EFFICACY OF BANANA PAPER AS A CARRIER FOR CONTROL AGENTS FOR THE MANAGEMENT OF ROOT- KNOT NEMATODES (*Meloidogyne* spp.) ON POTATOES (*Solanum tuberosum*) IN KIRINYAGA COUNTY, KENYA

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A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Crop Protection (Plant pathology option) in the School of Agriculture and Environmental Sciences, Department of Agricultural Science and Technology, Kenyatta University.

JUNE, 2024

DECLARATION

I declare that this thesis is my original work and has not been presented for a degree award in any other university or institution of higher learning.

Sign..... Date 21/06/2024

Dorris Wangui Kamau

Declