potential. First with the roots are a carbohydrate-rich foundation in many African cuisines and are used to make alcohol, and then the leaves which are high in protein and minerals, serve both as vegetables and feed for cattle and sheep. According to (Kavoo et al., 2022), it can also endure periods of occasional drought and rain. The vines are utilized as a source of sustenance for dairy livestock, including cows, sheep, and goats. When dairy cows are supplied with sweet potatoes as part of their diet, they often yield a bigger quantity of superior-quality milk, as documented by (Kivuva et al., 2015). Lastly, women and children in many African homesteads produce sweet potatoes as a means towards achieving food security (Filho et al., 2022).

In 2014, Kenya produced 763,643 tonnes of sweet potatoes that were cultivated on 61,067 hectares. The key producing regions comprised of Bungoma, Homabay, Busia and Migori Counties, with output statistics of 133,037, 127,725, 119,970, and 69,642 tonnes, respectively (Abong et al., 2016).

Nematodes are extensively disseminated across all ecosystems as both parasitic and free-living microorganisms, and they have diverse effects on crop output (Coyne & Ross, 2014). Even though sweet potatoes are home to a broad diversity of nematode species, only a limited number of the plant parasitic nematodes (PPN) are economically relevant. The most remarkable PPN of sweet potatoes are *Ditylenchus destructor*, *Rotylenchulus reniformis*, *Pratylenchus* spp., and *Meloidogyne* spp. (Luc et al., 2005).

Plant parasitic nematodes are projected to inflict five to ten percent of yield losses of sweet potatoes which are accurately assessed seasonally due to short crop cycles and fluctuating seasonal environmental factors. This is majorly contributed to by the *Meloidogyne* and *Rotylenchulus* species (Kemboi et al., 2022). Plant parasitic nematode infection happens at different plant development stages. For example, the reniform nematode, *Rotylenchulus reniformis*, affects sweet potatoes in their early stages of root development, leading to root system reduction through "pruning" (Karuri et al., 2016). When sweet potatoes experience simultaneous infection by numerous PPN species, they demonstrate varied responses (Maina et al., 2020). Key signs of nematode-infected sweet potatoes include the formation of root galls, necrosis, and root cracking (Coyne et al., 2014). Root galls impede nutrient and water absorption and delivery while cracking and necrosis degrade the quality and marketability of the store root. Additionally, the infected roots create entrance routes for secondary diseases, further lowering productivity.

Due to the increase in PPN densities that are associated with the shifts in temperature and weather patterns, the prevalence of PPN in Kenya's sweet potato producing agro-ecological zones (AEZ) pose a significant challenge to production(Coyne et al., 2003). It is crucial for farmers to employ appropriate management measures to limit the effects of PPN on their crops.

Nematode control in sweet potatoes is now focused largely on crop rotation, planting of clean material, and the use of nematicides. However, routine use of synthetic nematicides in managing PPN poses significant challenges for farmers. These chemical controls are often costly, increasing the overall production expenses, and their repeated applications raises concerns about their negative impacts on human health and the environment. Moreover, smallholder farmers may be unable to afford the products consistently. (Karuri et al., 2016). Therefore, there is need to explore alternative and sustainable PPN control options. The use of soil organic amendments that are cost-effective and widely accessible such as biochar and chicken manure present a viable strategy for efficiently managing sweet potato nematodes.

Biochar and chicken manure have shown potential as effective soil amendments for managing PPN in various cropping systems. For example, studies have reported that biochar can suppress nematode populations by improve soil health in tomato and cucumber by enhancing microbial altering soil properties and releasing nematicidal compounds (Ningsi et al., 2021; Cao et al., 2017). Likewise chicken manure has been reported to reduce nematode infestations in okra, pepper and eggplant due to its nutrient richness and natural nematicidal properties (Oka, 2010). However, despite these promising outcomes, there's limited understanding of how these amendments especially when used in combination affect nematode populations in sweet potato production systems particularly under field conditions. In response to the challenges, this study aims to assess the impact of soil organic amendment on plant parasitic nematodes population and growth performance of sweet potatoes under different farming systems in Bungoma County, Kenya. Ultimately, the study is expected to generate evidence on the practical applicability of biochar and chicken manure for managing PPN in sweet potatoes, thereby filling the existing gap concerning their combined use and field level efficacy within Kenya's sweet potato production systems.

1.2 Problem Statement

Plant parasitic nematodes drastically affect agricultural crop output. Stem nematodes pose a significant threat to sweet potato production by seriously affecting yield and quality, typically resulting in a 20 to 50% reduction in yield or even complete crop failure (Luo et al., 2024). This is equivalent to global cost of ≥ 118 billion united states dollar (USD) worldwide (Maina et al., 2020). *Meloidogyne* species, *Pratylenchus* species, and *Rotylenchulus* species are among the top three genera of nematodes that are generally recognized to inflict harm on sweet potatoes (Niere & Karuri, 2018). *Rotylenchus reniformis* has been reported to cause about 24% yield losses while *Pratylenchus brachyurus* is reported to have reduced leaf growth (Abel et al., 2007)

According to (Karuri et al., 2016) concerns about the negative effects of PPN on sweet potato production particularly in Kenya's AEZ stem from the fact that these nematodes represent a substantial barrier to productivity, with their impact potentially worsening due to temperature and moisture changes. They cause harm to both above-ground and below-ground plant components, resulting in symptoms such as galls, stunted development, chlorosis, and root cracking (Niere & Karuri, 2018). Their interruption of water flow and photosynthate transport causes to growth retardation, chlorosis, and lower yields, with a worldwide economic effect estimated at $118 billion USD annually, as reported by (Atkinson et al., 2013). With such persistent and widespread impacts, plant parasitic nematodes present a major challenge to sweet potato production, underscoring the need for sustainable management approaches such as the use of biochar and chicken manure.

1.3 Objectives

1.3.1 General Objective

To assess the impact of soil organic amendment on plant parasitic nematodes population and growth performance of sweet potatoes under different farming systems in Bungoma County, Kenya.

1.3.2 Specific Objectives

1. To assess the effect of drill and ridge farming systems on the yield of sweet potatoes.
2. To evaluate the effect of biochar and chicken manure on the growth and yield of sweet potatoes.
3. To determine the effect of biochar and chicken manure on the abundance and diversity of nematodes affecting sweet potatoes.

1.4 Hypothesis

1. Drill and ridge farming systems do not have a significant effect on the yield of sweet potatoes.
2. Biochar and chicken manure do not have a significant effect on the growth and yield of sweet potatoes.
3. Biochar and chicken manure do not have a significant effect on the abundance and diversity of plant parasitic nematodes in sweet potato fields.

1.5 Justification

Nematodes are present in all soil ecosystems, occurring in both free-living and parasitic forms playing diverse roles in agricultural systems. Among these, PPN are especially harmful since they harm plant roots and predispose crops to subsequent infections, hence generating significant yield losses (Maina et al., 2020). In root and tuber crops like sweet potatoes, nematode infestations usually go unnoticed until notable damage happens, hence causing great economic losses. Environmental factors have a major impact on the distribution and population dynamics of PPN. These include; soil temperature and moisture influencing their survival, reproduction and movement (Karuri et al., 2016).

Farmers have long depended on synthetic nematicides to control PPN. But worries about their toxicity to farm workers, non-target organisms, and long-term environmental effects have caused several of these products to be limited in use (Abd-Elgawad, 2021). Their high price and limited availability also render them inappropriate for small-scale farmers on a tight budget, particularly in underdeveloped areas (Renco, 2013). These constraints highlight the critical need for sustainable, reasonably priced substitutes for nematode control that are both environmentally beneficial and locally available.

Biochar and chicken manure are among the organic soil amendments have emerged as hopeful alternatives for improving soil health and controlling the PPN populations. Biochar has been demonstrated to increase soil structure, promote microbial activity improving soil health and ultimately raising the fungivore populations which are indications of healthy soil (Zhang et al., 2012). Similarly, chicken manure has exhibited nematicidal qualities and long-term advantages in soil fertility and structure (Forge et al., 2016). While these improvements have been addressed individually, their combined usage remains underexplored especially in the context of sweet potato cultivation in Kenya where integrated PPN management is seriously needed.

1.6 Significance of the Study

This study aims to identify an effective approach for managing sweet potato nematodes. The selected components are readily available and affordable making the accessible for practical application by farmers. Additionally, the use of biochar and chicken manure might deliver a sustainable and environmentally beneficial technique to manage sweet potato nematodes.

This study may also be used to highlight the possibility of applying organic materials for pest management, limiting the dependence on chemical pesticides that may have adverse impacts on the environment and human health. Furthermore, biochar and chicken manure can improve soil health by increasing soil organic matter, improving soil fertility, and stimulating soil biodiversity. This can lead to better crop growth and production.

The findings of this study may be repeated in other crops that are affected by nematodes, such as Irish potatoes. This could add on information to the existing scientific knowledge base and help us apply organic pest management measures in agriculture. For sustainable agriculture and overall food security, this may have substantial implications.

1.7 Limitations of the Study

The variety of sweet potato “Namunyekere” might potentially be a constraint. Different sweet potato varieties may have varying levels of vulnerability to nematode infection and respond differently to control techniques. Therefore, employing only one type of sweet potato in a study may not be typical of the entire sweet potato population.

Other variables, such as weather or other pests, may alter the research's conclusions. Controlling these variables might be problematic and may hinder the study's capacity to identify the impacts of the management practices adopted.

The study may be restricted in its capacity to extend its findings to other sweet potato-growing locations. Factors such as soil type, climate, and agricultural techniques may cause variations between locations and impact the effectiveness of management measures.

The study only examines a restricted number of factors, such as the impact of biochar and chicken manure on nematode populations as well as their effect on the growth and yield of sweet potatoes. There might be additional variables, such as soil pH or nutrient levels, that were not studied but could impact nematode populations and the growth and yield of sweet potatoes.

CHAPTER TWO :

LITERATURE REVIEW

2.1 Sweet Potato Production and Significance

Since ancient times, sweet potato has served as a significant food crop in Central and South America, as well as more recently in a wide range of nations in the tropics, subtropics, and temperate regions. It stands second as the seventh most significant food crop in the world and the fifth most significant crop in less advanced economies (Mukhopadhyay et al., 2011). Although the following section places emphasis on the production and use of tubers, in some places they also make use of above-ground plant parts, primarily for animal feed (Kays, 2004).

The annual output of sweet potatoes in sub-Saharan Africa exceeds 7 million metric tonnes, or around 5% of world production. Output in East and Central Africa has increased 1.5 times (to 250% of 1960 production) since the early 1960s. According to recent international food policy and research institute (IFPRI) predictions, production of sweet potatoes might exceed double in Africa by 2020 while being steady or declining elsewhere in the globe. In East Africa's heavily populated and heavily farmed mid-elevation production zones, sweet potato is a staple food. It is a significant secondary crop farmed for a developing fresh market in many other nations. Uganda (1.7 million tonnes), Rwanda (980,000 tonnes), Malawi (960,000 tonnes), and Kenya are the continent's leading producers (725,000 tonnes), while Rwanda and Burundi are the top two producers on a per-capita basis (Ewell, 2002).

The sweet potato is a significant staple crop in Kenya (Ongala et al., 2018). Because of a number of factors, including declining soil health in the majority of the country's AEZ, the removal of subsidies for fertilizer and seeds for important crops like wheat and maize as part of trade liberalization policies, catastrophic disease and pest infestations of important crops like wheat and maize, consumers' awareness has grown and shifted from the myths that sweet potatoes are a healthy crop to consume rather than a poor man's food, and an increasing number of farmers are now switching from producing sweet potatoes as a food crop to a commercial one (Ongala et al., 2018).

Sweet potatoes are regarded as a crop that promotes food security, mostly because of their consistent yields. They spread easily and thrive even on poor soils without any input and in a variety of rainfall patterns. It has regularly demonstrated its importance as an insurance crop despite being a primitive crop. It is also a tolerant crop that, once established, will consistently produce sufficient yields in difficult circumstances with no inputs and little to no attention. This is a huge benefit for poor households with individuals who depend on various forms of employment (informal), especially those who are human immunodeficiency virus / acquired immunodeficiency syndrome (HIV/AIDs) affected. (Ewell, 2002).

Additionally, sweet potatoes have a handful of nutritional characteristics that render them a very healthy food (Kays, 2005). The pro-vitamin A concentration of yellow to orange colored clones is usually high (Simonne et al., 1993), making them good sources of the vitamin. Consumers receive considerable health benefits from the comparatively high insoluble and soluble fiber content, such as decreased serum low-density lipoprotein (LDL) cholesterol, a lower incidence of cardiovascular disease, and a lower incidence of some malignancies and diabetes (Kays & Kays, 1998). Sweet potato also includes a sizable amount of polyphenols, which have been linked to a range of health advantages (e.g., reduced-free radical damage, anti-cancer effects, reduced serum cholesterol). Within the gene-pool, polyphenols, beta-carotene, and fiber exhibit significant quantitative and qualitative variability, demonstrating the potential for these qualities to be improved via breeding programs. When compared to most staple foods, sweet potatoes additionally feature a relatively low blood sugar level, which reduces the risk of diabetes (Kays, 2004).

2.2 Sweet Potato Production Challenges

Several biotic and abiotic factors frequently have an impact on sweet potato production (Gurmu et al., 2016). Insect pests also are a major constraint to sweet potato production. These insect pests are grouped into two categories that is foliar feeding insect pests such as cucumber beetle, sweet potato flea beetle and soil insects such as the sweet potato weevils and plant parasitic nematodes. Sweet potato weevils excavate cavities and create egg laying puncture in roots which reduce appeal of the roots reducing the market price. However, major damage is caused by larvae as they feed burrowing tunnels where they excrete leaving a pungent odour and hence reducing the marketable yield. They been estimated to cause losses of up-to 73% in Uganda and up-to 15-20% in Tanzania (Hue & Low, 2015).

Yield losses are primarily caused by soil-inhabiting insect pests, while severe infestations of foliar feeding insect pests only impair yield indirectly and are easily managed using foliar pesticides (George et al., 2024). Diseases such as; Alternaria blight, and root rots, are a few of the main biotic factors that affect sweet potatoes. According to (Ongala et al., 2018), viruses can cause yield losses of up to 78%, and the sweet potato weevil can cause losses of up to 45%. Plants infected with viruses and weevils are also more vulnerable to other diseases and pests, which can cause production losses of up to 100%. Alternaria blight, bacterial wilt, and fusarium wilt are additional ailments that afflict sweet potatoes.

Socially disadvantaged farmers are particularly exposed to lack of integrated pest management (IPM) methods as most IPM projects focus on large scale farms.

additionally, lack of access to improved varieties, clean planting material, and poor carotene content in the white fleshed sweet potatoes and a low dry matter content (DMC) in the orange fleshed sweet potato (OFSP) varieties that are currently available are other socioeconomic and quality attribute constraints. (Gurmu et al., 2016). Among the most important variables affecting the quality and value of the crop are improper post-harvest handling procedures. Additionally, poor crop establishment and low yield are caused by a number of factors, including inadequate land preparation, a lack of high yielding and adapted cultivars, the non - availability of good quality cuttings in sufficient numbers, sub- or hyper plant populations, improper planting technique and depth, careless harvesting, substandard post-harvest handling, and a lack of crop rotation (Gurmu et al., 2015).

Studies estimates the annual damage from plant parasitic nematodes is than that caused by other soil insect pests (Singh et al., 2015). These small, invisible to the naked eye worms cause a significant loss in crop productivity across many nations. According to (Singh et al., 2024) they resulted in a projected global yield loss of 12.3% amounting to 157 billion USD. Nematode damage typically results in plant responses including growth retardation, chlorosis, and other symptoms that are also suggestive of root damage brought on by a variety of other sources. As a result, the symptoms of nematode damage are typically not unique. Additionally, the precise symptoms can change based on how the plant reacts to the nematode invasion. For instance, whereas other plants infected with the same nematodes may not exhibit similar lesions, certain plants attacked by root-lesion nematodes may have apparent lesions on their roots. (Hart, 1959).

A number of PPN have been linked to sweet potatoes, including *Rotylenchulus, Pratylenchus, Ditylenchus, Paratrichodorus, Trichodorus, Longidorus,* *Helicotylenchus, Scutellonema, Hoplolaimus, Criconemella, Hemicycliophora, Hemicriconemoides*, and *Xiphinema* species (Haougui et al., 2011; Karuri et al., 2017; Niere & Karuri., 2018). These nematodes can be found alone or in groups with other species, and they can cause quite serious infections.

Compared to other root knot nematodes (RKN) species, *Meloidogyne incognita* is a significant pest that damages sweet potato causing yield losses worldwide (Lee et al., 2021). It may launch a lone strike or collaborate with other plant pathogens. It begins from J2 and continues to all of it next life cycles. It occurs in tropics, subtropics, and warmer regions of the world (CABI & EPPO, 2006). It is a polyphagous endoparasite and a primary pathogen favouring the establishment of secondary pathogens like bacteria, fungi and viruses such the black rot plant bed (*Ceratocystis fimbriata*) and stem rots (*Fusarium oxysporum f.sp. batatas*) which are usually some of the sweet potato pathogenic pests that follow damage of *Meloidogyne incognita* (Okada et al., 2017). However, *Meloidogyne incognita's* effect on a sweet potato is typically vastly underestimated. Due to a lack of knowledge about what the damage caused by *M. incognita* to food crops looks like and how it manifests itself, many regions have disregarded this problem for a long time. (Wendimu, 2021). Above ground symptoms of infection by *Meloidogyne incognita* can be stunted growth yellowing of leaves, wilting of leaves, plant death. The below ground symptoms typically include deformed tubers which are characterized by the presence of galls (irregular bumpy structures) or swellings on the roots. These galls limit water supply disrupting the plants physiology. The giant cells that form galls are as a result of secretions by the J2's as they feed causing abnormal cell division (Youssef, 2013). However, the symptoms caused by this nematode are used as a template to indicate presence but definitive identification can only be through collection of soil samples, extraction and accurate identification of the nematode as these symptoms can also be imposed by other agents (Table 2.1).

Rotylenchulus reniformis is another species lowering sweet potato output and, in the USA, it is classified as the second most harmful nematode after the *Meloidogyne* species. Cultural techniques such as crop rotation do not function as the nematode can persist in the soil for up-to 20 years in the absence of a suitable host (Smith et al., 2017). This nematode substantially affects the size, number and general quality of sweet potato storage roots. one of the observable indications linked with its existence is the cracking of storage roots. However, to arrive at a definitive conclusion, it is required to collect soil and root samples, extract the nematodes and precisely identify the species involved. This is crucial since comparable symptoms might come from nutrient shortages or water stress, making appropriate diagnosis important for effective management.

Table 2.1: Diagnostic and biological traits of plant parasitic nematodes economically associated with sweet potatoes.

Nematode Genus	Diagnostic morphological traits	Infective Stage	Parasitic Strategy	Key Symptoms on Sweet Potato
Meloidogyne spp.	pear shaped sedentary female	J2	endoparasite	Root galling
	slender body tapering anteriorly (J2)			Stunted growth
	short and slender stylet			Reduced tuber formation
	conoid tail			Chlorosis
Pratylenchus spp.	strongly cuticularized labial region	J2/J3	Migratory endoparasite	Reduced root mass
	short and strong stylet			Brown root lesions
	ventral pharyngeal overlap			Secondary fungal infections
	subcylindrical-conoid tail			
	vulva at 70% region of body			Yellowing
Rotylenchulus spp.	strong stylet with round knobs sloping posteriorly	J2	Semi-endoparasite	Stunting
	assume c shape when heat killed			Reduced vigor
	have a hyaline potion on the tail			Fine root decline
	mature females are kidney shaped			

2.3 Management Practices of Sweet Potato Nematodes

Crop rotation, floods, sanitation, two to three times of ploughing, composting, adding soil organic amendments, maximizing the planting area in the field, planting at the right time, weed management and the use of cover crops are cultural techniques that can minimize the severity and intensity of plant parasitic nematodes. In warm climates, a fallow approach is particularly beneficial. *Meloidogyne incognita* intensity in the field can be decreased by uprooting the majorly infected sweet potatoes and other alternative host plants in each cropping system. For instance, in South Africa, farmers burn the tobacco remains on-site or remove the harvested plants and expose them to sun. (Wendimu, 2021).

Chemical nematicides such as fumigants have been shown to be effective in decreasing sweet potato RKN and can potentially be used by growers of sweet potatoes. However, they have negative effects on non-target organisms like free living nematodes. (Liu & Grabau, 2022).

With the introduction of high yielding nematode resistant sweet potato types, the use of resistant cultivars has also been documented, and active breeding efforts are being carried out in the USA, Japan, India, and China. This was proven, in particular, with the RKN, where densities dropped below detectable levels within 95 days of cultivation (Mohandas & Siji, 2012). The use of PPN resistant sweet potato cultivars would be the most economical and effective approach. However, in Kenya, the sweet potato varieties such as the "SPK 004" which have shown resistance particularly to the *Meloidogyne* species (Hellen, 2020) are not widely adopted by farmers due to limited availability, lack of awareness or simply preference.

On the contrary, innovative chemicals that rely on biological control agents, including biopesticides like abamectin that belong to the avermectin group, were present in unconventional methods that reflect new trends and alternative approaches. The bacteria Streptomyces avermitilis, which is responsible for the formation of avermectins, naturally ferments a combination of macro-cyclic lactone metabolites to create abamectin (Khalil, 2013).

2.3.1 Use of Drill and Ridge Farming Systems with Organic and Inorganic Amendments

The extent of crop damage caused by PPN is influenced by their distribution within the soil profile, as noted by (Nguyen et al., 2020). The depth at which PPN are found plays a crucial role in the effectiveness of certain control methods. For example, in the case of potato and cabbage crops, there was an interaction observed between the depth at which *Belonolaimus longicaudatus* was present and the impact of nematicide treatment on PPN.

In various crop systems, the vertical distribution of PPN varies across different depths, impacting their management. (Ou et al., 2005) found that in paddy and maize fields, PPN populations decreased with depth, reaching their lowest levels between 80cm and 100cm. In soybean fields, *Paratrichodorus minor* and *Meloidogyne incognita* exhibited unpredictable vertical distribution, while *Pratylenchus brachyurus* was abundant at depths ranging from 15 cm to 30 cm (McSorley & Dickson, 1990).

When the synthetic nematicide Ethoprop was applied at a depth of 0 – 15 cm before planting sweet potatoes, it resulted in a reduction in the populations of *Meloidogyne* and *Helicotylenchus* species. Additionally, incorporating green manure into soil columns alongside tomato plants led to a decrease in the abundance of *Meloidogyne chitwoodi* in the upper zone where amendments were present, but not in the unamended lower layers. Furthermore, in a vineyard context at a depth of 0 - 60 cm, the population of *Xiphinema* index nematodes was reduced after the application of chicken and sheep manure.

Additionally, the drill planting system introduces precision planting by using a drill auger that ensures uniform planting depth and plant placement in the drill subplots

(Sela, 2023; Sharaby et al., 2019). This promotes uniform plant growth and crop performance and saves on labor.

The ridge farming system also contributes to the management of PPN of sweet potatoes. The study by (Suzuki et al., 2014) explored the use of a continuous ridge use (CRU) farming system to manage RKN's across cropping seasons whereby nematode damage was lower in the CRU system as it prevented the increase in RKN populations following the minimization of soil disturbance through continuous ridge use. The ridge farming system also provides a baseline for comparison as it is the most commonly employed cultivation practice for sweet potatoes among farmers in western kenya

2.3.2 Use of Biochar

The term alludes to a biomass-derived material that has a considerable amount of carbon that has undergone pyrolysis, which is produced when an organic material thermally decomposes at a high temperature in an oxygen-deficient environment (Lehmann & Joseph, 2015). Algae, sewage, animal and chicken waste, and agricultural and forestry residues are among the most typical biomass feedstocks for the manufacture of biochar (Duku et al., 2011). The chemical and physical properties of biochar, which may have an impact on soil fertility, are significantly influenced by the type of feedstock and the pyrolysis conditions.

The application of biochar has the potential to alter a wide range of soil attributes, including soil pH, water holding capacity, nutrient availability, bulk density, and soil structure, depending on the kind of biochar used (Lehmann et al., 2015). In grapevine cultivation, the application of biochar derived from poultry litter led to a notable reduction in the populations of soil-dwelling PPN like *Meloidogyne javanica, Tylenchulus semipenetrans, Pratylenchus* spp., *Helicotylenchus* spp., and *Criconemoid* sp. This decline was attributed to an enhanced diversity of beneficial organisms associated with plants (Rahman et al., 2014).

Additionally, the utilization of biochar derived from wheat straw had a discernible impact on the nematode population diversity in a microcosm trial. It resulted in an increase in the number of fungivores while causing a decrease in PPN, including those belonging to genera like *Coslenchus, Hirschmanniella, Rotylenchus*, and *Tylenchus*, as demonstrated in the study by (Zhang et al., 2012). The best biochar application rate has not yet been determined because it changes depending on the type of biochar used, the soil type, and the target species. Positive plant growth responses have been seen at application rates ranging from 0.5 to 135 tonnes per hectare (Schulz et al., 2013).

To add on, it can decrease soil acidity due to its basic composition, which can benefit crop yield. In soils with high levels of both Nitrogen and Phosphorus, biochar and biochar-enhanced compost effectively controlled plant-parasitic nematode infestations. According to the findings of (Cao et al., 2017) compost supplemented with biochar lessens the potential environmental concerns in overly fertilized vegetable soils.

Biochar presents a sustainable approach to managing PPN operating through multiple mechanisms. For instance, PPN may be successfully combatted by altering the biodiversity of nematode populations in the soil. This is because the application of biochar made from wheat straw resulted in an increase in fungivores and a decrease in PPN, including those belonging to the *genera Coslenchus, Hirschmanniella, Rotylenchus,* and *Tylenchus*, among others, in a mini trial (Poveda et al., 2021).

It has been demonstrated that applying biochar had positive antipathogen responses; however, these ramifications differed in their potency and modes of operation. The source material, the pyrolysis conditions, and the application rate employed in soils are the main factors that determine biochar characteristics and the impact they have on soil attributes and pathogen control (Poveda et al., 2021).

Derived from agricultural waste, biochar emerges as a promising approach for the management of plant parasitic nematodes, necessitating local research and optimization efforts to fully harness its potential. Its effectiveness in controlling these nematodes is underpinned by multifaceted mechanisms that warrant in-depth exploration and adaptation to specific regional contexts.

2.3.3 Use of Chicken Manure

To reduce fungi and PPN, different kinds of manures and composts have been added to the soil (Litterick & Wood, 2009). Many farmers conventionally added readily accessible poultry manure to their fields before replanting, either in addition to or as a substitute for fumigation. They did this in the hope that it would help control parasitic nematode populations (Forge et al., 2016). A typical type of poultry manure is made up of both excrement and pine shaving bedding. It is a great source of micronutrients like calcium, magnesium, phosphorus, nitrogen, and potassium. Because of these nutrients, chicken litter is a great alternative to synthetic fertilizers (Riegel & Noe, 2000).

According to (Atandi et al., 2017), adding chicken litter to soil as an organic amendment can help reduce the number of plant-parasitic nematodes present therein. This is probably caused by the litter's elevated antimicrobial activity and component toxicity. Uric acid, which makes up the majority of the nitrogen in poultry manure, may be quickly converted to ammonium nitrogen at the right temperature, pH, and moisture conditions. It has been demonstrated that this ammonia generation kills plant parasitic nematodes (Riegel & Noe, 2000). Additionally, for plants to use the nitrogen present in the soil, organic nitrogen must be converted into inorganic nitrogen. Consequently, using chicken litter as fertilizer has advantages beyond just providing plants with essential nutrients (Riegel & Noe, 2000).

Furthermore, research has shown that nitrogen rich organic amendments, like chicken manure, can reduce the survivability of soil borne plant pathogens. This is a result of the release of hazardous volatiles, such as nitrous acid (HNO_2) and ammonia (NH_3) (Vara et al., 2012). Other elements have been discovered to play a role in the nematode-suppressive effects of using chicken litter as a soil amendment, in addition to its nitrogen content. The inhibition of nematode penetration seen in tomato roots 10 days after inoculation is connected to bacteria found in chicken litter. The observed restriction could have been caused by the eggs' disintegration or by impacts on second stage juveniles (J2) before penetration, since the inoculum employed was eggs (Meyer et al., 2011).

Despite the growing literature on biochar and organic amendments, several important gaps remain about their combined or independent effects on sweet potato growth and yield, particularly under field conditions where farmers mostly use relatively low to no inputs. Most available studies focus on other crops or controlled environments, leaving a gap on how these amendments interact with sweet potato physiology in real world settings.

Additionally, in as much as sweet potatoes are important in small holder farming systems gaps exist in understanding how agronomic practices influence productivity and resilience. There is limited empirical evidence on how the drill versus ridge farming system affect sweet potato yield under smallholder conditions.

There is also insufficient understanding of how biochar and chicken manure influence abundance and diversity of nematodes economically associated with sweet potatoes.

Existing studies focus on suppression mechanisms but rarely quantify how these amendments modify nematode populations across multiple seasons in sweet potato fields. Collectively, these gaps demonstrate the need for integrated field based studies that evaluate farming systems, soil amendments, and nematode ecology simultaneously to provide actionable recommendations to farmers.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site Characteristics

The study was carried out in Bungoma County, located on the western side of Kenya whose coordinates are: N 0° 38' 53.4463", longitude: E 34° 41' 11.2098", latitude E: N 0° 38.890772', longitude: E 34° 41.18683', latitude:0.64818°, longitude:34.686447° (Wabwile, 2016). It borders Kakamega County, Busia County, and Trans-Nzoia County. (figure 3.1).

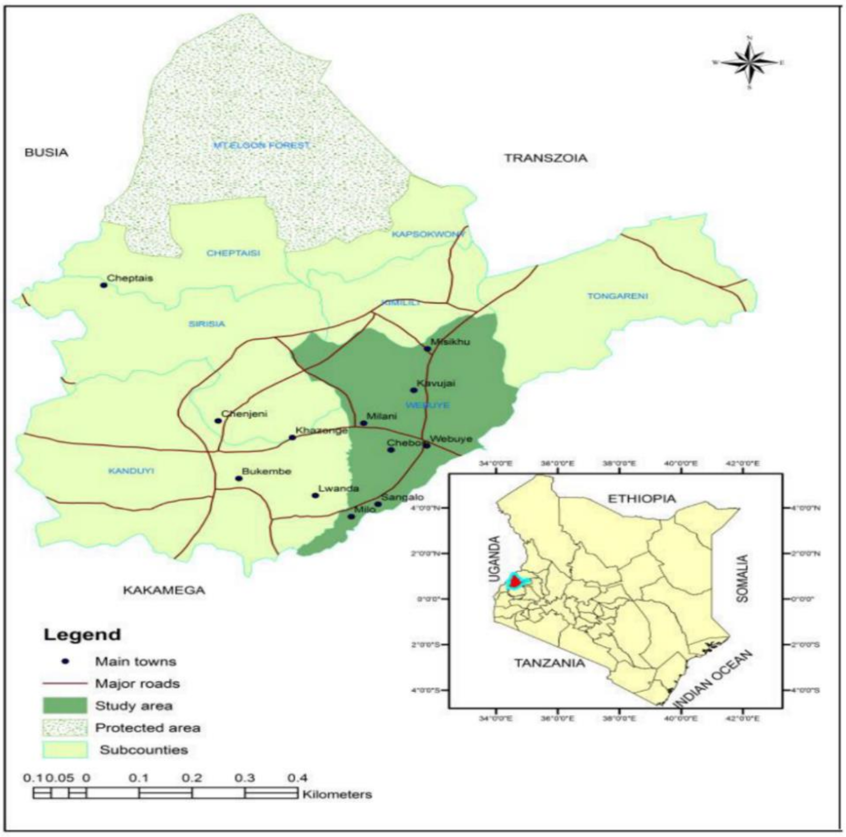

Figure 3.1: Map representing the research study site, Bungoma County, Kenya (Wabwile, 2016)

Agriculture forms the cornerstone of Bungoma County, providing sustenance for the majority of families through crop cultivation and animal rearing. The main crops grown include but are not limited to: maize, beans, finger millet, sweet potatoes, bananas, and

Irish potatoes. These crops are mainly grown for self-sufficiency, with any excess being sold to meet other family needs. It is generally hot and rainy throughout the year, especially in the evenings the wettest area in the country. The heaviest rainfall was recorded in May 2024, with 720.16 mm of precipitation, while the lowest rainfall was observed in January 2023, with only 16.40 mm. The annual rainfall varies between 1,753.90 mm and 2,785.40 mm. Throughout the year, temperatures fluctuate, with a minimum recorded temperature of 14.11°C and a maximum of 32.46°C, indicating a generally warm climate with notable seasonal variations (Kenya Meteorological Department, 2024). Given that the prevailing weather and soil conditions in Bungoma County are highly conducive to sweet potato growth and yield, the site provided an appropriate environment for assessing the treatment performance under realistic farmer field conditions. Additionally, the area has also been documented as a hotspot for nematode related yield losses in sweet potatoes (Karuri et al., 2017), making it suitable for studying pest population dynamics and host susceptibility. In line with the study's farmer oriented objective, the experiment further evaluated locally accessible and environmentally compatible management options under site conditions known to directly influence nematode activity, treatment efficacy, and overall crop development.

3.2 Experimental Design

The experiment was laid out using a completely randomized design (CRD) in the first season as the nematode baseline population levels from the estimated initial population in all subplots, each field data analyzed separately had no significant differences. Additionally, the baseline nutrient levels were also not significantly different. This aligns with the study by (Ochola et al., 2022) who used the CRD after collecting soil samples and extracting nematodes and finding no significant differences in the initial population (A1.1 & A1.2). Randomized complete block design (RCBD) was applied in the second season because of the heterogeinity conditions in the field in terms of the initial population because of high soil moisture conditions. This aligns with the study of (Durner, 2021) who reported that the experimental design is essential to control variation increasing precision and efficiency of the experiment. In both, the treatments randomly distributed treatments that were replicated thrice across three experimental fields. Multiple fields were used as part of the within-study replication where the research is repeated using similar methods and same materials in multiple locations to enhance confidence the study's results as well as build confidence that the observed patterns are biologically meaningful in broader environmental contexts (Filazzola & Cahill, 2021). The fields were as follows; Ben, Mabanga and Nafula. Ben's farm was centrally located, approximately 2.5 kilometers from Mabanga and Nafula farms which were positioned on opposite sides of Ben's farm. The farms coordinates were as follows: Ben (0°35'09.9"N 34°36'44.4"E), Mabanga (0°36'12.1"N 34°37'23.4"E), and Nafula (0°34'41.4"N 34°35'32.1"E). The fields were selected to evaluate the effect of biochar and chicken manure in different locations, the effect of the treatments in the PPN of sweet potato diversity and abundance, growth and yield of sweet potatoes, and ridge and drill farming systems performance. The study employed a single treatment approach that was done at planting after collection of soil samples for nematode extraction, identification and counting. The treatments used for this experiment were laid out in two farming systems, drill and ridge and were as follows; (1) drill + ten tonnes chicken manure, (2) drill + five tonnes chicken manure, (3) drill + ten tonnes biochar, (4) drill + five tonnes biochar, (5) drill + inorganic fertilizer, (6) ridge + ten tonnes chicken manure, (7) ridge + five tonnes chicken manure, (8) ridge + five tonnes biochar, (9) ridge + ten tonnes biochar, (10) ridge + inorganic fertilizer, (11) farmer practice (control). The farmer practice (control) represents the conventional method of sweet potato cultivation. In this approach, farmers simply prepare ridges and plant sweet potatoes without applying soil amendments, inorganic fertilizers or any additional inputs. This treatment served as a baseline to compare the effects of biochar and chicken manure treatments that were laid out in the ridge and drill farming systems. The inorganic fertilizer used was Baraka fertilizer Planting with a nitrogen: phosphorus:potassium ratio (N:P:K) of; 14:29:6 from Timac Agro East Africa Limited.

3.3 Effect of Biochar and Chicken Manure on the Growth and Yield of Sweet Potatoes

3.3.1 Source and Preparation of Biochar

Bagasse from the sugarcane milling process at Nzoia sugar was dried in the sun until the moisture level was less than 20%. Bagasse derived biochar has a high fixed carbon content, improved thermal stability, appreciable cation exchange capacity making it suitable for soil enhancement (Mohd. et al., 2023). The dry bagasse was then placed in the upper chamber of a Kontiki kiln, a cone-shaped structure built of metal that includes a burning chamber and a collecting chamber and bagasse was packed loosely to allow for ventilation.

The pyrolysis process began by lighting match sticks used to ignite a controlled fire at the top of the kiln. As the temperature (measured with an infrared thermometer) within the kiln rose to between 300 °C and 700 °C, the bagasse underwent thermal breakdown in the absence of oxygen, producing biochar. The temperature was kept constant to ensure that it remained within the correct spectrum, preventing incomplete pyrolysis or combustion. After the pyrolysis was complete, the kiln was cooled with water to keep the biochar from burning when exposed to air. After cooling, the biochar, which appeared as a black, lightweight charcoal-like substance, was extracted from the kiln. It was subsequently crushed into tiny fragments for use as a soil amendment. Chicken manure for charging biochar was obtained from Samba Poultry Farm in Kitale, Trans-Nzoia County and collected throughout a span of one week. The manure was transported to the biochar production site and mixed with the generated biochar in a ratio of one to one.

This combination was then allowed to decompose for two weeks, during which time the biochar absorbed the nutrients from the poultry manure. The final product, having been equally enriched and completely degraded, was termed Biochar fertilizer. A ½ kg sample was taken and sent to crop nutrition laboratories in Nairobi for nutrient analysis, after which it was applied to the randomized field plots at the calculated rates of five and ten tonnes per hectare as outlined in section 3.4.5.

3.3.2 Source of Chicken Manure

Skier Enterprises, a large-scale poultry farmer in Kesses, Uasin Gishu County, provided the chicken manure for the project. The stand-alone treatment of chicken manure was obtained from a separate farmer and was not produced on the Samba farm. It was sun-dried, encased in tree branches, and left to disintegrate for two weeks. The chicken manure was split into 50 kg bags. A ½ kg sample was taken from the processed bags and sent to crop nutrition laboratories in Nairobi for nutrient analysis. The chicken manure was applied to the randomized field plots at the calculated rates of five and ten tonnes per hectare as outlined in section 3.4.5.

3.3.3 Field Preparation

Ploughing was done with a disk plough, followed by harrowing three weeks later. There were 33 subplots per field, randomized in three columns. Each subplot consisted of five rows. Each row included ten plants, spaced 0.75 m (row to row) by 0.3 m (plant to plant). A 0.25 m space was allowed between the plot's boundary and the first plant.

Another 0.25 m space was allowed between the last plant in a row (the tenth plant) and the plot border. A border row of sweet potato vines in a ridge was planted throughout the length and width of the entire field, 0.5 m away from the 0.25 m mark from all other subplots. As a result, each subplot measured 3.2 m lengthwise by 3.5 m width, resulting in the overall field dimensions of 11.6 m by 44.5 m. Ridges were created using jembes and lifted to a height of 0.1 m above ground. Drilling was done using a powerful hand-held drill, and 0.2 m holes were dug in the corresponding subplots based on how the treatments were randomly assigned in the field.

3.3.4 Sweet Potato Variety

The sweet potato vine variety used in the study was "Namunyekere". It was sourced from a Kenya agricultural livestock and research organization (KALRO) certified seed entrepreneur under the farmer capacity building subcomponent to strengthen existing inventory technology intensive management practices with a focus on climate resilience, nutrition and safer production practices. The seed entrepreneur was based in Bungoma County. The variety was developed by KALRO in 2015. It is a farmer preferred variety because of its moderate resistance to sweet potato weevil attacks, high yielding properties of 25 tonnes/ha. It is also resistant to Alternaria and is rich in Beta carotenes. It is also popular in the local market due to its sweet taste. The variety is also weather resilient and drought resistant crop making it a reliable choice for areas with unreliable rainfall patterns (Agcenture, 2023).

3.3.5 Planting

Planting for season one was done on September 2023 during the short rains season, while second season planting was done on May 2024 during the long rains season in Kenya. Prior to planting the sweet potato vines, the quantities of biochar, chicken manure, and inorganic fertilizer treatments were calculated to determine the precise amounts to be applied per planting hole within the respective subplots. The amount of biochar, chicken manure, and inorganic fertilizer treatments to be used were calculated from the recommendations of the soil test, biochar and chicken manure test results from crop nutrition laboratories based in Nairobi as illustrated in (A2.1 – 3.2). The calculations were as follows;

1 hectare =10000 m^2

Spacing of sweet potatoes (within rows and between rows) = 0.3 m by 0.75 m

Area covered by one plant $0.3\ m \times 0.75\ m = 0.225 m^2$

No. of plants per hectare minus 0.5 m around the edges of the field to be

99 m by 99 m

$$99\ m \times 99\ m = 9801\ m^2$$

No. of plants: $\frac{9801\ m^2}{0.225\ m^2}$ (area covered by one plant) = 43560 plants per hectare.

Amount of biochar applied;

Consider five tonnes per hectare rate of biochar (from recommendations from the crop nutrition laboratories)

Rate per plant in kg?

5000 kg/ha divide by No. of plants/hectare

$$\frac{5000}{43560} = 0.115\ kg$$

Five tonnes per hectare of Biochar = 0.115 kg

Dry weight of Biochar = 32%

$$\frac{115 \times 132}{100} = 151.80\ g$$

Hence; 152 g for the five tonnes per hectare treatment and 304 g for ten tonnes per hectare treatment

Amount of inorganic fertilizer applied;

Recommendation from the crop nutrition laboratory = 360 kg/ha from a compound fertilizer with N:P:K ratio, 11:23:23

Amount of P_2O_5 needed = $\frac{23 \times 360}{100} = 82.80\ kg$ of P_2O_5

Fertilizer to be used is Baraka fertilizer planting N:P:K ratio (14:29:6)

To obtain the same amount of P_2O_5 like from the recommended we need;

$\frac{82.8 \times 100}{29} = 285.52\ kg/ha$

Rate applied per plant therefore;

$$\frac{28500}{43560} = 6.50\ g$$

Amount of chicken manure applied;

Recommendation from crop nutrition laboratory is 4050 kg/ha

Rate per plant therefore;

Rate per ha/plant population /ha = $\frac{4050 \times 1000}{43560} = 92.97\ g/ha$

Account for the moisture content = 68%

Dry matter content = $100 - 68 = 32\%$

Amount needed per plant = $\frac{92.97 \times 132}{100} = 122.72$ g/ha for the five tonnes per hectare treatment and 246 g/ha for the ten tonnes per hectare treatment.

The treatments, administered at rates of five and ten tonnes per hectare, were measured and dispersed into subplots with plastic tins. These tins were designed to carry one scoop for five tonnes and two scoops for ten tonnes when filled to the brim without compression. Separate tins were utilized for biochar and chicken manure, while inorganic fertilizer was dispensed into the corresponding subplots using a pre-calibrated water bottle cap, which was a flat-filled cap weighing roughly 6.5 g according to the estimates above. The sweet potato vines were then cut off into 0.3 m lengths from the tip. Cut vines were inserted into drilled holes and holes on ridges in subplots before being covered with soil.

3.3.6 Field Management and Harvesting

Hand weeding and ridge hilling were the field management practices applied. This was done every three weeks after planting for four months throughout the growth phase, which was September 2023 to January 2024. Harvesting occurred on the fourth month, January 31, 2024. Second season tubers were harvested on August 2024 having been planted on May 2024. Growth and yield were measured using the following parameters: total tuber weight, marketable tuber weight, non-marketable tuber weight, total tuber numbers, marketable tuber numbers, non-marketable tuber numbers, and plant biomass (fresh weight), which were determined at the time. To remove the border bias, three of the five rows were harvested. The first and last plants in the three rows were likewise overlooked. This resulted in 24 plants per subplot, from which yield and biomass data was obtained.

Data for growth and yield was collected at harvesting. It was collected from all the 11 treatments aforementioned in section 3.2. Yield data was determined in terms of the following parameters: total tuber weight, marketable tuber weight, non-marketable tuber weight, total tuber numbers, marketable tuber numbers, and non-marketable tuber numbers. Tubers were collected from three rows out of five rows to eliminate the border bias, and the first and last tuber in each row was also not included while collecting data for the aforementioned parameters. Tuber numbers were determined before weighing. The weights were determined using the premier (PM-401) weighing scale manufactured in China with a precision of ± 2g. Marketable tubers were characterized as those that were free from pest, disease, and nematode infections, as well as tubers that were over ≥100 g in weight and those that were relatively straight (Wanjala et al., 2019).

Growth data was derived from the biomass (fresh weight) parameter. To avoid border bias, biomass was collected in each plot from three of the five rows, and the first and last vine in each row was also excluded from the biomass data collection. The vines were chopped at their base and stacked from three rows. The sweet potato vines were then packed in a sack and secured with a sisal rope, and the weight was determined using an electronic weighing scale suspended across a metal bar.

3.4 Effect of Drill and Ridge Farming Systems on the Yield of Sweet Potatoes

The experiment was conducted using two distinct farming systems: Flat bed planting using auger drilled holes and ridge planting with hand-made holes. The farming systems were implemented on clean and well-prepared plots which were prepared following the aforementioned experimental design to ensure unbiased treatment allocation. In the flatbed system the planting holes were made using a petrol-powered soil auger, creating uniform 20 cm deep holes. Each subplot consisted of five rows with ten holes per row resulting in 50 planting holes per subplot, drilled in accordance to the CRD subplots layout.in the ridge system, ridges were manually constructed using a jembe, raising the soil 20 cm above the ground level. Planting holes were made using a wooden stick, with each ridge containing ten holes to ensure uniform distribution. The standard spacing of 30cm-by-30cm plant to plant was maintained wile making holes in both systems to ensure uniform plant density and resource distribution.

Data from the two farming systems was collected from the total tuber weight parameter and from all the treatments aforementioned in section 3.2. However, due to the additive effect of the treatments only two treatments were used for analysis. The treatments include; ridge + inorganic fertilizer and drill + inorganic fertilizer. The data was collected at harvesting and the total weight of the sweet potato tubers was measured using an electronic weighing balance, the premier(PM-401) weighing scale manufactured in China with a precision of ± 2g.

3.5 Effect of Biochar and Chicken Manure on the Abundance and Diversity of Sweet Potato Nematodes

3.5.1 Soil Sampling and Nematode Extraction

Soil samples were obtained for both estimation of initial population and final population of nematode that is, before the treatments were set out at planting and again during harvest as aforementioned in section 3.3.5 and 3.3.6 . At harvest both soil and root samples were collected for final population of nematodes estimation. Soil sampling was performed in drilled holes and on ridges where vines were to be planted. The soil samples were obtained at a depth of 15 cm. This was done in five rows per subplot using a trowel from which made up a composite sample of 1 kg.

The soil and root samples were packed in well labeled khaki bags (according to the treatment and their respective replications) and transported to Moi University nematology laboratory and kept at ambient room temperature of 25℃ awaiting extraction of nematodes. Nematode extraction was done using the Modified Baermann's Funnel (European and Mediterranean Plant Protection Organization, 2013) which was set one day after samples were transported to the lab. While awaiting processing, the following preparations were done; Baermann's equipment used for nematodes extraction namely the sieves, plates, scissors were thoroughly cleaned using liquid soap and a sponge and well labelled then arranged in the nematology laboratory in order of the number of treatments and their replications per farm.

While setting up the Modified Baermann's Funnel, 100 cc of soil was used from the composite of 1 kg which was measured using a 100 ml beaker. Roots were cleaned thoroughly with water and feeder roots were cut into very small pieces of 1 cm using scissors and then weighed into five grams for every root sample. The Baermann's were then filled with 50 ml of water for each sample and left for 48 hours when the first nematode extraction was done as depicted in figure 3.2. However, during the 48 hours, monitoring was done to add water to the Baermann funnels to make sure the nematode densities estimations were accurate as the nematodes retreat back into the soil and roots samples whenever the soil and root samples start drying up. Nematode extraction was then done using a 25 mm sieve and the nematode samples were dispensed in well labelled graduated 5 ml falcon tubes and topped up-to the 4 ml mark.

The Baermann's trays were then refilled with 50 ml of water and left for another 48 hours completing 96 hours and extraction was done as before using 25 mm sieve and nematode samples were dispensed in well labelled graduated 5 ml falcon tubes. The experiment was then terminated.

Figure 3.2: Modified Baermann trays in the nematology laboratory during nematode extraction from soil and roots (Credit: George Ngatia).

3.5.2 Nematode Identification and Counting

Identification of nematodes was done up to the genera level. It was carried out in accordance with the handbook (Bert & Karssen, 2012) and counting was done using a mechanical tally counter. Nematode identification and counting was done simultaneously using the Euromex Iscope series (1053-PLPOLRi) light compound microscope from Prosource Scientific, Canada, in the Moi University nematology laboratory. This was done using a glass slide where five drops of 20 μ of the extracted nematode samples were dispensed and counting and identification was done.

Emphasis was laid on plant parasitic nematodes especially those that cause economic losses on sweet potatoes. This included the *Meloidogyne* species, *Pratylenchus* species and *Rotylenchulus* species of nematodes as illustrated in (A4.1 – A4.3). The nematodes counts from the five drops of 20 μ each were extrapolated to the final volume of each sample (100 cc) that had been standardized to 4 ml in each falcon tube.

Nematode abundance was calculated using population density, which is the number of individuals of a species found in a given unit, expressed as individuals per unit area; frequency of occurrence, which is how often a particular species is found in a set of samples; and prominence values, which is a weighted measure that looks at how abundant a species is as well as how regularly it occurs. Population density (PD) per 100 cc soil and 5 g roots was calculated according to (Wanjala et al., 2025) as follows;

$$PD = \frac{Total\ Counts\ in\ all\ subplots\ per\ genus}{Total\ number\ of\ sublots\ per\ field(n = 33)}$$

Frequency of occurrence (FO) and prominence values (PV) were calculated according to (De Waele & Jowaan, 1988) as follows;

$$FO = \frac{no\ of\ subplots\ where\ a\ genus\ was\ detected(per\ field)}{total\ number\ of\ subplots}$$

$$PV = PD\ \times \frac{\sqrt{FO}}{10}$$

Nematode diversity was defined in terms of species richness (amount of per genus) and functional diversity. Functional diversity focused on the plant-parasitic nematodes that cause economic losses in the production of sweet potatoes. According to (Karuri et al.,

2016) three genera of nematodes, namely *Pratylenchus sp.*, *Meloidogyne sp.*, and *Rotylenchulus sp.,* have been determined to be the most prevalent in sweet potato production in Kenya, and hence the study was limited to only the three. Data on nematode abundance and diversity was exported to Microsoft Excel and tables were generated.

3.6 Data Analysis

The growth, yield and farming systems data were analysed using the R software version 4.4.1. The data comprised six parameters; total tuber weight, marketable tuber weight, non marketable tuber weight, total tuber numbers, marketable tuber numbers and non marketable tuber numbers. This data naturally contained many zeros due to plant failure or lack of production. Because the dataset was unbalanced and violated key ANOVA assumptions such as normality and homogeneity of variances, a Generalized Linear Model (GLM) was adopted to provide amore robust analysis. GLMs allowed the data to be modelled without requiring strict normal distribution assumptions which are chosen based on distribution and not normality but residuals are still checked. The variances are incorporated as a function of the mean but not from assumptions following the choice of distribution by GLM allowing valid inference when variances differ among treatments. Following the mode fitting, Type 2 ANOVA was selected because it provides the most reliable inference when dealing unbalanced data and models without interaction terms to evaluate the main effect of the treatments. A post-hoc test using Tukey was set but it was adjusted to Sidak which offers stronger control of the family wise error while maintaining more statistical power when the number of comparisons is large and reduces the risk of type 1 error without being overly conservative. A compact letter display (CLD) test was used to assign letter notations facilitating treatment group differentiation. The results including means, standard errors and statistical groupings were then exported to Microsoft Excel where tables were generated to visually represent the findings across different farms. Bar graphs were plotted using the R software.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Yield response of sweet potatoes to drill and ridge farming systems (Season 1)

In Ben's farm, the use of the drill and ridge farming systems had no effect on the yield of sweet potatoes in terms of the total tuber weight. The treatment of inorganic fertilizer and drill had a mean of 194.79±1.14 g, while the treatment of inorganic fertilizer and the ridge system was 191.17±1.25 g. When the two treatments were compared, there was no significant difference between the treatments (figure. 4.1).

The lack of significance in the total tuber weight when the two farming systems were used could be attributed to the following reasons: This field had predominantly sandy soil; hence, nutrients were easily washed away in these conditions for both the drill and ridge systems due to their high permeability, hence facing similar deficiencies resulting in the lack of significance when the two systems were compared. Ridge systems typically provide better aeration and drainage, which can enhance growth in heavier soils. However, in sandy soil, where natural drainage is already high, the ridge system might not offer any additional benefits.

In this field there was also a lot of tree shade at the edge of the field and from macadamia trees in between the plots. Tree cover moderates' temperature fluctuations and reduces soil evaporation. This may have mitigated sandy soil stress, but it would have affected both systems equally, reducing the chance of one outperforming the other.

In Mabanga Farm, the use of the ridge farming system led to a significant increase in the yield of sweet potatoes in terms of total tuber weight. The treatment inorganic fertilizer and drill had a mean of 319.06±1.15 g, while the treatment inorganic fertilizer and ridge had a mean of 361.75±1.58 g. When the two treatments were compared, there was statistical significance. The treatment with inorganic fertilizer and drill had the highest total tuber weight (figure 4.1).

In Nafula's farm, the use of the ridge farming system led to a significant increase in the yield of sweet potatoes in terms of the total tuber weight. The treatment inorganic fertilizer and drill had a mean of 413.28±2.51 g, while the treatment inorganic fertilizer and ridge had a mean of 492.83±1.46 g. When the two treatments were compared, there was statistical significance. The treatment with inorganic fertilizer and drill had the highest total tuber weight. This farm had the highest tuber weight of all the three farms (figure 4.1).

The fact that the total tuber weight was higher in the ridge farming system in Mabanga and Nafula farms could be explained in the following ways: To begin with, since both drilled holes and ridges had the same spacing of 30 cm (plant to plant), ridges utilize the gaps that are left between the holes, therefore getting more soil, which in turn results in more space for lengthening of the storage root during development. Despite the fact that the entire field was ridged during hilling, that is, all plots were hilled, even those that had been planted in drilled holes, under favourable environmental conditions, sweet potato storage root initiation begins 14 days after transplanting. Therefore, the first 14 - 30 days are very crucial for storage root development (Wijewardana et al., 2018). The vines that were transplanted in drilled holes started with cool soil temperatures and less aeration, which slowed down early root development.

Soil in ridges was also less compacted than that of drilled holes. Sweet potatoes do well in well-drained sandy loam or loam soils. These soils have sufficient water content, easy root penetration, and they are well aerated and sufficiently serve the plant by availing nutrients optimally. Restriction in root penetration and subsequent retardation of other physiological activities of vines planted in drilled holes due to compaction led to a decline in terms of the storage root weight of the sweet potatoes (total tuber weight). This is consistent with the research of (Sakamoto & Suzuki, 2024) who found that soil compaction had a significant effect on th*e* physiological characteristics of sweet potato, reducing the net photosynthetic rate and chlorophyll content, ultimately reducing yield.

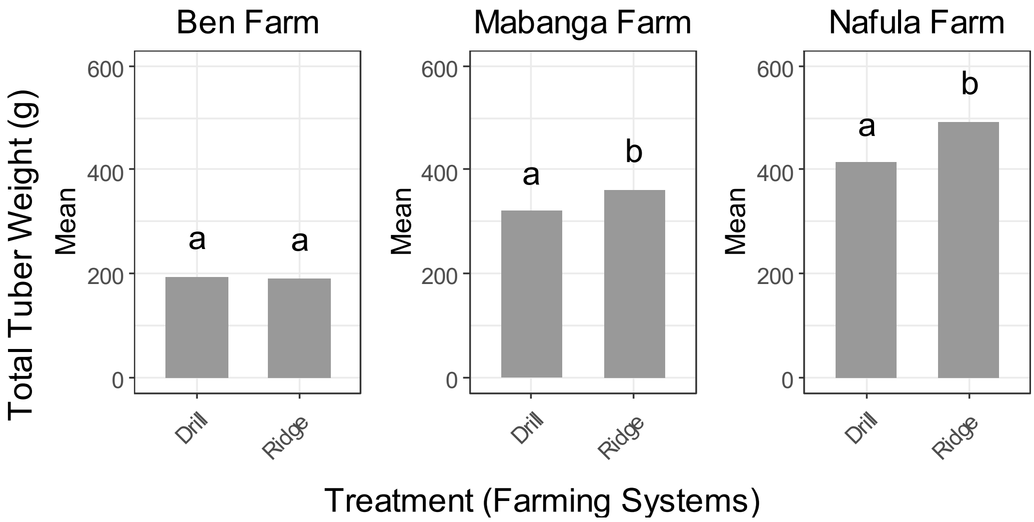

Figure 4.1: Mean±SE tuber weight of sweet potatoes grown under ridge and drill farming systems at Ben Mabanga and Nafula farm. letters represents statistically significant differences between treatments ($P \leq 0.05$)

4.2 Influence of biochar and chicken manure on sweet potato growth and yield performance (Season 1)

For the total tuber weight parameter, the use of biochar and chicken manure resulted in different responses of sweet potatoes between the two methods of production. The treatment of five and ten tonnes of biochar and chicken manure at Ben's Farm, under the convention system-ridging, resulted in a significant increase in the total tuber weight when compared to the control. The addition of ten tonnes of biochar resulted to an increase in the total tuber weight of sweet potatoes with a mean of 308.35±45.72 g which was significantly different from the control. The addition of biochar five tonnes in the convention system(ridges) also led to a significant increase in the total weight of sweet potato tubers with a mean of 238.36±31.60 g which was significantly different from the control. Chicken manure in the convention system at five and ten tonnes also increased significantly the total tuber weight with means of 259.76±40.1 g and 260.81±32.29 g respectively. An ANOVA score of $P = 0.0013$ showed a high level of statistical significance between treatments and the control and all the treatments were significantly different from the control. According to the drill farming approach, the application of ten tonnes of chicken manure resulted in the highest tuber weight with a mean of 351.76±39.63 g and was significantly different from the control. Additionally, the use of five tonnes of chicken manure in the drill system also significantly increased the total tuber weight of sweet potatoes with a mean of 169.13±26.78 g and were significantly different from the control. Biochar five tonnes and ten tonnes also increased the total tuber weight of sweet potatoes in the drill systems with means of 195.99±32.55 g and 180.39±28.98 g respectively (Table 4.1).

Utilizing the farmer practice method at Mabanga Farm, the application of five and ten tonnes of biochar and chicken manure resulted in a significant increase in the total weight of the tubers. five and ten tonnes of biochar in the convention system had means of 339.25±42.62 g and 317.67±33.42 g which were significantly different from the control. In the drill system five and ten tonnes of biochar also increased the total tuber weight of tubers and were significantly different from the control with means of 264.29±31.44 g and 387.85±46.37 g respectively. Similarly, when chicken manure was applied with the drill-farming approach, five and ten tonnes increased the total weight of tubers and were significantly different from the control with means of 321.78±30.52 g and 406.13±40.61 g respectively.in the convention system, the use of five and ten tonnes of chicken manure also resulted to a significant increase in the total tuber weight of sweet potatoes and had means of 363±34 g and 375.99±42.98 g respectively which were significantly different from the control. An ANOVA score of $P = 0.00047$ showed a high statistical significance when comparing all the treatments to the control and all the treatments were significantly different from the control. ten tonnes biochar under the drill farming system and ten tonnes chicken manure under the convention farming system demonstrated the highest tuber weight with the means of 387.85±46.37 g and 375.99±42.98 g respectively (Table 4.1).

Under both the drill-farming and farmer-farming techniques at Nafula Farm, the treatment of five and ten tonnes of biochar and chicken manure in both the drill and the convention system had no effect on the overall tuber weight of sweet potatoes. There was also a lack of statistical significance when the treatments were compared to the control as evidenced by an ANOVA score of $P = 0.085$. The control had the highest tub er weight represented by a mean of 564.44±46.23 g (Table 4.1).

The bacteria in the chicken manure break down complex nutrients to simple forms, enabling nitrogen, phosphorous, and potassium for the plant to take in (Antonious, 2023; Antonious, 2024). Soil organic amendments enhanced the total tuber weight by improving the water holding capacity, decreasing acidity, and therefore encouraging the absorption of macronutrients like phosphorus (Ferreira et al., 2020).

Plants receive nutrients during the growing season, when there is an organic supply of nutrients that ultimately enhances crop yield (Boru et al., 2017). Application of farmyard manure to the soil enhances its physiochemical properties and efficiency for nutrient recovery, consequently enhancing sweet potato yield (Patel et al., 2000). These results match those of (Agbede & Adefemi., 2022) for a study done in the years 2019 and 2020, where biochar and poultry manure substantially impacted $p \leq 0.05$ the root storage yield of sweet potatoes in both years where the yield increased.

The total tuber weight of sweet potatoes grew with an increase in the biochar and chicken manure rates; ten tonnes of chicken manure and ten tonnes of biochar recorded the maximum tuber weight. This is connected to improved mineral composition, boosting soil fertility due to the favorable impacts of chicken manure and biochar (Agbede & Adefemi., 2022; Ferreira et al., 2020). This is also consistent with the soil chemistry findings for biochar and chicken manure rates (Chaganti & Crohn., 2015).

Table 4.1: Effect of biochar and chicken manure on the total tuber weight of sweet potatoes.

Total Weight (g) of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatments	**Mean±SE**	**Mean±SE**	**Mean±SE**
Drill + Biochar 10	180.39 ± 28.98 c	387.85 ± 46.37 g	488.76 ± 56.18 f
Ridge + Biochar 10	308.35 ± 45.72 g	317.67 ± 33.42 c	422.90 ± 46.54 de
Drill + Chicken Manure 10	351.76 ± 39.63 h	406.13 ± 40.61 h	345.36 ± 48.82 a
Ridge + Chicken Manure 10	260.81 ± 32.29 f	375.99 ± 42.98 f	425.07 ± 52.77 e
Drill + Biochar 5	195.99 ± 32.55 d	264.29 ± 31.44 b	392.69 ± 50.98 c
Ridge + Biochar 5	238.36 ± 31.60 e	339.25 ± 42.62 d	384.43 ± 45.12 bc
Drill + Chicken Manure 5	169.13 ± 26.78 b	321.78 ± 30.52 c	374.24 ± 38.98 b
Ridge + Chicken Manure 5	259.76 ± 40.11 f	363.32 ± 34.32 e	507.04 ± 55.63 g
Farmer Practice control	140.81 ± 20.50 a	177.64 ± 20.83 a	564.44 ± 46.23 h
Inorganic Fertilizer + Drill	194.79 ± 28.88 d	319.06 ± 26.71 c	413.28 ± 76.45 d
Inorganic Fertilizer + Ridge	191.167±31.87 d	361.75 ± 36.85 e	492.83 ± 44.39 f

Letters represents statistically significant differences between treatments ($P \leq 0.O5$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

The main effects of biochar and poultry manure as treatments in the experimental fields showed an increase in the marketable weight of sweet potatoes. At Bens Farm, under the drill system, applying five and ten tonnes of biochar and chicken manure significantly increased the marketable tuber weight compared to the control. five and ten tonnes of biochar in the drill system significantly increased the marketable weight with means of 191.26±32.37 g and 172.32±28.57 g respectively and were significantly different from the control. Chicken manure at five and ten tonnes also significantly increased the marketable weight of tubers and had means of 163.39±26.51 g and 334.93±38.90 g respectively and were significantly different from the control. Under the convention farming system, five and ten tonnes of biochar also significantly increased the marketable tuber weight with means of 216.51±30.47 g and 297.11±45.34 g respectively. five and ten ton of chicken manure under this system also increased the marketable weight of sweet potato tubers and had means of 244.03±39.44 g and 250.56±31.78 g respectively. In the convention system for both biochar and chicken manure treatments they were significantly different from the control. There was high statistical significance between the treatments and the control group indicated by ana ANOVA score of $P = 0.00016$. In the drill farming system, ten tonnes of chicken manure showed the highest tuber weight at with a mean of 334.93±38.90 g (Table 4.2).

At Mabanga Farm, using the convention system, both five and ten tonnes of biochar and chicken manure significantly increased the marketable tuber weight biochar five and ten tonnes had means of 328.10±42.15 g and 304.47±32.38 g respectively. Chicken manure five and ten tonnes had means of 354.35±34.25 g and 363.63±43.04 g respectively. In the convention system all the five and ten tonnes of chicken manure treatments were significantly different from the control. Similarly, these applications in the drill-farming system led to significant increases in total tuber weight. Five and ten tonnes of biochar had means of 250.21±31.38 g and 374.24±45.76 g respectively. Chicken manure five and ten tonnes had means of 314.35±30.17 g and 402.17±40.50 g. Both biochar and chicken manure treatments in the drill system were significantly different from the control. There was high statistical significance when all the treatments were compared to the control indicated by an ANOVA score of $P = 0.00025$. Ten tonnes chicken manure and ten tonnes biochar under drill farming practice had the highest mean marketable weight at 402.17±40.50 g and 374.24±45.76 g respectively (Table 4.2).

At Nafula Farm, the application of five and ten tonnes of biochar and chicken manure under both the drill-farming and convention farming systems the treatment had no effect on the marketable tuber weight of sweet potatoes and they were marginally non-significant when compared to the control illustrated by an ANOVA score of $P = 0.089$. The control had the highest mean of 549.96±46.53 g (Table 4.2).

Marketable tubers were characterized by the following qualities; being free from pest and disease infection and having a tuber weight of $\geq 100g$ (Gobena et al., 2022; Wanjala et al., 2019). All fields were planted with the same variety "Namunyekere" but had varying yields, with Mabanga having the highest tuber weight. Despite using the same variety, this might be explained by the three farms' varying environmental conditions. This is similar to the results of (Gobena et al., 2022), who observed that the location of the field had a substantial influence on sweet potato production.

Soil organic amendments such as chicken manure and biochar offer a significant quantity of nutrients, stimulating the production of growth hormones and boosting the absorption of nutrients ultimately having an influence on the size and weights of tubers (Sidhu et al., 2007). Additionally, the high significance of the number of marketable tubers in the treated plots may be related to the ability of soil organic amendments, such as farmyard manure, biochar, etc., to enhance the soil structure. This is in line with the findings of (Boru et al., 2017), who found out that soil treated with farmyard manure is likely to be loose, hence having adequate aeration facilitating microbial activities in the soil, resulting in high growth in terms of maximum tuber yield and above-ground biomass as well.

Table 4.2: Effect of biochar and chicken manure on the marketable weight of sweet potatoes.

Marketable Weight (g) of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatment	**Mean±SE**	**Mean±SE**	**Mean±SE**
Drill + Biochar 10	172.32 ± 28.57 c	374.24 ± 45.76 h	477.60 ± 56.15 f
Ridge + Biochar 10	297.11 ± 45.34 g	304.47 ± 32.38 c	412.50 ± 46.76 e
Drill + Chicken Manure 10	334.93 ± 38.90 h	402.17 ± 40.50 i	338.78 ± 48.88 a
Ridge + Chicken Manure 10	250.56 ± 31.78 f	363.53 ± 43.04 g	408.26 ± 52.28 e
Drill + Biochar 5	191.26 ± 32.37 d	250.21 ± 31.38 b	381.07 ± 50.04 c
Ridge + Biochar 5	216.51 ± 30.47 e	328.10 ± 42.15 e	369.04 ± 44.62 b
Drill + Chicken Manure 5	163.39 ± 26.51 b	314.35 ± 30.17 d	363.72 ± 39.04 b
Ridge + Chicken Manure 5	244.03 ± 39.44 f	354.35 ± 34.26 g	496.11 ± 54.84 g
Farmer Practice control	130.06 ± 19.97 a	165.17 ± 20.36 a	549.96 ± 46.53 h
Inorganic Fertilizer + Drill	187.13 ± 28.96 d	305.68 ± 26.31 cd	392.79 ± 75.09 d
Inorganic Fertilizer + Ridge	177.90 ± 31.46 c	343.56 ± 36.41 f	476.17 ± 44.20 f

Letters represents statistically significant differences between treatments ($P \leq 0.05$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

Application of biochar and chicken manure elicited different responses in terms of the non-marketable weight of sweet potatoes in each farm. In Ben's farm there was a significant difference when the treatments were compared to the control apart from the treatment ridge and ten tonnes of biochar and ridge and ten tonnes of chicken manure indicated by an ANOVA score $P = 0.023$. The treatments such as drill + five tonnes of biochar and drill + five tonnes of chicken manure had low non-marketable yields with means of 4.72±1.87 g and 5.74±2.30 g, respectively. They were also significantly different when compared to the control. The highest non-marketable yield was observed in the treatment with ridge and biochar of five tonnes (Table 4.3).

In Mabanga farm, there was statistical significance when the treatments drill + chicken manure five tonnes, ridge + chicken manure five tonnes, and drill + chicken manure ten tonnes were compared to the control. All the other treatments were not significantly different from the control. The treatment drill + chicken manure ten tonnes recorded the lowest non-marketable weight with a mean of 3.96±1.41 g, highlighting the treatment's potential in reducing non-marketable tubers. This treatment was significantly different from the control (Table 4.3).

In Nafula's farm, only the treatment ridge + biochar five tonnes was not significantly different from the control. The lowest non-marketable tuber weight was recorded in the treatment drill + chicken manure ten tonnes with a mean of 6.58±2.32 g. It was also significantly different from the control (Table 4.3).

The application of the treatment drill and ten tonnes of chicken manure demonstrates potential for decreasing non-marketable sweet potato tubers. Chicken manure is abundant in vital elements, including nitrogen, phosphorus, and potassium, which are required for the growth and tuber development of sweet potatoes. The gradual release of nutrients over time in organic manure enhances nutrient availability and reduces leaching, resulting in improved tuber development and fewer deformities. (Agegnehu et al., 2016). The observed decreases in non-marketable weights with the chicken manure treatment indicate enhancements in soil structure, aeration, and microbial activity; hence, promoting plant health and reducing stress-induced tuber malformations. The differences in terms of non-marketable tuber weight among farms indicate that local soil and environmental factors affect treatment effectiveness, requiring site-specific recommendations.

Table 4.3: Effect of biochar and chicken manure on the non-marketable weight of sweet potatoes.

Non-Marketable Weight (g) of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatment	**Mean±SE**	**Mean±SE**	**Mean±SE**
Drill + Biochar 10	8.07 ± 1.95 b	13.61 ± 2.57 d	11.17 ± 2.68 b
Ridge + Biochar 10	11.24 ± 2.92 c	13.19 ± 4.09 d	10.40 ± 3.10 b
Drill + Chicken Manure 10	16.83 ± 3.67 e	3.96 ± 1.41 a	6.58 ± 2.32 a
Ridge + Chicken Manure 10	10.25 ± 2.52 c	12.46 ± 2.73 cd	16.81 ± 9.16 d
Drill + Biochar 5	4.72 ± 1.87 a	14.08 ± 2.85 d	11.63 ± 2.61 b
Ridge + Biochar 5	21.85 ± 4.23 f	11.15 ± 2.65 c	15.39 ± 3.71 cd
Drill + Chicken Manure 5	5.74 ± 2.30 a	7.43 ± 1.86 b	10.51 ± 2.73 b
Ridge + Chicken Manure 5	15.74 ± 2.96 e	8.97 ± 2.49 b	10.93 ± 3.09 b
Farmer Practice control	10.75 ± 2.58 c	12.47 ± 2.95 cd	14.49 ± 3.17 c
Inorganic Fertilizer + Drill	7.67 ± 1.79 b	13.38 ± 2.71 d	20.49 ± 4.38 e
Inorganic Fertilizer + Ridge	13.26 ± 2.91 d	18.19 ± 4.59 e	16.67 ± 3.41 d

Letters represents statistically significant differences between treatments ($P \leq 0.05$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

For total tuber numbers at Mabanga Farm, under the ridge farming system and drill-farming system, using biochar and chicken manure had no effect on the overall tuber counts when the treatments were compared to the control. There was a lack of statistical significance between the treatments and the control indicated by an ANOVA score of $P = 0.81$ (Table 4.4).

At Bens Farm, applying biochar and chicken manure with the drill-farming system and the ridge farming system had no effect on the total tuber numbers of sweet potatoes. When all the treatments were compared to the control, there was no statistical difference indicated by an ANOVA score of $P = 0.97$. Ten tonnes of chicken manure under drill farming system had the highest median tuber number at 1.97±0.19 but it was not significantly different from the control (Table 4.4).

At Nafula's Farm, applying chicken manure ten tonnes significantly increased the total tuber numbers of sweet potatoes in both drill and the ridge system. the treatments were also significantly different from the control with ten tonnes of chicken manure under drill and ten tonnes of chicken manure under ridge system having means of 1.51±0.20 and 1.53±0.16 respectively. There was statistical significance when all the treatments were compared to the control shown by an ANOVA score of $P = 0.016$ (Table 4.4).

Biochar is proven to promote water retention in soils. However, in areas where water is abundant, this advantage may not result in increased tuber numbers when compared to chicken manure. Sweet potatoes are particularly drought-tolerant; therefore, the water-retention effects of biochar may not be as significant in generating more tuber numbers under good irrigation or rainfall. Both biochar and manure promote soil aeration; however, if soil compaction or poor aeration is not a limiting factor in tuber development, the benefits of biochar and manure on tuber numbers may be insignificant.

Sweet potato cultivars may react differently to organic amendments depending on their genetic composition. Some types may not significantly benefit from biochar or manure treatments in terms of increasing tuber numbers, but they may still display other advantages, such as improved tuber size or quality.

Table 4.4: Effect of biochar and chicken manure on total tuber numbers of sweet potatoes.

Total Numbers of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatment	**Mean±SE**	**Mean±SE**	**Mean±SE**
Drill + Biochar 10	1.21 ± 0.16 ab	2.07 ± 0.21 a	1.88 ± 0.18 ab
Ridge + Biochar 10	1.74 ± 0.24 bc	1.69 ± 0.21 a	1.93 ± 0.19 ab
Drill + Chicken Manure 10	1.97 ± 0.19 c	1.78 ± 0.18 a	1.51 ± 0.20 a
Ridge + Chicken Manure 10	1.57 ± 0.16 abc	1.82 ± 0.16 a	1.53 ± 0.16 a
Drill + Biochar 5	1.15 ± 0.19 ab	1.75 ± 0.18 a	2.08 ± 0.23 ab
Ridge + Biochar 5	1.61 ± 0.20 abc	1.92 ± 0.20 a	1.93 ± 0.20 ab
Drill + Chicken Manure 5	1.00 ± 0.15 a	1.88 ± 0.17 a	1.72 ± 0.17 ab
Ridge + Chicken Manure 5	1.58 ± 0.20 abc	1.81 ± 0.17 a	1.96 ± 0.22 ab
Farmer Practice control	1.33 ± 0.17 abc	1.65 ± 0.15 a	2.42 ± 0.16 b
Inorganic Fertilizer + Drill	1.24 ± 0.14 ab	2.07 ± 0.18 a	2.06 ± 0.19 ab
Inorganic Fertilizer + Ridge	1.51 ± 0.21 abc	2.00 ± 0.20 a	2.33 ± 0.19 b

Letters represents statistically significant differences between treatments ($P \leq 0.O5$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

For marketable tuber numbers, the sweet potato tubers had different responses from the biochar and chicken manure treatments. At Bens Farm, under the farmer practice system-ridging, the addition of chicken manure had no effect on the marketable tuber numbers compared to the control. Under the drill-farming approach, using biochar and chicken manure also had no effect on the marketable tuber numbers of sweet potatoes. This is as a result of a lack of statistical significance when all the treatments were compared to the control. An ANOVA score of $P = 0.37$ showed no statistical significance when all the treatments were compared to the control (Table 4.5).

At Mabanga Farm, employing the ridging technique while using biochar and chicken manure had no effect on the marketable tuber numbers of sweet potatoes. An ANOVA score of $P = 0.06$ illustrated marginal non-significance when all the treatments were compared to the control. When compared to the control, ten tonnes of chicken manure under the drill farming system had the highest marketable tuber numbers with a mean of 1.64±0.17. At Nafula Farm, using biochar and chicken manure showed no effect on the marketable tuber numbers and this was demonstrated by non-significance when all the treatments were compared to the control with an ANOVA score of $P = 0.1$ (Table 4.5).

The absence of significance at $p \leq 0.05$ in the treatments in terms of improving the marketable tuber numbers might be related to some of the limiting aspects of applying soil organic amendments. This includes, and is not limited to, poor supply of nitrogen by the chicken manure and poultry manure-based biochar (Ierna & Distefano, 2024). This is also in accordance with the studies of (Rempelos et al., 2013) who reported having low levels of chlorophyl in the leaves of potatoes but claimed that potassium was the key component of the manure restricting productivity. Poor availability of nutrients normally utilized in organic production systems are the major contributors to the yield difference in comparison with the inorganic sweet potato production systems. Maintaining proper soil fertility is paramount in organic potato production, given that the efficacy of organic fertilization in organic systems depends on a variety of factors, including the type of fertilizer used (quantity, timing), soil conditions, and weather patterns during the plant's growth stages (Rempelos et al., 2013).

However, the combinations of biochar and chicken manure influenced the marketable tuber counts. This is consistent with the findings of (Boru et al., 2017), in which the use of organic and inorganic fertilizer improves the marketable yield of tubers and quantities of sweet potatoes in western Ethiopia.

Table 4.5: Effect of biochar and chicken manure on the marketable tuber numbers of sweet potatoes.

Marketable Numbers of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatment	**Mean±SE**	**Mean±SE**	**Mean±SE**
Drill + Biochar 10	0.90 ± 0.13 a	1.54 ± 0.16 a	1.53 ± 0.16 a
Ridge + Biochar 10	1.32 ± 0.19 a	1.28 ± 0.13 a	1.60 ± 0.16 a
Drill + Chicken Manure 10	1.38 ± 0.13 a	1.64 ± 0.17 a	1.31 ± 0.18 a
Ridge + Chicken Manure 10	1.19 ± 0.13 a	1.40 ± 0.13 a	1.35 ± 0.15 a
Drill + Biochar 5	1.13 ± 0.19 a	1.28 ± 0.14 a	1.54 ± 0.19 a
Ridge + Biochar 5	0.90 ± 0.12 a	1.57 ± 0.18 a	1.50 ± 0.16 a
Drill + Chicken Manure 5	0.81 ± 0.12 a	1.57 ± 0.15 a	1.40 ± 0.14 a
Ridge + Chicken Manure 5	0.97 ± 0.15 a	1.51 ± 0.14 a	1.58 ± 0.16 a
Farmer Practice control	0.88 ± 0.12 a	1.19 ± 0.12 a	2.01 ± 0.15 a
Inorganic Fertilizer + Drill	0.93 ± 0.13 a	1.64 ± 0.15 a	1.49 ± 0.15 a
Inorganic Fertilizer + Ridge	0.96 ± 0.15 a	1.53 ± 0.16 a	1.79 ± 0.15 a

Letters represents statistically significant differences between treatments ($P \leq 0.O5$). 5 and 10 represent the rates of biochar and chicken manure applied in Tonnes per hectare.

In the two agricultural systems in Ben's farm, sweet potatoes reacted differently to the application of biochar and chicken manure in terms of non-marketable tuber numbers. Using five tonnes of biochar under the drill farming system had an effect on the non-marketable tuber numbers in that they reduced and there was statistical significance when it was compared to the control with a mean of 0.03±0.03. All other treatments in the drill farming system were not significantly different from the control. Under the ridging farming system, all the treatments were not significantly different when compared to the control. There was non-statistical significance between the treatments and the control indicated by an ANOVA value of $P = 0.092$ (Table 4.6).

At Mabanga Farm, utilizing the drill-farming approach, both five and ten tonnes of biochar and chicken manure had no effect on the non-marketable tuber numbers.

Similarly, in the ridging farming system, all treatments exhibited no significant variations in non-marketable tuber numbers when compared to the control indicated by an ANOVA score of $P = 0.12$ (Table 4.6).

At Nafula's Farm, using five and ten tonnes of chicken manure and biochar for both farming systems showed no effect on the non-marketable tuber numbers of sweet. When all the treatments were compared to the control there was no statistical differences showed by an ANOVA score of $P = 0.078$ (Table 4.6).

The amount of non-marketable tubers varied across the three treatments, the reduction in terms of non-marketable tuber numbers and lack of significances show that there was minimal waste. The discrepancy in statistical significance between the sites might be attributed to changes in soil composition, climate, and other environmental variables, which can impact the efficiency of the treatments. This is consistent with the results of (Dumbuya et al., 2021), who observed an increase in yield and the yield parameters of sweet potatoes that were propagated in a cool environment.

The strong impact of treatments such as five tonnes of biochar and five tonnes of chicken manure in Ben could imply that that the amendments are especially successful in that region's environment. The absence of substantial variations in several treatments across sites (particularly in Mabanga and Nafula) shows universally success of treatments and location-specific changes could lead for even better outcomes.

This is compatible with the conclusion of (Shi et al., 2021), who planted sweet potatoes in four distinct growing sites, and in addition to having diverse yield and yield component output, their starch compositions were also variable.

Table 4.6: Effect of biochar and chicken manure on the non-marketable tuber numbers of sweet potatoes.

Non-Marketable Numbers of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatment	**Mean±SE**	**Mean±SE**	**Mean±SE**
Drill + Biochar 10	0.31±0.07 abc	0.53±0.09 b	0.35±0.07 abc
Ridge + Biochar 10	0.42±0.12 bc	0.42±0.12 ab	0.33±0.10 abc
Drill + Chicken Manure 10	0.60±0.13 c	0.14±0.05 a	0.21±0.07 ab
Ridge + Chicken Manure 10	0.38±0.08 bc	0.42±0.08 ab	0.18±0.05 a
Drill + Biochar 5	0.03±0.03 a	0.47±0.09 b	0.47±0.10 abc
Ridge + Biochar 5	0.71±0.13 c	0.35±0.07 ab	0.43±0.09 abc
Drill + Chicken Manure 5	0.19±0.07 ab	0.31±0.07 ab	0.32±0.08 abc
Ridge + Chicken Manure 5	0.61±0.11 c	0.29±0.09 ab	0.38±0.09 abc
Farmer Practice control	0.46±0.09 bc	0.46±0.09 ab	0.40±0.08 abc
Inorganic Fertilizer + Drill	0.31±0.08 abc	0.43±0.08 ab	0.57±0.11 c
Inorganic Fertilizer + Ridge	0.56±0.12 c	0.47±0.09 b	0.54±0.10 bc

Letters represents statistically significant differences between treatments $(P \leq 0.O5)$. 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

Biomass was collected as a growth parameter and sweet potatoes exhibited different responses to the application of biochar and chicken manure in the three farms. At Bens Farm, the application of ten tonnes of chicken manure under the ridging farming system resulted to an increase in biomass compared to the control group with a mean of 34.10±0.44 kg. all the other treatments in the ridge farming systems were not significantly different from the control. Under the drill-farming technique, the addition of ten tonnes of biochar produced a substantial increase in biomass with a mean of 37.71±4.53 kg. All the other treatments in this farming system were not significantly different when compared to the control. There was a marginal statistical significance difference among the treatments and the control with an ANOVA score of $P = 0.037$. The highest biomass was recorded under the drill farming method in the treatment ten tonnes of biochar with a mean of 37.71±4.53 kg and ten tonnes of chicken manure under the ridge farming system with a mean of 34.10±0.44 kg (Table 4.7).

The application of ten tonnes of biochar and chicken manure at Mabanga Farm, resulted an increase in biomass in the drill-farming system as well in the ridge farming. Ten tonnes of chicken manure under the ridge farming system had the highest biomass with a mean of 39.01±5.72 kg and ten tonnes of chicken manure under the drill farming system had a mean of 37.25±7.38 kg. Both of these treatments were significantly different from the control. The other treatments were not significantly different from the control. An ANOVA score of $P = 0.23$ showed no statistical significance when comparing all the treatments to the control (Table 4.7).

At Nafula Farm, the treatment of five and ten tonnes of biochar and chicken manure under both the drill-farming and ridge farming systems improved the biomass weight. The treatments ridge and biochar ten tonnes with a mean of 35.86±1.99 kg, drill and biochar five tonnes with a mean of 35.15±1.96 kg, drill and chicken manure five tonnes with a mean of 40.96±3.38 kg, and ridge and chicken manure five tonnes with a mean of 39.49±7.83 kg were significantly different when compared to the control. The treatment of chicken manure and drill five tonnes had the highest biomass weight with a mean of 40.96±3.38 kg. There was a marginal statistical significance when all the treatments were compared to the control indicated by an ANOVA score of $P = 0.048$ (Table 4.7).

Chicken manure being a nutrient rich soil organic amendment has high levels of phosphorus and nitrogen hence its effectiveness as fertilizer in plant development promotion (Agbede & Adefemi, 2022). The fundamental features of chicken manure-based biochar are connected to its potential to increase soil alkalinity, soil structure cation exchange capacity, and nutrient retention. This aligns with the findings of (Dróżdż et al., 2023), which indicate that the application of soil conditioners derived from chicken manure leads to a direct correlation between the nutritional composition of biochar and the development of crops.

Ten tonnes of chicken manure performed better, having the maximum biomass weight. This is a consequence of the carbon-to-nitrogen ratio between chicken manure and biochar. The greater the Carbon:Nitrogen ratio, the longer it takes for breakdown to proceed, thereby delaying nutrition availability (Agbede et al., 2024). This is compatible with the result of the (Ayobami et al., 2021) study, where a high concentration of nitrogen in chicken manure brought about the rapid development of the vine, promoting vegetative growth. This is compatible with the results of (Darko et al., 2020), who reported finding a high biomass index that they ascribed to robust vegetative growth as a resultant of organic manure treatment, consequently a high vine fresh weight.

Table 4.7: Effect of biochar and chicken manure on the biomass of sweet potatoes.

Biomass (kg) of Sweet Potato Tubers per Farm			
Farm	**Ben**	**Mabanga**	**Nafula**
Treatment	**Mean±SE**	**Mean±SE**	**Mean±SE**
Drill + Biochar 10	37.71 ± 4.53 c	33.50 ± 4.47 abc	30.12 ± 1.99 ab
Ridge + Biochar 10	29.38 ± 3.69 abc	33.22 ± 2.40 abc	35.86 ± 2.31 b
Drill + Chicken Manure 10	31.51 ± 3.71 abc	37.25 ± 7.38 bc	32.95 ± 4.48 ab
Ridge + Chicken Manure 10	34.10 ± 0.44 abc	39.01 ± 5.72 c	31.11 ± 2.57 ab
Drill + Biochar 5	26.34 ± 2.84 abc	25.13 ± 1.74 abc	35.15 ± 1.96 b
Ridge + Biochar 5	21.16 ± 2.28 ab	24.39 ± 4.33 a	26.26 ± 5.73 ab
Drill + Chicken Manure 5	22.40 ± 4.21 ab	23.83 ± 3.10 abc	40.96 ± 3.38 b
Ridge + Chicken Manure 5	22.43 ± 7.46 ab	31.87 ± 8.52 abc	39.49 ± 7.83 b
Farmer Practice control	18.97 ± 1.51 a	22.33 ± 4.31 a	19.73 ± 2.31 a
Inorganic Fertilizer + Drill	22.64 ± 3.77 ab	25.60 ± 5.66 abc	25.48 ± 2.59 ab
Inorganic Fertilizer + Ridge	21.24 ± 4.01 ab	22.82 ± 4.40 ab	28.83 ± 5.65 ab

Letters represents statistically significant differences between treatments ($P \leq 0.05$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

4.3 Effect of biochar and chicken manure on nematode communities and population dynamics (Season 1)

The *Pratylenchus* species ranges in population density from 4.85 in roots to 26.67 in soil. This is in accordance with their migratory character, *Pratylenchus* species was far more concentrated in soil than in the roots. The nematode moves and infects plant roots over time in where they establish suitable habitat in the soil. For the *Meloidogyne* species in roots the PD was 25.45 but not significantly present in roots. This shows that *Meloidogyne* species was significantly concentrated in soil, agreeing with the study by dash that *Meloidogyne* population in the soil rose with the use of organic fertilizers (Tian et al., 2020) (Table 4.8; Table 4.9).

The frequency of occurrence for *Rotylenchulus* species in roots was low, about 9.09%, whereas in soil, it reached 15.15%. This suggests that *Rotylenchulus* species was detected more frequently in soil than in roots. The low frequency in roots imply that it moved between soil and roots depending on moisture and temperature conditions. For *Pratylenchus* species it was 6.06% in roots but rose to 45.55% in soil. The increased frequency in soil underscores the necessity of monitoring soil health for *Pratylenchus* species, since the soil functions as its major habitat and source for root infection. For *Meloidogyne* species, in roots was likewise 9.09%, which is relatively high compared to other genera but suggests it was more concentrated in the soil (Table 4.8; Table 4.9).

The prominence values for the *Rotylenchulus* species was 0.20 in roots and 4.25 in soil. The high PV in soil indicated the importance of *Rotylenchulus* species in the soil, where they play a significant role in destroying sweet potatoes by feeding on roots. This complements its reniform (kidney-shaped) morphology, which is ideal for existence in soil. For *Pratylenchus* species, in soil it was significantly greater (17978.7) than in roots (1.2), demonstrating that its population was more significant and impacting in soil. For Meloidogyne species, the PV was 1.8 in roots and 69.6 in soil, showing it was less significant overall than *Pratylenchus* species or *Rotylenchulus* species, despite its root-knot galls which cause severe localized influence on plant development (Table 4.8; Table 4.9).

Pratylenchus species affects nutrient absorption and lower general plant health. *Meloidogyne* species makes galls on roots, therefore inhibiting plant development and lowering yields (Kemboi et al., 2022). Although less aggressive than Meloidogyne, Rotylenchulus species (Reniform Nematode) can nonetheless cause significant yield losses by feeding on plant roots and nhence affecting plant growth (Rusinque et al., 2023).

For *Rotylenchulus* species, the PD in soil (Mabanga farm) was 10.91 while in roots was 3.64. This suggests that *Rotylenchulus* species were more common in the soil and they were less often in roots. This is in line with its recognized semi-endoparasite behavior—that of residing partly in and out the root. The greater PD in the soil implies that *Rotylenchulus* species, most likely feeding on feeder root tissues or root exudates, and that they mostly prefer the soil environment.

Pratylenchus species are typically connected with lesions on roots, causing to nutritional shortages in the host plant. The greater prevalence in soil accords with research demonstrating that *Pratylenchus* species thrives in soils with minimal organic matter and poor structure. The *Meloidogyne* species is often a serious concern in monoculture systems, as repeated planting of sensitive crops can lead to expanded populations over time (Gómez & Verdejo, 2018). The substantially reduced population density and prominence values reported in this study imply that crop rotation or soil management methods may be in place to inhibit this nematode. The increased abundance of *Rotylenchulus* species in soil coincides with its semi-endoparasitic nature, since it prefers to infect a wide range of crops in tropical and subtropical locations. *Rotylenchulus* species is generally more troublesome in soils with high moisture content, which can sustain its life cycle. Water management and organic amendments additions, such as manure and biochar, can lower *Rotylenchulus* species populations (Moosavi, 2022). The data demonstrates diverse patterns for each nematode genus, with *Pratylenchus* species and *Rotylenchulus* species being more dominant in soil, same as *Meloidogyne* species showing higher influence in soil samples. This underlines the significance of soil and root health in regulating nematode numbers. Sustainable soil management approaches, crop rotation, and biological control measures may be effective ways for decreasing nematode damage, particularly in locations where these genera are present.

Table 4.8: Effect of biochar and chicken manure on the abundance and diversity of sweet potato nematodes in roots

	Farm	Nematode species		
		Pratylenchus sp	*Meloidogyne* sp	*Rotylenchulus* sp
Population Density (5g)	Ben	4.85	3.64	3.64
	Mabanga	1.21	2.42	0
	Nafula	1.21	6.06	1.21
Prominence Values	Ben	1.2	1.1	1.1
	Mabanga	0.2	0.4	0
	Nafula	0.2	1.8	0.2
Frequency of Occurrence (%)	Ben	6.06	9.09	9.09
	Mabanga	3.03	3.03	0
	Nafula	3.03	9.09	3.03

Table 4.9: Effect of biochar and chicken manure on the abundance and diversity of sweet potato nematodes in soil

	Farm	Nematode species		
		Pratylenchus sp	*Meloidogyne* sp	*Rotylenchulus* sp
Population Density (100cc)	Ben	26.67	19.39	10.91
	Mabanga	7.27	80	0
	Nafula	3.64	25.45	2.42
Prominence Values	Ben	17978.7	11.69	4.25
	Mabanga	2.83	69.6	0
	Nafula	0.63	16	0.6
Frequency of Occurrence (%)	Ben	45.45	36.36	15.15
	Mabanga	15.15	75.76	0
	Nafula	3.03	39.39	6.06

4.4 Sweet potato yield under drill and ridge farming systems (Season 2)

The use of the ridge farming system led to a significant increase in the total tuber weight of sweet potatoes in Ben's farm. The treatment of inorganic fertilizer in the drill system had a mean of 190.36±22.70 g, and the treatment of inorganic fertilizers in the ridge system had a mean of 289.90±26.30 g. The ANOVA value of $p \leq 2.2e - 06$ is also indicative of the high level of significant difference when the treatments in the two farming systems were compared. (figure 4.2)

In Mabanga Farm, the use of drill and ridge farming systems led to a significant increase in the total tuber weight of sweet potatoes. An ANOVA value of $p \leq 2.2e - 06$ indicates a high level of significant difference when the two treatments were compared. The treatments had means of 286.93±25.10 g and 420.21±42.60 g for inorganic fertilizer in the drill system and inorganic fertilizer in the ridge system, respectively. (figure 4.2)

In Nafula's farm, the use of the ridge farming system as in Ben and Mabanga farms led to a significant increase in the total tuber weight of sweet potatoes. An ANOVA value of $p \leq 2.2e - 06$ indicates a high level of statistical significance when the two treatments were compared. The treatment of inorganic fertilizer in the drill system had a mean of 354.90±38.3 g, while inorganic fertilizer in the ridge system had a mean of 486.49±33.40 g. (figure 4.2)

The ridge farming system significantly higher output in terms of the total tuber weight in all three farms. This could be attributed to the efficacy of this system to improve aeration and drainage, especially during rainy seasons like when this data was collected, minimizing the effects of waterlogging. This aligns with the study of (Parwada & Gadzirayi, 2016) who reported that ridge farming for sweet potatoes led to longer storage root development, increasing the root dry weight.

Additionally, ridge planting promotes greater nutrient use efficiency than drilled holes. This is as a result of improved soil structure enhancing root proliferation that helps in promoting nutrient uptake and utilization. This aligns with the study of (Chagonda et al., 2014) who concluded that ridge planting significantly increased sweet potato tuber yield attributed to the enhanced nutrient uptake and absorption effect of ridged soils.

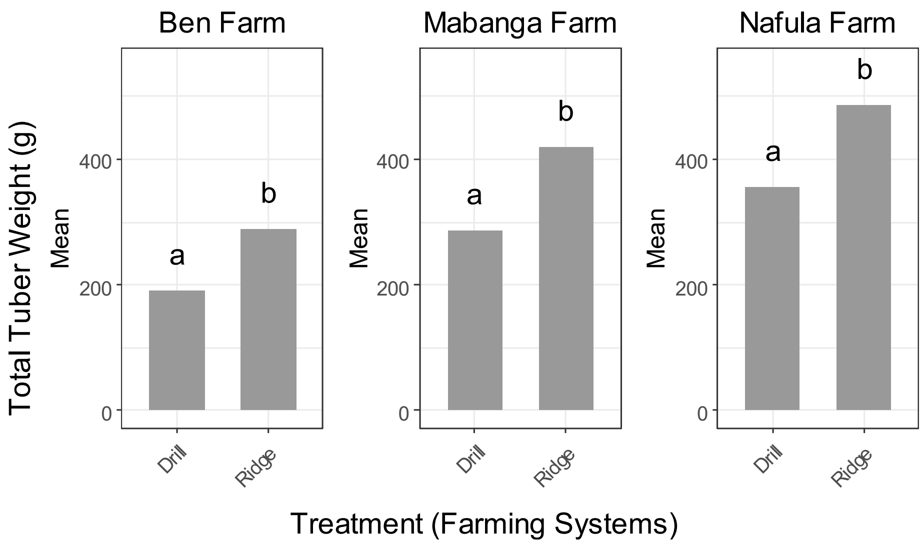

Figure 4.2: Ridge vs. drill farming: Mean±SE tuber weight of sweet potatoes at Ben, Mabanga and Nafula farm. letters represents statistically significant differences between treatments ($P \leq 0.05$).

4.5 Impact of organic amendments (biochar and chicken manure) on sweet potato agronomic performance (Season 2)

The total weight of sweet potato tubers was evaluated across three farms to assess the impact of biochar and chicken manure treatment. At Ben's Farm, the control (FP) had a mean tuber weight of 158.83±17.32 g. The ANOVA result of $P = 0.001$ showed a high level of statistical significance when the treatments were compared to the control. The maximum total weight was obtained under the five tonnes of biochar treatment in the drill farming system with a mean of 247.32±27.09 g, which was substantially different from the control. All other treatments were likewise significantly different from the control apart from ten tonnes of biochar in the drill farming method that had a mean of 164.38±25.72 g (Table 4.10).

At Mabanga, the control (FP) had a mean tuber weight of 334.34±31.44 g. The ANOVA result of $P = I.6e - 13$ indicated a very high level of statistical significance when the treatments were compared to the control. All the treatments from the two farming systems were significantly different from the control. The maximum weight was recorded under five tonnes of biochar in the ridge farming system with a mean of 466.17±41.64 g (Table 4.10).

At Nafula, the control (FP) had a mean tuber weight of 269.98±39.13 g. The ANOVA result of $P = 0.0024$ indicated a high level of statistical significance when the treatments were compared to the control. All the treatments exhibited significantly greater total weights when compared to the control. The highest overall weight aside from the control was recorded under five tonnes of chicken manure in the drill system with a mean of 550.21±38.47 g (Table 4.10).

The addition of biochar and chicken manure greatly improved the total tuber weights of the three farms. According to (Agbede et al., 2024) synergistic advantages of biochar and chicken manure result in sweet potato yield enhancement and nutritional efficiency. This is as a result of biochar's potential to boost the leaf nutrient concentrations and the root store minerals. Biochar's organic nature (60-80% carbon) and highly active surface area and functionality is employed for enhancing soil quality. It also improves the soil tensile strength and increases the water retention, making soil more friable and less compactable, which facilitates root penetration (Yu et al., 2019). Its application boosted the soil fertility, as it is viewed as an organic fertilizer containing organic carbon and plant nutrients such as N:P:K, depending on what its precursor is (Yu et al., 2019).

According to (Adekiya et al., 2018) chicken manure use enhances the macronutrient concentrations in the soil, enhancing plant Vigor and overall production. Since soil fertility is enhanced by the accumulation of nitrogen, increasing nitrogen mineralization capacity and its availability to the crop, the application of chicken manure increases crop production and height by increasing the soil microbial activity (Abukari et al., 2024). Additionally, nutrient and water consumption increases with the addition of manure, which ultimately improves the crop output (Hudson, 1994: Najm et al., 2013).

The slight varied responses across farms and treatments are in line with the findings of (Anyebe et al., 2025) who suggested that the effectiveness of biochar is strongly influenced by site-specific factors like climate and soil type, and these variations play significant roles in modulating biochar's efficacy.

Table 4.10: Total tuber weight of sweet potatoes under biochar and chicken manure treatments.

Total Weight (g) of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatments	**Mean±SE**	**Mean±SE**	**Mean±SE**
Farmer Practice control	158.83 ± 17.32 a	334.34 ± 31.44 a	269.98 ± 39.13 a
Drill+Biochar 10	164.38 ± 25.72 ab	430.67 ± 46.30 b	354.90 ± 38.27 e
Ridge+Biochar 10	236.81 ± 23.68 b	384.15 ± 39.16 b	486.49 ± 33.39 h
Drill+Chicken Manure 10	181.42 ± 32.41 c	419.38 ± 46.18 c	452.25 ± 36.84 b
Ridge+Chicken Manure 10	227.49 ± 30.23 c	205.11 ± 30.74 d	444.63 ± 43.85 c
Drill+Biochar 5	247.32 ± 27.09 c	456.97 ± 41.25 e	517.38 ± 44.37 e
Ridge+Biochar 5	155.56 ± 19.48 d	466.17 ± 41.64 f	331.85 ± 52.29 g
Drill+Chicken Manure 5	185.90 ± 26.59 e	351.50 ± 42.92 f	550.21 ± 38.47 e
Ridge+Chicken Manure 5	247.44 ± 34.29 f	292.00 ± 29.97 f	298.68 ± 40.41 d
Inorganic fertilizer+Drill	184.83 ± 21.32 f	286.93 ± 25.15 g	452.47 ± 42.87 d
Inorganic fertilizer+Ridge	289.90 ± 26.27 g	420.21 ± 42.58 g	362.57 ± 48.10 f

Letters represents statistically significant differences between treatments $(P \leq 0.O5)$. 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

Marketable weight of sweet potato tubers was measured across three farms to determine the influence of biochar and chicken manure applications. At Ben's Farm, the control (FP) had a mean weight of 144.44±16.82 g. The ANOVA result of $P = 0.0025$ illustrated a high level of statistical significance when the treatments were compared to the control. All treatments in the two farming systems, apart from ten tonnes of biochar in the drill farming system which had a mean of 145.18±25.64 g significantly increased marketable tuber weight compared to the control; five tonnes of biochar in the drill system had the highest marketable weight with a mean of 229.40±26.88 g (Table 4.11).

At Mabanga, the control (FP) had a mean marketable weight of 322.44±31.59 g. There was a high level of statistical significance when the treatments were compared to the control indicated by an ANOVA result of $P = 3.1se - 06$. All treatments in the two farming systems significantly enhanced marketable weight. The highest marketable weight was recorded under five tonnes of biochar in the conventional farming method (ridging) that had a mean of 462.51±41.37 g (Table 4.11).

At Nafula, the control (FP) had a mean marketable weight of 234.71±37.31 g. The ANOVA result of $P = 9.3e - 06$ high level of statistical significance when the treatments were compared to the control. All treatments resulted in significantly higher marketable weights when compared to the control in both farming systems. The highest marketable weight was recorded under five tonnes of chicken manure in the drill farming method with a mean of 537.36±38.55 g (Table 4.11).

Biochar and chicken manure considerably enhanced the marketable weight of sweet potato tubers across all three farms. These results are in line with the findings of (Agegnehu et al., 2016) who demonstrated that the combined use of organic matter and biochar improves crop yield and produces quality tubers due to the higher microbial activity and reduced nutrient leaching. Additionally, (Biederman & Harpole, 2013) research findings revealed that biochar considerably boosts marketable yield, especially when applied alongside other organic amendments.

Five tonnes of chicken manure recorded the greatest mean tuber weight in Nafula farm, which was altogether the highest weight across all three farms. According to (Nyarko et al., 2022) chicken manure boosts the marketable root yield of sweet potato tubers by boosting the soil nitrogen and phosphorus levels, which are connected with tuber expansion and uniformity (big tubers), which are among the market preferences. Biochar five tonnes dominated in Ben and Mabanga farms, and this is correlated with the study by (Adekiya et al., 2022) who reported that moderate biochar dosage resulted in significant increases in marketable yield due to changes in pH, porosity and moisture retention, whereas higher rates might inhibit nutrient absorption due to the sorption effect, where nutrients are trapped by the biochar particles and not made use of by the plant.

Across all three farms, the drill farming system had the highest mean marketable weight compared to the ridge farming system. This is a result of superior rhizosphere positioning improving better soil root contact of drilled holes. This agrees with the findings of (Ding et al., 2023) who indicated that incorporation of drill systems can improve fertilizer utilisation efficiency, especially in rainfed agricultural systems.

Table 4.11: Marketable tuber weight in response to biochar and chicken manure treatments.

Marketable Weight (g) of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatments	**Mean±SE**	**Mean±SE**	**Mean±SE**
Farmer Practice control	144.44 ± 16.82 a	322.44 ± 31.59 a	234.71 ± 37.31 a
Drill+Biochar 10	145.18 ± 25.64 ab	416.49 ± 45.54 b	327.56 ± 37.01 e
Ridge+Biochar 10	217.01 ± 23.59 b	376.56 ± 39.36 b	462.50 ± 34.34 i
Drill+Chicken Manure 10	156.50 ± 31.39 c	409.69 ± 45.19 c	435.53 ± 36.43 b
Ridge+Chicken Manure 10	210.01 ± 29.49 cd	199.98 ± 30.75 d	424.07 ± 43.10 c
Drill+Biochar 5	229.40 ± 26.88 d	440.44 ± 39.84 e	508.06 ± 44.09 f
Ridge+Biochar 5	138.25 ± 17.55 e	462.51 ± 41.37 f	322.39 ± 52.08 h
Drill+Chicken Manure 5	162.36 ± 25.39 ef	344.71 ± 42.35 f	537.36 ± 38.55 f
Ridge+Chicken Manure 5	221.44 ± 34.09 fg	284.63 ± 29.86 f	293.36 ± 40.25 d
Inorganic fertilizer+Drill	163.53 ± 21.76 g	277.93 ± 25.14 g	441.76 ± 42.94 c
Inorganic fertilizer+Ridge	276.96 ± 25.92 h	414.86 ± 42.43 h	347.18 ± 47.51 g

Letters represents statistically significant differences between treatments ($P \leq 0.05$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

Non-marketable sweet potato tuber weight was measured across the three farms to investigate the influence of biochar and chicken manure applications. At Ben's Farm, the control (FP) had an average non-marketable weight of 14.39±2.83 g. There was statistical significance when all the treatments were compared to the control, although the treatments had no effect in reducing the non-marketable weight of sweet potatoes, except for ten tonnes of biochar in the drill system that a mean of mean of 19.19±3.55 g, and was not significantly different from the control. The maximum mean non-marketable weight was seen under five tonnes of chicken manure in the ridge farming system 26.00±4.02 g, which was also not significantly different from the control (Table 4.12).

At Mabanga, the control (FP) had an average non-marketable weight of 11.90±2.54 g. The ANOVA result of $P = 0.011$ showed a high level of statistical significance when the treatments were compared to the control. Apart from ten tonnes of biochar in the drill system treatment that had a mean of 14.18±3.80 g, all treatments considerably reduced non-marketable weight relative to the control. Using five tonnes of biochar in the ridge system resulted in the lowest non-marketable weight of 3.65±1.52 g, which was much lower than the control (Table 4.12).

At Nafula, the control (FP) had an average non-marketable weight of 35.26±15.90 g. There was a high level of statistical significance when the treatments were compared to the control indicated by an ANOVA result of $P = 0.0031$. All of the treatments significantly decreased non-marketable weight in comparison to the control. The drill farming system had the lowest non-marketable weight with a mean of 5.32±1.77 g for ten tonnes of chicken manure treatment, which was significantly lower than the control (Table 4.12).

The lowest non-marketable weight was reported in Mabanga under five tonnes of biochar in the ridge system, with a mean of 3.65±1.52 g, and in Nafula under ten tonnes of chicken manure in the drill system, with a mean of 5.32±1.77 g. Both were significantly different from the control.

The use of biochar and chicken manure contributed to minimising the non-marketable weight of sweet potatoes. According to (Sayed et al., 2024), biochar increases nutrient availability, resulting in improved root growth and tuber yield due to its capacity to break down organic material and increase nutrient solubility and uptake. Because the biochar employed in this study was charged with chicken manure, it helped to increase tuber weight above the threshold of less than 100 g. According to (Liu et al., 2022), biochar containing chicken manure boosts native soil mineralisation, accessible phosphorus soil microorganisms, and organic matter.

Chicken manure additionally contributed to decreasing non-marketable weight, which can be explained by its ability to increase dry matter content in the soil, which improves soil structure, which is beneficial for root penetration and tuber expansion (Babu et al., 2021). This is in accordance with the findings of (Chan et al., 2008; Kimani et al., 2021), who determined that the treatment of chicken manure enhances organic matter content, hence improving yield. The ability of chicken manure to decrease diseases transmitted by soil also led to high-quality, marketable yields, reducing the quantity of the non-marketable yield (Zhang et al., 2021).

Table 4.12: Non-marketable tuber weight influenced by the use of soil organic amendments (biochar and chicken manure).

Non Marketable Weight (g) of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatments	**Mean±SE**	**Mean±SE**	**Mean±SE**
Farmer Practice control	14.39 ± 2.83 a	11.90 ± 2.54 a	35.26 ± 15.90 a
Drill+Biochar 10	19.19 ± 3.55 a	14.18 ± 3.80 b	20.56 ± 7.49 b
Ridge+Biochar 10	19.79 ± 3.78 b	7.60 ± 2.14 b	12.85 ± 3.23 b
Drill+Chicken Manure 10	24.92 ± 4.69 bc	9.68 ± 3.22 c	5.32 ± 1.77 b
Ridge+Chicken Manure 10	17.47 ± 3.09 bc	5.14 ± 1.62 c	9.46 ± 3.05
Drill+Biochar 5	17.92 ± 4.42 bcd	16.53 ± 4.16 cd	16.72 ± 3.24 c
Ridge+Biochar 5	17.31 ± 5.88 cd	3.65 ± 1.52 de	9.32 ± 2.90 de
Drill+Chicken Manure 5	23.54 ± 4.32 de	6.79 ± 2.07 e	10.71 ± 2.59 ef
Ridge+Chicken Manure 5	26.00 ± 4.02 ef	7.38 ± 2.21 f	15.39 ± 4.92 f
Inorganic fertilizer+Drill	21.31 ± 3.73 f	9.00 ± 1.94 g	27.35 ± 9.33 g
Inorganic fertilizer+Ridge	12.94 ± 2.76 f	5.35 ± 2.35 h	18.35 ± 3.88 h

Letters represents statistically significant differences between treatments ($P \leq 0.05$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

The total counts of sweet potato tubers were measured in three farms to determine the effect of biochar and chicken manure applications. At Ben's Farm, the control (FP) had an average tuber count of 1.79±0.18. An ANOVA result of $P = 0.06$ showed a modest level of statistical insignificance when the treatments were compared to the control. The treatments did not significantly differ from the control, with the exception of inorganic fertilizer in the ridge system (positive control), which had a slightly higher mean of 2.06±0.17. The lowest count was found in five tonnes of biochar in the ridge system, with a mean of 1.28±0.14, which was not significantly different from the control (Table 4.13).

Chicken manure also contributed to the decrease of non-marketable weight, which is justified by its qualities of boosting the dry matter content in the soil, which improves soil structure, which are beneficial for root penetration and tuber expansion (Babu et al., 2021).

At Mabanga, the control group (FP) had an average tuber number of 2.14±0.16. There was statistical significance when the treatments were compared to the control. Apart from ten tonnes of biochar in drill and ridge farming systems, all other treatments had significantly lower tuber numbers compared to the control, including ten tonnes of chicken manure in the ridge system which had a mean of 0.90±0.12. The maximum count was reported under five tonnes of biochar in the ridge system, with a mean of 1.97±0.22, which was significantly lower than the control (Table 4.13).

At Nafula, the control (FP) had an average tuber number of 1.94±0.22. An ANOVA result of $P = 4.2e - 07$ a high level of statistical significance when the treatments were compared to the control. Several treatments showed higher tuber numbers, including five tonnes of chicken manure in the drill system with a mean of 2.56±0.21, five tonnes of biochar in both ridge and drill systems, and five tonnes of chicken manure in the ridge system with means of 2.50±0.19, 2.25±0.21, and 1.83±0.22, respectively. These treatments were significantly different from the control. The lowest count was recorded under ten tonnes of chicken manure in the ridge system, with a mean of 1.38±0.18, significantly different from the highest values but n ot when compared to the control. In the ridge farming system, Mabanga had the lowest tuber count at 0.90±0.12, while Nafula had the highest count at 2.71±0.17, both significantly different from the control (Table 4.13).

The effect of biochar and chicken manure varies by location; in Bens farms, there were no significant changes between treatment and control, whereas in Nafula and Mabanga farms, there were substantial differences. The lack of significance can be linked to environmental variables such as the considerable rain that occurred this season, which may have contributed to nutrient leaching and prevented roots from absorbing nutrients to their full potential. This is consistent with the findings of (Zhu et al., 2024), who observed that intense precipitation accelerates nutrient losses through leaching.

Because the soils had differing native macro- and micro-nutrients, the addition of biochar and chicken manure would have resulted in vegetative growth, which increased biomass rather than tuber development. This is consistent with the findings of (Koch et al., 2024), who concluded that adding nitrogen to previously nutrient-rich soils lowers tuberization. However, due to the benefits of biochar and chicken manure, such as the provision of macro- and micronutrients and their retention in the root zone, the total tuber numbers increased, for example, in Nafula farm. This is consistent with the results of (Agbede et al., 2024), who observed that sweet potato tuber counts increased due to improved nutrient retention with the use of chicken manure and biochar.

Table 4.13: Total numbers of sweet potato tubers under biochar and chicken manure treatments.

Total Numbers of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatments	**Mean±SE**	**Mean±SE**	**Mean±SE**
Farmer Practice control	1.79 ± 0.18 a	2.14 ± 0.16 a	1.94 ± 0.22 a
Drill+Biochar 10	1.44 ± 0.15 ab	1.74 ± 0.19 ab	2.33 ± 0.21 ab
Ridge+Biochar 10	1.94 ± 0.17 ab	1.81 ± 0.17 ab	2.56 ± 0.15 abc
Drill+Chicken Manure 10	1.67 ± 0.21 ab	1.81 ± 0.21 b	1.46 ± 0.18 abcd
Ridge+Chicken Manure 10	1.79 ± 0.21 ab	0.90 ± 0.12 b	1.38 ± 0.18 bcd
Drill+Biochar 5	1.96 ± 0.19 ab	1.97 ± 0.22 b	2.50 ± 0.19 cd
Ridge+Biochar 5	1.28 ± 0.14 ab	1.75 ± 0.18 b	2.25 ± 0.21 cd
Drill+Chicken Manure 5	1.67 ± 0.22 ab	1.46 ± 0.18 b	2.56 ± 0.21 cd
Ridge+Chicken Manure 5	2.00 ± 0.20 ab	1.49 ± 0.14 b	1.83 ± 0.22 cd
Inorganic fertilizer+Drill	1.94 ± 0.17 b	1.88 ± 0.16 b	2.13 ± 0.24 cd
Inorganic fertilizer+Ridge	2.06 ± 0.17 b	1.82 ± 0.17 b	2.71 ± 0.17 d

Letters represents statistically significant differences between treatments ($P \leq 0.05$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

Marketable sweet potato tuber numbers were measured in three farms to evaluate the impact of biochar and chicken manure applications. At Ben's Farm, the control group (FP) had an average marketable tuber number of 1.18±0.12. There was no statistical difference when the treatments were compared to the control indicated by an ANOVA value of $P = 0.08$. Most treatments did not significantly differ from the control, with the exception of inorganic fertilizer in the ridge farming system (positive control) which had the highest mean count of 1.63±0.14. The application of ten tonnes of biochar in the drill farming system resulted in the lowest count with a mean of 0.88±0.12, which was not significantly different from the control (Table 4.14).

At Mabanga, the control group (FP) had an average marketable tuber number of 1.73±0.14. There was statistical significance when the treatments were compared to the control. However, none of the treatments had any effect on the marketable tuber counts of sweet potatoes, since they were significantly lower than the control. In the ridge system, inorganic fertilizer resulted in the highest tuber count 1.67±0.15, although it was still significantly lower than the control (Table 4.14).

At Nafula, the control group (FP) had an average marketable tuber number of 1.54±0.21. There was a high level of statistical significance when the treatments were compared to the control indicated by an ANOVA result of $P = 3.9e - 06$. Using five tonnes of chicken manure in the drill system resulted in a significant increase in sweet potato tuber counts, which had a mean of 2.19±0.19 compared to the control group. The ridge farming system had the lowest count especially for ten tonnes of chicken manure treatment, that had a mean of 1.17±0.16. However, it was not significantly different from the control but was lower than the highest values (Table 4.14).

Mabanga had the lowest marketable tuber count under ten tonnes of chicken manure treatment in the ridge system, which had a mean of 0.69±0.10, and was significantly different from the control. Nafula had the highest tuber count under inorganic fertilizer in the ridge system (positive control), that had a mean of 2.19±0.15, which was also significantly different from the control.

The use of biochar and chicken manure had variable effects on marketable tuber quantities across the three farms. The increased marketable tuber numbers in Nafula's farms could be ascribed to the beneficial effects of biochar and chicken manure. All of these factors work together to enhance sweet potato tuber development. This is in agreement with the results of (Agbede et al., 2024), who concluded that applying biochar and chicken manure increased sweet potato output by up to 220% compared to the control. However, on some other soils, the addition of biochar and chicken manure would have little influence on marketable tuber quantities, particularly in existing fertile soils (Agegnehu et al., 2016). This emphasises the significance of accounting for site-specific variables, such as undertaking nutritional analysis assessments prior to applying the changes. The absence of major significances could possibly be ascribed to the significant rainfall during this season, which may have decreased the availability of nutrients for tuber growth and development (Koch et al., 2024).

Table 4.14: Marketable tuber count of sweet potatoes with biochar and chicken manure application.

Marketable Numbers of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatments	**Mean±SE**	**Mean±SE**	**Mean±SE**
Farmer Practice (control)	1.18 ± 0.12 a	1.73 ± 0.14 a	1.54 ± 0.21 a
Drill+Biochar 10	0.88 ± 0.12 a	1.47 ± 0.17 b	1.96 ± 0.19 ab
Ridge+Biochar 10	1.25 ± 0.12 a	1.60 ± 0.16 b	2.15 ± 0.14 abc
Drill+Chicken Manure 10	0.90 ± 0.14 a	1.57 ± 0.18 b	1.32 ± 0.16 abc
Ridge+Chicken Manure 10	1.19 ± 0.15 ab	0.69 ± 0.10 b	1.17 ± 0.16 abc
Drill+Biochar 5	1.40 ± 0.14 ab	1.58 ± 0.19 b	2.06 ± 0.16 bc
Ridge+Biochar 5	0.90 ± 0.10 ab	1.64 ± 0.16 b	1.94 ± 0.18 bc
Drill+Chicken Manure 5	0.93 ± 0.13 ab	1.26 ± 0.16 b	2.19 ± 0.19
Ridge+Chicken Manure 5	1.19 ± 0.14 ab	1.28 ± 0.12 b	1.50 ± 0.18 c
Inorganic fertilizer+Drill	1.17 ± 0.13 ab	1.54 ± 0.13 b	1.68 ± 0.17 c
Inorganic fertilizer+Ridge	1.63 ± 0.14 b	1.67 ± 0.15 b	2.19 ± 0.15 c

Letters represents statistically significant differences between treatments ($P \leq 0.O5$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

The number of non-marketable sweet potato tubers was assessed across three farms to determine the impact of biochar and chicken manure applications. In Ben's Farm, the control (FP) had a mean non-marketable tuber number of 0.61±0.13. There was no statistical significance when the treatments were compared to the control indicated by an ANOVA result of $P = 0.12$. The treatment that had the lowest non-marketable tubers was five tonnes of biochar in the ridge farming system with a mean of 0.38±0.09 (Table 4.15).

In Mabanga, the control (FP) had an average non-marketable tuber number of 0.41±0.08. When comparing the treatments to the control, there was no statistical significance indicated by an ANOVA result of $P = 0.19$. The lowest mean tuber count was 0.11±0.04 in the ridge system, while the highest was 0.40±0.09 in the drill system, both with five tonnes of biochar (Table 4.15).

In Nafula, the control (FP) had an average non-marketable tuber number of 0.40±0.08. There was no statistical significance when the treatments were compared to the control indicated by an ANOVA result of $P = 0.22$. The lowest mean tuber count was found in ten tonnes of chicken manure applied in the drill farming system 0.14±0.05 (Table 4.15).

Ben's Farm had the highest average non-marketable tuber count 0.81±0.12 under five tonnes of chicken manure in the ridge farming system, whereas Mabanga had the lowest mean tuber count 0.11±0.04 under five tonnes of biochar (Table 4.15).

The lack of significant differences in non-marketable tuber weight is attributable to variation in organic amendments during sweet potato tuber development. While biochar and chicken manure improve soil fertility and plant growth, their impact on particular yield components, such as nonmarketable tuber numbers, is variable. According to (Agegnehu et al., 2016), organic amendments such as biochar do not impact individual yield components such as malformed or small tubers because their advantages often develop gradually over multiple seasons and may not be visible right away. Furthermore, environmental changes may mask the effect of biochar and chicken manure on the proportion of tubers considered marketable, causing them to remain statistically insignificant. This is in line with the findings of (Dawerasha et al., 2024), who concluded that while biochar boosted marketable tubers, total tuber numbers and non-marketable tuber counts did not differ significantly between treatments.

Table 4.15: Non-marketable tuber count of sweet potatoes under biochar and chicken manure treatments.

Non Marketable Numbers of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatments	**Mean±SE**	**Mean±SE**	**Mean±SE**
Farmer Practice control	0.61 ± 0.13 a	0.41 ± 0.08 a	0.40 ± 0.08 a
Drill+Biochar 10	0.57 ± 0.09 a	0.26 ± 0.06 a	0.38 ± 0.08 a
Ridge+Biochar 10	0.69 ± 0.12 a	0.21 ± 0.06	0.40 ± 0.09 a
Drill+Chicken Manure 10	0.76 ± 0.14 a	0.24 ± 0.09 a	0.14 ± 0.05 a
Ridge+Chicken Manure 10	0.60 ± 0.10 a	0.21 ± 0.06 a	0.21 ± 0.07 a
Drill+Biochar 5	0.56 ± 0.11 a	0.40 ± 0.09 a	0.44 ± 0.08 a
Ridge+Biochar 5	0.38 ± 0.09 a	0.11 ± 0.04 a	0.31 ± 0.09 a
Drill+Chicken Manure 5	0.74 ± 0.13 a	0.19 ± 0.06 a	0.36 ± 0.08 a
Ridge+Chicken Manure 5	0.81 ± 0.12 a	0.21 ± 0.06a	0.33 ± 0.09 a
Inorganic fertilizer+Drill	0.78 ± 0.13 a	0.33 ± 0.07 a	0.44 ± 0.13 a
Inorganic fertilizer+Ridge	0.43 ± 0.08 a	0.15 ± 0.06 a	0.44 ± 0.09 a

Letters represents statistically significant differences between treatments $(P \leq 0.O5)$. 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

Biomass was assessed as a growth parameter, and sweet potatoes responded differentially to the application of biochar and chicken manure across the three farms. At Ben's Farm, the control (FP) had a mean biomass of 16.90±5.49 kg. There was minimal level of statistical non-significance when the treatments were compared to the control indicated by an ANOVA result of $P = 0.07$. Five tonnes of chicken manure in the ridge farming system was significantly different from the control with a mean of 19.99±1.18 kg. The maximum biomass was seen in the treatment of ten tonnes of biochar in the ridge farming system with a mean of 43.27±11.13 kg and five tonnes of biochar in the ridge farming system with a mean of 38.04±9.69 kg, albeit neither was statistically different from the control (Table 4.16).

At Mabanga, the control (FP) had a mean biomass of 28.29±11.98 kg. There was a modest level of statistical significance when the treatments were compared to the control indicated by an ANOVA result of $P = 0.49$. Five tonnes of biochar in the ridge system with a mean of 40.66±14.69 kg, five tonnes of chicken manure in the drill system with a mean of 31.12±9.24 kg, and five tonnes of chicken manure in the ridge system with a mean of 21.31±3.25 kg were significantly different from the control. The maximum biomass was reported in the treatment of ten tonnes of biochar in the ridge system with a mean of 46.31±12.16 kg, which was not significantly different from the control (Table 4.16).

At Nafula, the control (FP) had a mean biomass of 20.97±6.23 kg. An ANOVA result of $P = 0.05$ a marginal level of statistical significance when the treatments were compared to the control. These significantly different treatments included five tonnes of biochar in the ridge system with a mean of 40.89±4.69 kg, five tonnes of chicken manure in the drill system with a mean of 37.24±6.38 kg, and inorganic fertilizer in the ridge farming system with a mean of 21.19±1.11 kg. The maximum biomass was seen in ten tonnes of biochar in the drill system with a mean of 48.38±1.37 kg, which was not significantly different from the control (Table 4.16).

The highest biomass values were reported at Nafula under ten tonnes of biochar in the drill system with a mean of 48.38±1.37 kg and at Mabanga under ten tonnes of biochar in the ridge system with a mean of 46.31±12.16 kg.

The application of biochar at ten tonnes per hectare considerably boosted the biomass (fresh weight of sweet potatoes) across all three farms. This is as a result of biochar's capability to increase soil structure, aggregate soil stability, aeration, water holding capacity and nutrient retention (Mbabazize et al., 2023). The addition of charged biochar not only boosts soil organic nitrogen, nitrate and ammonium but also minimises loss of these nutrients to leaching because of the organic carbon in biochar that gets stored upon the soil (Bai et al., 2015; Xu et al., 2014).

According to (Uchenna & Solomon, 2020) the application of biochar and poultry manure have essential nutrients, which are nitrogen and phosphorus with a high pH level that improves the nutrient use efficiency, which is the measure of the ability plant to utilize the available nutrients in the soil and is the yield (biomass) per unit of input. The application of chicken manure also at five tonnes per hectare significantly increased the biomass of sweet potatoes, which aligns with the study by (Biratu et al., 2018) who reported that the addition of chicken manure at the rate of 4.2 tonnes per hectare significantly improved the yield and biomass of cassava. This is as a result of chicken manure's tendency to elevate soil nitrogen and phosphorus levels, thereby boosting biomass (Haque et al., 2023). The increased nitrogen content also enhances the photosynthetic activity of the plant, increasing the chlorophyll content and ultimately biomass (Garko et al., 2021). Marginal significance and non-significance of biomass results across the farms: despite similar agronomic processes, the same treatments are linked to microclimatic variances despite the farms being within a limited geographical zone. This is because areas that are more humid and cooler could have slower rates of organic matter breakdown, delaying nutrient release (Crop Nutrition Laboratories, 2020). Also, the changes in soil pH, soil textures and nutrient profiles are important considerations. This is consistent with the findings of (Huang et al., 2023) who observed that the use of biochar in acidic soils enhanced plant height and biomass, while there were significant differences in alkaline soils.

Table 4.16: Biomass response to biochar and chicken manure application in sweet potatoes.

Biomass (kg) of Sweet Potato Tubers per Farm			
	Ben	**Mabanga**	**Nafula**
Treatments	**Mean±SE**	**Mean±SE**	**Mean±SE**
Farmer Practice control	16.90 ± 5.49 a	28.29 ± 11.98 a	20.97 ± 6.23 a
Drill+Biochar 10	33.29 ± 3.02 ab	42.53 ± 10.22 ab	48.38 ± 1.37 a
Ridge+Biochar 10	43.27 ± 11.13 ab	46.31 ± 12.16 ab	26.16 ± 0.60 ab
Drill+Chicken Manure 10	22.28 ± 3.23 ab	30.31 ± 7.64 ab	33.47 ± 5.39 abc
Ridge+Chicken Manure 10	22.36 ± 4.19 ab	23.22 ± 3.13 abc	31.63 ± 0.71 abc
Drill+Biochar 5	25.33 ± 0.70 abc	29.94 ± 8.66 abcd	37.78 ± 6.21 abc
Ridge+Biochar 5	38.04 ± 9.69 abcd	40.66 ± 14.69 bcd	40.89 ± 4.69 bc
Drill+Chicken Manure 5	22.43 ± 4.55 abcd	31.12 ± 9.24 bcd	37.24 ± 6.38 bc
Ridge+Chicken Manure 5	19.99 ± 1.18 bcd	21.31 ± 3.25 cd	36.82 ± 5.41 bc
Inorganic fertilizer+Drill	27.51 ± 4.16 cd	16.85 ± 3.09 cd	35.11 ± 1.56 bc
Inorganic fertilizer+Ridge	29.05 ± 3.44 d	25.00 ± 10.37 d	21.19 ± 1.11 c

Letters represents statistically significant differences between treatments ($P \leq 0.05$). 5 and 10 represent the rates of biochar and chicken manure applied in tonnes per hectare.

4.6 Nematode community responses to biochar and chicken manure applications (Season 2)

Nematode population densities were assessed to see how biochar and chicken manure affected their dynamics. In the soil ecosystem, *Meloidogyne* species had the highest population density, with Mabanga farm leading at 135.76, Nafula at 84.85, and Ben's farm at 72.73. This suggests that *Meloidogyne* species of nematodes are primarily present in soil, particularly at Mabanga farm. Similar results were reported in roots, with *Meloidogyne* species having the maximum population density at 13.33 in Mabanga farm, 6.06 in Nafula farm, and 2.42 in Ben's farm. Mabanga farm had the highest *Rotylenchulus* species density in the soil ecosystem, at 29.09, followed by Ben's farm at 18.08 and Nafula farm at 7.27. In terms of roots, Ben's farm had the highest population density at 3.64, while Mabanga and Nafula farms had substantially lower densities at 1.21. Within the soil ecosystem, *Pratylenchus* species had the lowest overall population density, with Mabanga farm having the highest at 9.70, Ben's having 3.64, and Nafula farm having 1.21. A similar pattern was observed in roots, with *Pratylenchus* species exhibiting the lowest density; the highest value reported was 2.42 in Mabanga Farm and 1.21 in Ben's Farm. This species was completely absent on the Nafula farm (Table 4.17; Table 4.18).

The prominence values were also assessed to determine the dominance of three PPN genera in the soil community and sweet potato roots. *Meloidogyne* species again had the highest prominence value across all three farms, with the highest value at Mabanga farm being 40.25 in the soil and 2.08 in the roots. *Rotylenchulus* species PV followed a similar trend, with Mabanga Farm having the greatest PV (6.60 in soil and 0.07 in roots). Ben's farm has the greatest PV in roots, measuring 0.35. The PV values in the soil for *Pratylenchus* species were rather low; nevertheless, Mabanga farm had the highest PV among the three farms, at 1.31. In terms of roots, the PV for this species was similarly rather low, with Mabanga farm reporting a PV of 0.19, Ben's farm reporting a PV of 0.07, and Nafula farm reporting the lack of this nematode. The various PV values among farms may indicate different levels of sensitivity to *Pratylenchus* species, necessitating specific control tactics (Table 4.17; Table 4.18).

The frequency of occurrence was also calculated to determine how frequently the three genera of nematodes were found in various subplots of the field. In the soil ecosystem, the *Meloidogyne* species in Mabanga farm had the highest FO, with values of 0.88 and 0.24 in the roots. Nafula and Ben's farms exhibited significantly lower FO in their roots

(0.09 and 0.06, respectively). *Rotylenchulus* species FO was highest in Mabanga farm at 0.52 and was found on all farms; however, in roots, Ben's farm had the highest FO for this species at 0.09, followed by Nafula and Mabanga farms at 0.03. *Pratylenchus* species had the lowest FO in the soil, ranging from 0.18 to 0.03 for Mabanga and Nafula farms, respectively, and in the roots, it was only found in Mabanga and Ben's farms, with FO's of 0.06 and 0.03, respectively. This implies that the presence of *Pratylenchus* species was insignificant, implying that it had little impact on root health in the other locations. As a result, the low FO for this genus may indicate adverse conditions for survival or reproduction in those settings (Table 4.17; Table 4.18).

Biochar and chicken manure's influence on microbial communities causes changes in nematode abundance and diversity (Edussuriya et al., 2023). According to (Liu et al., 2020), manure and biochar increased the soil microbial biomass carbon by 15%, increasing the abundance of free-living nematodes such as bacteriovores by up to 59%. However, biochar may lack a direct nematicidal effect on some nematode species, for example, with the high prominence and frequency of occurrence of the *Meloidogyne* species in the second season. This is in line with the study by (Huang et al., 2015) who found that the application of biochar had no effect in controlling the RKN species numbers in rice.

Chicken manure contributes greatly to soil fertility by providing essential nutrients as well as increasing populations of beneficial soil microbes. Its application is associated with suppression of PPN and enhanced plant growth (Adekiya et al., 2018; Abukari et al., 2024). The *Pratylenchus* species in the second season reduced significantly, which is a result of chicken manure creating a more balanced soil ecosystem, reducing harmful nematodes while supporting beneficial ones. This is in accordance with the research of

(Ali et al., 2021) who concluded that the extended use of animal manure resulted in the population density decrease in *Pratylenchus, Tylenchorhynchus* and *Helicotylenchus* species of nematode.

The *Rotylenchulus* species of nematode reacted moderately to the application of biochar and chicken manure, being more persistent than *Pratylenchus* and less dominant than the *Meloidogyne* species. However, the numbers of this species were relatively high, which could be as a result of the species' penetration and root colonization ability that is dependent on root exudates and other environmental cues. This is in line with the study of (Liu et al., 2019) who reported that the root exudates of cotton plants attracted *Rotylenchulus reniformis* through chemotaxis, increasing their abundance.

Table 4.17: Nematode diversity and abundance in sweet potatoes soil under biochar and chicken manure use.

	Farm	**Nematode species**		
		Pratylenchus sp	*Meloidogyne* sp	*Rotylenchulus* sp
Population Density (n=33)	Ben	3.64	72.73	18.18
	Mabanga	9.70	135.76	29.09
	Nafula	1.21	84.85	7.27
Prominence Values	Ben	0.28	18.78	3.00
	Mabanga	1.31	40.25	6.60
	Nafula	0.07	22.88	0.69
Frequency of Occurrence (%)	Ben	0.06	0.67	0.27
	Mabanga	0.18	0.88	0.52
	Nafula	0.03	0.73	0.09

Table 4.18: Nematode diversity and abundance in sweet potatoes roots under biochar and chicken manure use.

	Farm	Nematode species		
		Pratylenchus sp	*Meloidogyne* sp	*Rotylenchulus* sp
Population Density (n=33)	Ben	1.21	2.42	3.64
	Mabanga	2.42	13.33	1.21
	Nafula	0.00	6.06	1.21
Prominence Values	Ben	0.07	0.19	0.35
	Mabanga	0.19	2.08	0.07
	Nafula	0.00	0.58	0.07
Frequency of Occurrence (%)	Ben	0.03	0.06	0.09
	Mabanga	0.06	0.24	0.03
	Nafula	0.00	0.09	0.03

Season 1 experienced relatively dry conditions, whereas season 2 was characterized by higher and more consistent rainfall, which directly influenced sweet potato growth, tuber development and nematode activity. Additionally, the initial soil samples indicated that baseline populations of PPN varied between the two seasons. The first season saw no significant differences between the treatments and the control in the 3 farms but the second season there were significant differences reflecting inherent heterogeneity in nematode pressure across the experimental fields. Given these differences, combining the datasets would have confounded the treatments effects with seasonal variability and masked the consistency of the treatment performance. The study focused on assessing treatment consistency across season seasons rather than exploring treatment season farming system and field interactions to provide a clearer understanding of the relative efficacy of each treatment under differing environmental and nematode population contexts.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The ridge farming system outperformed the drill farming system in boosting the overall tuber weight of sweet potatoes. During the first season, the ridge system significantly enhanced yield at Mabanga and Nafula farms, whereas no significant variations were noted at Ben's farm due to site-specific factors, including soil type and environmental conditions. Nonetheless, the ridge farming systems surpassed the drill farming systems in total tuber weight. In the second season, the ridge farming system surpassed the drill farming system at all three study locations. The statistically robust results demonstrated the significant impact of the ridge farming method on sweet potato productivity.

The use of biochar and chicken manure positively influenced sweet potato growth and yield in both seasons. The impact of effectiveness, however, differed according to treatment, farm, and agricultural system. In the first season, ten tonnes of chicken manure consistently enhanced both total and marketable tuber weight, notably within the drill farming system. Biochar primarily boosted biomass accumulation but had a lower impact on tuber output. At Nafula Farm, the impact of biochar and chicken manure was constrained, suggesting the influence of specific environmental or soil conditions. In the second season, the combination of five tonnes of biochar and five tonnes of chicken manure within the ridge system improved the total and marketable tuber weights and also had the lowest non-marketable tuber weights, indicating improved tuber quality. Maximum biomass was nonetheless recorded under ten tonnes of biochar. Tuber counts had no significant differences between the three fields.

The application of biochar and chicken manure altered the PPN abundance and diversity, with effects varying by nematode genus, location and season. In the first season *Pratylenchus* and *Meloidogyne* species were more frequent in the soil, while *Rotylenchulus* species populations were often higher in soil than in roots. In the second season, Meloidogyne species remained dominant across all farms, especially in Mabanga. *Rotylenchulus* species exhibited moderate reaction to biochar and chicken manure treatments and was consistent across all three farms. *Pratylenchus* species had the lowest densities and was entirely missing in several root samples, especially at Nafula's farm.

5.2 Recommendations

According to the results of this study, farmers seeking to boost sweet potato output both in terms of yield quantity and quality should employ the ridge farming systems as the major cultivation method. This method consistently outperformed the drill farming system across the two seasons and farms, delivering much higher overall tuber weights.

To further optimize results, the recommended organic amendment treatment is the application of five tonnes of biochar and five tonnes of chicken manure per hectare, particularly under the ridge farming system, as they consistently improved total and marketable yield as well as reduced non-marketable weight. For farmers operating in areas where biochar is limited, ten tonnes of chicken manure remains a viable option, especially within the drill system as shown in the first season.

While biochar contributed positively to biomass accumulation, it had a lower effect on yield. Therefore, it would be beneficial if used together with chicken manure. However, site-specific conditions should be considered so as to tailor these amendment application rates effectively.

Given the limited suppressive effects of these amendments, especially on the *Meloidogyne* species which remained dominant across the two seasons and farms, farmers should not solely rely on biochar and chicken manure amendments for nematode control. Instead, these inputs should be incorporated into a larger nematode management strategy, such as biological nematode controls, usage of resistant varieties of sweet potato and crop rotation to handle the persistent nematode threat effectively.

Farmer training on ideal field preparation processes, identification of region-appropriate sweet potato varieties and field management practices is necessary. This involves timely weeding and hilling of the sweet potatoes, which is crucial for boosting yield. Policymakers and agricultural extension officers ought to promote the adoption of soil organic amendments like biochar and chicken manure through increasing accessibility to certified organic fertilizers and integrating them into wider sustainable agriculture programmes.

Future studies should focus on understanding site-specific responses to biochar and chicken manure, their long-term impacts on soil health and finding application rates that optimize their nematicidal qualities. Additionally, regulations that enable the widespread adoption of organic modifications should be devised to enhance sustainable and economically feasible sweet potato production. These solutions have the potential not only to improve sweet potato productivity and soil conditions but also to contribute meaningfully to sustainable farming practices and integrated pest management systems.

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APPENDICES

Appendix 1: Justification of the CRD experimental design based on baseline nematode population and supporting literature

A1.1: Initial population of nematodes data analysis from Ben, Mabanga and Nafula farms

pi **data of *Meloidogyne* sp. and soil chemical properties**

```
> CLD.model.mabanga.glm
 trt  emmean       SE  df asymp.LCL asymp.UCL  .group
 BT10  -18.3 3301.019 Inf  -9360.78   9324.18  a
 BT2   -18.3 3301.019 Inf  -9360.78   9324.18  a
 BT4   -18.3 3301.019 Inf  -9360.78   9324.18  a
 BT6   -18.3 3301.019 Inf  -9360.78   9324.18  a
 BT5   -18.3 3301.019 Inf  -9360.78   9324.18  a
 BT9   -18.3 3301.019 Inf  -9360.78   9324.18  a
 BT3   -18.3 3301.019 Inf  -9360.78   9324.18  a
 BT11  -18.3 3301.019 Inf  -9360.78   9324.18  a
 BT1     1.9    0.224 Inf      1.26      2.53  a
 BT8     1.9    0.224 Inf      1.26      2.53  a
 BT7     1.9    0.224 Inf      1.26      2.53  a

Results are given on the log (not the response) scale.
Confidence level used: 0.95
Conf-level adjustment: sidak method for 11 estimates
P value adjustment: sidak method for 55 tests
significance level used: alpha = 0.05
NOTE: If two or more means share the same grouping symbol,
      then we cannot show them to be different.
      But we also did not show them to be the same.
```

	Nafula	Mabanga	Ben
Parameter			
N	0.12%	0.12%	0.10%
P	3.66 ppm	3.98ppm	4.94ppm
K	3.21%	**10.80%**	2.49%
pH	5.52	5.03	4.97

```
> CLD.model.nafula.melo.glm
 trt  emmean       SE  df asymp.LCL asymp.UCL  .group
 BT1  -19.30 5442.460 Inf -15422.45  15383.84  a
 BT9  -19.30 5442.460 Inf -15422.45  15383.84  a
 BT7  -19.30 5442.460 Inf -15422.45  15383.84  a
 BT6  -19.30 5442.460 Inf -15422.45  15383.84  a
 BT3  -19.30 5442.460 Inf -15422.45  15383.84  a
 BT11 -19.30 5442.460 Inf -15422.45  15383.84  a
 BT10 -19.30 5442.460 Inf -15422.45  15383.84  a
 BT2  -19.30 5442.460 Inf -15422.45  15383.84  a
 BT8  -19.30 5442.460 Inf -15422.45  15383.84  a
 BT5    1.90    0.224 Inf      1.26      2.53  a
 BT4    2.59    0.158 Inf      2.14      3.04  a

Results are given on the log (not the response) scale.
Confidence level used: 0.95
Conf-level adjustment: sidak method for 11 estimates
P value adjustment: sidak method for 55 tests
significance level used: alpha = 0.05
NOTE: If two or more means share the same grouping symbol,
      then we cannot show them to be different.
      But we also did not show them to be the same.
```

3.MELOIDOGYNE-BEN

```
trt  emmean       SE  df asymp.LCL asymp.UCL  group
 BT11 -16.30 1214.377 Inf -3453.209   3420.60  abc
 BT3  -16.30 1214.377 Inf -3453.209   3420.60  abc
 BT4    1.20    0.316 Inf     0.309      2.10  a
 BT2    1.20    0.316 Inf     0.309      2.10  a
 BT5    1.90    0.224 Inf     1.264      2.53  ab
 BT7    1.90    0.224 Inf     1.264      2.53  ab
 BT1    1.90    0.224 Inf     1.264      2.53  ab
 BT9    2.30    0.183 Inf     1.786      2.82  ab
 BT6    2.59    0.158 Inf     2.143      3.04   b
 BT8    2.59    0.158 Inf     2.143      3.04   b
 BT10   3.28    0.112 Inf     2.967      3.60    c

Results are given on the log (not the response) scale.
Confidence level used: 0.95
Conf-level adjustment: sidak method for 11 estimates
P value adjustment: sidak method for 55 tests
significance level used: alpha = 0.05
NOTE: If two or more means share the same grouping symbol,
      then we cannot show them to be different.
      But we also did not show them to be the same.
```

A1.2: Supporting literature for the use of CRD in the field

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Wrap-and-plant technology to manage sustainably potato cyst nematodes in East Africa

Juliet Ochola[1,2], Laura Cortada[3,4], Onesmus Mwaura[1], Meklit Tariku[4], Shawn A. Christensen[5], Margaret Ng'ang'a[2], Ahmed Hassanali[2], Tahira Pirzada[6], Saad Khan[6], Lokendra Pal[7], Reny Mathew[8], Dick Guenther[8], Eric Davis[8], Tim Sit[8], Danny Coyne[3,4] ✉, Charles Opperman[8] ✉ and Baldwyn Torto[1] ✉

Renewable eco-friendly options for crop protection are fundamental in achieving sustainable agriculture. Here, we demonstrate the use of a biodegradable lignocellulosic banana-paper matrix as a seed wrap for the protection of potato plants against potato cyst nematode (PCN), *Globodera rostochiensis*. Potato cyst nematodes are devastating quarantine pests of potato globally. In East Africa, *G. rostochiensis* has recently emerged as a serious threat to potato production. Wrapping seed potatoes within the lignocellulose banana-paper matrix substantially reduced *G. rostochiensis* field inoculum and increased potato yields by up to fivefold in Kenya, relative to farmer practice, whether or not impregnated with ultra-low doses of the nematicide abamectin (ABM). Markedly, ABM-treated banana paper at ~1,000 times lower than conventional recommendations reduced PCN inoculum. Assays and analyses revealed that the lignocellulose matrix disrupts parasite–host chemical signalling by adsorbing critical PCN hatching and infective juvenile host location chemicals present in potato root exudate. Recovery experiments confirmed adsorption of these host location chemicals. Our study demonstrates the use of waste organic material to sustainably manage PCN, and potentially other crop root pests, while increasing potato yields.

Potato (*Solanum tuberosum*) is a major food crop worldwide. In ... years. They are consequently intractable pests and difficult to man-

sites were situated at elevations >2,500 m above sea level and had clay and sandy loam soils. Physico-chemical and soil texture analyses (Supplementary Tables 2 and 3) were conducted for each site at planting and harvest at the laboratory of the Kenya Agricultural and Livestock Research Organization in Nairobi, using a composite sample from across each site pre-planting and from a composite sample for each treatment per site at each harvest. No remarkable differences in soil composition between treatments were observed (Supplementary Table 4). The accumulated rainfall for the county was 859.9 mm and 458.3 mm for 2016 and 2017, respectively.

Field experiments. Plant parasitic nematode densities were assessed at both Pi and Pf. For both Pi and Pf, nematode infestation was assessed using a 200 ml sub-sample from a composite sample of ~1 kg removed from five randomly selected soil sampling points per plot from ~20 cm depth in each field. PCN cysts were extracted using the Fenwick can method[9]. As no differences ($P < 0.05$) were observed between the Pi infestation levels of PCN cysts and other nematodes, a completely randomized design was implemented. The PCN juveniles and other nematodes were identified to the genus level using morphometric traits, while the molecular-based European and Mediterranean Plant Protection Organization diagnostic protocol PM 7/40(3)[9] was used to determine the PCN species.

The experiment involved four treatments: ABM–LCM (seeds 'wrapped' with LCM impregnated with ~0.8 ng cm^{-2} of abamectin (100 ng ABM per sheet), u-LCM (not impregnated with ABM), ABM alone (drenching the soil with ABM Tervigo (8 l ha^{-1}) following the commercial recommendations (0.19 ml active

Appendix 2: Soil test analysis results and recommendations for Ben, Mabanga and Nafula farms

A2.1: Soil nutrient analysis results from Ben's farm

Soil Analysis
Complete Soil Analysis with Recommendations

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CROPNUTS Laboratory Services ISO/IEC17025 Accredited

Customer:	George Ngatia	**Crop:**	Sweet Potato	**Date Received:**	14-Jul-23
Address:	ngatiageorge.ac@gmail.com	**Crop Stage:**		**Analysis Date:**	20-Jul-23
Farm Name:	George Ngatia	**Comments:**		**Report Date:**	21-Jul-23
Contact Person:	George Ngatia	**Condition:**	Moist	**Sample ID:**	CG368SA0002

Field: ID:BenjaminF2 Top Soil

To maintain the correct history ensure that the next sample sent from this Field is labelled: ID:BenjaminF2

History (Last 3 analysis)

Parameter	Unit	Result	Guide Low	Guide High	Low	Optimum	High	Symbol	Current	Method
pH (H2O)		**4.97**	5.50	7.00				pH	4.97	Potentiometric
*EC (Salts)	uS/cm	**27.3**		< 800				EC(S)	27.3	Potentiometric
Phosphorus	ppm	**4.94**	30.0	100				P	4.94	Mehlich 3 - ICP
Potassium	ppm	**50.3**	120					K	50.3	Mehlich 3 - ICP
Calcium	ppm	**346**	517	724				Ca	346	Mehlich 3 - ICP
Magnesium	ppm	**58.4**	80.0					Mg	58.4	Mehlich 3 - ICP
Sulphur	ppm	**10.9**	10.0	200				S	10.9	Mehlich 3 - ICP
*Sodium	ppm	**19.2**		< 59.5				Na	19.2	Mehlich 3 - ICP
Iron	ppm	**102**	50.0	350				Fe	102	Mehlich 3 - ICP
Manganese	ppm	**49.0**	20.0	250				Mn	49.0	Mehlich 3 - ICP
Boron	ppm	**0.12**	0.80	2.00				B	0.12	Mehlich 3 - ICP
Copper	ppm	**1.30**	1.00	10.0				Cu	1.30	Mehlich 3 - ICP
Zinc	ppm	**0.34**	2.00	20.0				Zn	0.34	Mehlich 3 - ICP
*C.E.C	meq/100g	**5.17**	15.0	30.0				C.E.C	5.17	Calculated
*Total Nitrogen	%	**0.099**	0.20	0.50				N	0.099	Kjeldahl
*Organic Matter	%	**2.52**	2.50	3.50				OM	2.52	Walkley Black
*C/N ratio		**14.8**	10.0	25.0				C:N	14.8	Calculated
***PERCENTAGES AND RATIOS**										
Calcium %	%	**33.4**	50	70				Ca%	33.4	
Magnesium %	%	**9.40**	8	18				Mg%	9.40	
Potassium %	%	**2.49**	2	10				K%	2.49	
Sodium % (ESP)	%	**1.61**	0	5				Na%	1.61	
Other Bases %	%	**7.46**	3	10				OB%	7.46	
Hydrogen %	%	**45.6**	10	15				H%	45.6	
Total	%	**100.00**								
Ca:Mg Ratio	%	**3.55**	30	100				Ca:Mg	3.55	

COMMENTS #
>Very Low pH in this Top Soil>Very Low Phosphorus in this Top Soil>Very Low Potassium in this Top Soil>Very Low Calcium in this Top Soil>Very Low Magnesium in this Top Soil>Very Low Boron in this Top Soil>Very Low Zinc in this Top Soil>Very Low C.E.C in this Top Soil>Very Low Total Nitrogen in this Top Soil>Very Low Calcium % in this soil.>Very High Hydrogen % in this soil.>Very Low Ca:Mg Ratio in this soil.

A2.2: Soil nutrient analysis results from Mabanga farm

Soil Analysis
Complete Soil Analysis with Recommendations

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Customer:	George Ngatia	**Crop:**	Sweet Potato	**Date Received:**	14-Jul-23
Address:	ngatiageorge.ac@gmail.com	**Crop Stage:**		**Analysis Date:**	20-Jul-23
Farm Name:	George Ngatia	**Comments:**		**Report Date:**	21-Jul-23
Contact Person:	George Ngatia	**Condition:**	Moist	**Sample ID:**	CG368SA0003

Field: ID:ATCF1 Top Soil

To maintain the correct history ensure that the next sample sent from this Field is labelled: ID:ATCF1

History (Last 3 analysis)

Parameter	Unit	Result	Guide Low	Guide High	Low	Optimum	High	Symbol	Current	Method
pH (H2O)		**5.03**	5.50	7.00				pH	5.03	Potentiometric
*EC (Salts)	uS/cm	**20.6**		< 800				EC(S)	20.6	Potentiometric
Phosphorus	ppm	**3.98**	30.0	100				P	3.98	Mehlich 3 - ICP
Potassium	ppm	**49.1**	120					K	49.1	Mehlich 3 - ICP
Calcium	ppm	**355**	519	727				Ca	355	Mehlich 3 - ICP
Magnesium	ppm	**67.4**	80.0					Mg	67.4	Mehlich 3 - ICP
Sulphur	ppm	**12.7**	10.0	200				S	12.7	Mehlich 3 - ICP
*Sodium	ppm	**13.2**		< 59.7				Na	13.2	Mehlich 3 - ICP
Iron	ppm	**96.8**	50.0	350				Fe	96.8	Mehlich 3 - ICP
Manganese	ppm	**78.2**	20.0	250				Mn	78.2	Mehlich 3 - ICP
Boron	ppm	**0.026**	0.80	2.00				B	0.026	Mehlich 3 - ICP
Copper	ppm	**2.24**	1.00	10.0				Cu	2.24	Mehlich 3 - ICP
Zinc	ppm	**0.61**	2.00	20.0				Zn	0.61	Mehlich 3 - ICP
*C.E.C	meq/100g	**5.19**	15.0	30.0				C.E.C	5.19	Calculated
*Total Nitrogen	%	**0.12**	0.20	0.50				N	0.12	Kjeldahl
*Organic Matter	%	**3.23**	2.50	3.50				OM	3.23	Walkley Black
*C/N ratio		**15.6**	10.0	25.0				C:N	15.6	Calculated
***PERCENTAGES AND RATIOS**										
Calcium %	%	**34.2**	50	70				Ca%	34.2	
Magnesium %	%	**10.8**	8	18				Mg%	10.8	
Potassium %	%	**2.43**	2	10				K%	2.43	
Sodium % (ESP)	%	**1.11**	0	5				Na%	1.11	
Other Bases %	%	**7.34**	3	10				OB%	7.34	
Hydrogen %	%	**44.1**	10	15				H%	44.1	
Total	%	**100.00**								
Ca:Mg Ratio	%	**3.16**	30	100				Ca:Mg	3.16	

COMMENTS #
>Very Low pH in this Top Soil>Very Low Phosphorus in this Top Soil>Very Low Potassium in this Top Soil>Very Low Calcium in this Top Soil>Very Low Magnesium in this Top Soil>Very Low Boron in this Top Soil>Very Low Zinc in this Top Soil>Very Low C.E.C in this Top Soil>Low Total Nitrogen in this Top Soil>Very Low Calcium % in this soil.>Very High Hydrogen % in this soil.>Very Low Ca:Mg Ratio in this soil.

A2.3: Soil nutrient analysis results from Nafula farm

Soil Analysis

Complete Soil Analysis with Recommendations

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CROPNUTS Laboratory Services ISO/IEC17025 Accredited

Customer:	George Ngatia	**Crop:**	Sweet Potato	**Date Received:**	14-Jul-23
Address:	ngatiageorge.ac@gmail.com	**Crop Stage:**		**Analysis Date:**	21-Jul-23
Farm Name:	George Ngatia	**Comments:**		**Report Date:**	21-Jul-23
Contact Person:	George Ngatia	**Condition:**	Moist	**Sample ID:**	CG368SA0001

Field: ID:Anicet.WafulaF3 Top Soil

To maintain the correct history ensure that the next sample sent from this Field is labelled: ID:Anicet.WafulaF3

History (Last 3 analysis)

Parameter	Unit	Result	Guide Low	Guide High	Low	Optimum	High	Symbol	Current	Method
pH (H2O)		**5.52**	5.50	7.00				pH	5.52	Potentiometric
*EC (Salts)	uS/cm	**14.9**		< 800				EC(S)	14.9	Potentiometric
Phosphorus	ppm	**3.66**	30.0	100				P	3.66	Mehlich 3 - ICP
Potassium	ppm	**70.2**	120					K	70.2	Mehlich 3 - ICP
Calcium	ppm	**523**	560	784				Ca	523	Mehlich 3 - ICP
Magnesium	ppm	**86.0**	80.0					Mg	86.0	Mehlich 3 - ICP
Sulphur	ppm	**12.2**	10.0	200				S	12.2	Mehlich 3 - ICP
*Sodium	ppm	**20.0**		< 64.4				Na	20.0	Mehlich 3 - ICP
Iron	ppm	**102**	50.0	350				Fe	102	Mehlich 3 - ICP
Manganese	ppm	**48.3**	20.0	250				Mn	48.3	Mehlich 3 - ICP
Boron	ppm	**0.12**	0.80	2.00				B	0.12	Mehlich 3 - ICP
Copper	ppm	**1.75**	1.00	10.0				Cu	1.75	Mehlich 3 - ICP
Zinc	ppm	**0.63**	2.00	20.0				Zn	0.63	Mehlich 3 - ICP
*C.E.C	meq/100g	**5.60**	15.0	30.0				C.E.C	5.60	Calculated
*Total Nitrogen	%	**0.12**	0.20	0.50				N	0.12	Kjeldahl
*Organic Matter	%	**3.25**	2.50	3.50				OM	3.25	Walkley Black
*C/N ratio		**15.7**	10.0	25.0				C:N	15.7	Calculated
***PERCENTAGES AND RATIOS**										
Calcium %	%	**46.7**	50	70				Ca%	46.7	
Magnesium %	%	**12.8**	8	18				Mg%	12.8	
Potassium %	%	**3.21**	2	10				K%	3.21	
Sodium % (ESP)	%	**1.55**	0	5				Na%	1.55	
Other Bases %	%	**6.36**	3	10				OB%	6.36	
Hydrogen %	%	**29.4**	10	15				H%	29.4	
Total	%	**100.00**								
Ca:Mg Ratio	%	**3.65**	30	100				Ca:Mg	3.65	

COMMENTS #

>Very Low Phosphorus in this Top Soil>Very Low Potassium in this Top Soil>Low Calcium in this Top Soil>Very Low Boron in this Top Soil>Very Low Zinc in this Top Soil>Very Low C.E.C in this Top Soil>Low Total Nitrogen in this Top Soil>Low Calcium % in this soil.>Very High Hydrogen % in this soil.>Very Low Ca:Mg Ratio in this soil.

A2.4: Recommendations based on the baseline soil nutrient levels from Ben, Mabanga and Nafula farms

RECOMMENDATIONS REPORT #

SOIL FERTILITY CORRECTION AND CROP FERTILIZER PROGRAMS

CROPNUTS Laboratory Services ISO17025 Accredited

Customer:	George Ngatia	Crop:	Sweet Potato	Date Received:	14-Jul-23
Address:	ngatiageorge.ac@gmail.com	Crop Stage:		Analysis Date:	20-Jul-23
Farm Name:	George Ngatia	Comments:		Report Date:	21-Jul-23
Contact Person:	George Ngatia	Condition:	Moist	Sample ID:	CG368SA0002

Crop	Sweet Potato	Yield Target	30 t/Ha

*** This includes any nutrient deductions from manure/compost application.*
To improve the accuracy of these recommendations, please send a sample of manure/compost.

SOIL FERTILITY CORRECTION & FERTILIZER PROGRAM

PROBLEM	SOLUTION /INPUT	RATE		COMMENTS	STAGE (Input Type)
		Kg/Ha	Kg/Acre		
Low calcium /pH levels in the soil. Calcium :magnesium imbalance.	CALCITIC LIME (35 - 40% Ca, <1% Mg) Find Calcitic Lime Suppliers	1200	485	Apply before rains in Feb/March or Sept/Oct. Don't apply more than 3,000 kg/ha (2 kg/tree) per annum of any lime. If magnesium is low, always apply dolomitic lime first. Always test	PREPLANTING (Soil Correction)
Low magnesium /pH levels in the soil. Calcium :magnesium imbalance.	DOLOMITIC LIME (20 - 24% Ca, 10 - 14% Mg) Find Dolomitic Lime Suppliers	800	325	Apply before main planting season. If magnesium is low in soils, always apply this lime first. Testing lime quality highly recommended. quality.	PREPLANTING (Soil Correction)
Soil nutrients build up required	MANURE/COMPOST ** (Source: Default Manure/Compost) Find Compost Suppliers	10000	4050	Apply along planting holes - caution not to apply compost or manure directly in to planting hole, can burn roots of young seedlings	PREPLANTING (Soil Correction)
Phosphorus fertilization required.	11.23.23 +4S 0.25B Find NPK Fertilizers (>20% P2O5) Suppliers	360	145	Incorporate into ridges before planting.	PLANTING (Fertilizer)
Nitrogen fertilization required.	Urea Find Urea Suppliers	90	35	Topdress at 45 days after planting	TOP DRESS (Fertilizer)

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Appendix 3: Chicken manure and biochar nutrient analysis reports and recommendations

A3.1: Chicken manure nutrient test results and recommendations

Manure Compost Analysis Report

Complete Compost/Manure Analysis

KENAS TL/21

CROPNUTS Laboratory Services ISO/IEC17025 Accredited

Report Ref#: CN-206813

Customer:	George Ngatia	**Fertilizer:**	Compost	**Date Received:**	14-Jul-23
Address:	ngatiageorge.ac@gmail.com	**Crop Stage:**		**Analysis Date:**	21-Jul-23
Farm Name:	George Ngatia	**Comments:**		**Report Date:**	25-Jul-23
Contact Person:	George Ngatia	**Condition:**	Dry Organic Material	**Sample ID:**	CG368CM0002

Field: Chicken Manure

History (Last 3 analysis)

Parameter	Unit	Result	Guide Low	Guide High	Low	Optimum	High	Symbol	Current				Method
pH		**9.18**	6.00	8.50				pH	9.18				Potentiometric
EC (Salts)	mS/cm	**11.5**	0.75	1.20				EC(S)	11.5				Potentiometric
Dry matter	%	**37.6**						DM	37.6				Gravimetric
Carbon	%	**38.1**	13.0	60.0				C	38.1				Combustion
Total Nitrogen	%	**2.52**	0.80	4.00				N	2.52				DUMAS
Phosphorus	%	**1.50**	0.20	3.00				P	1.50				Spectroscopy
Potassium	%	**2.30**	0.40	2.00				K	2.30				Spectroscopy
Calcium	%	**6.81**	1.00	10.0				Ca	6.81				Spectroscopy
Magnesium	%	**0.84**	0.20	0.80				Mg	0.84				Spectroscopy
Sulphur	%	**0.45**	0.20	0.50				S	0.45				Spectroscopy
Manganese	ppm	**535**	200	800				Mn	535				Spectroscopy
Iron	ppm	**2070**						Fe	2070				Spectroscopy
Zinc	ppm	**466**	40.0	1000				Zn	466				Spectroscopy
Copper	ppm	**78.7**	8.00	400				Cu	78.7				Spectroscopy
Boron	ppm	**32.1**	20.0	140				B	32.1				Spectroscopy
Sodium	ppm	**3650**		< 3000				Na	3650				Spectroscopy
C/N ratio		**15.1**	10.0	20.0				C:N	15.1				Calculated

NUTRIENT CONTRIBUTION PER TON

N	P	K	Ca	S	Mg
kg/Ha	kg/Ha	kg/Ha	kg/Ha	kg/Ha	kg/Ha
2.84	1.69	2.59	7.68	0.51	0.95

NOTES:

Nutrient Contribution & Fertilizer Deductions

These figures estimate the quantity of nutrients supplied per 1000 kg (1 ton) of this manure/compost applied each hectare of land. The calculation takes into account the material dry matter %, the nutrient content % result above, and an estimated nutrient release of 30% to the first crop.

A3.2: Biochar nutrient test results and recommendations

Manure Compost Analysis Report

Complete Compost/Manure Analysis

KENAS TL/21

CROPNUTS Laboratory Services ISO/IEC17025 Accredited

Report Ref#: CN-206812

Customer:	George Ngatia	**Fertilizer:**	Compost	**Date Received:**	14-Jul-23
Address:	ngatiageorge.ac@gmail.com	**Crop Stage:**		**Analysis Date:**	21-Jul-23
Farm Name:	George Ngatia	**Comments:**		**Report Date:**	25-Jul-23
Contact Person:	George Ngatia	**Condition:**	Dry Organic Material	**Sample ID:**	CG368CM0001

Field: Biochar

History (Last 3 analysis)

Parameter	Unit	Result	Guide Low	Guide High	Low	Optimum	High	Symbol	Current	Method
pH		9.10	6.00	8.50				pH	9.10	Potentiometric
EC (Salts)	mS/cm	4.28	0.75	1.20				EC(5)	4.28	Potentiometric
Dry matter	%	24.2						DM	24.2	Gravimetric
Carbon	%	34.0	13.0	60.0				C	34.0	Combustion
Total Nitrogen	%	1.16	0.80	4.00				N	1.16	DUMAS
Phosphorus	%	1.15	0.20	3.00				P	1.15	Spectroscopy
Potassium	%	1.23	0.40	2.00				K	1.23	Spectroscopy
Calcium	%	3.61	1.00	10.0				Ca	3.61	Spectroscopy
Magnesium	%	0.51	0.20	0.80				Mg	0.51	Spectroscopy
Sulphur	%	0.24	0.20	0.50				S	0.24	Spectroscopy
Manganese	ppm	1870	200	800				Mn	1870	Spectroscopy
Iron	ppm	11700						Fe	11700	Spectroscopy
Zinc	ppm	343	40.0	1000				Zn	343	Spectroscopy
Copper	ppm	52.1	8.00	400				Cu	52.1	Spectroscopy
Boron	ppm	45.2	20.0	140				B	45.2	Spectroscopy
Sodium	ppm	2580		< 3000				Na	2580	Spectroscopy
C/N ratio		29.3	10.0	20.0				C:N	29.3	Calculated

NUTRIENT CONTRIBUTION PER TON

N	P	K	Ca	S	Mg
kg/Ha	kg/Ha	kg/Ha	kg/Ha	kg/Ha	kg/Ha
0.84	0.83	0.89	2.62	0.17	0.37

NOTES:

Nutrient Contribution & Fertilizer Deductions

These figures estimate the quantity of nutrients supplied per 1000 kg (1 ton) of this manure/compost applied each hectare of land. The calculation takes into account the material dry matter %, the nutrient content % result above, and an estimated nutrient release of 30% to the first crop.

Appendix 4: Images of the economically significant nematodes of sweet potatoes identified in Ben, Mabanga and Nafula farms

A4.1: ***Meloidogyne sp.*** **under the microscope from the collected field samples**

A4.2: ***Rotylenchulus*** **sp. identified from the collected field samples**

A4.3: ***Pratylenchus*** **sp. identified from the collected field samples**

Appendix 5: Plagiarism Awareness Certificate

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Awarded by

Prof. Anne Syomwene Kisilu
CERM-ESA Project Leader Date: 09/09/2025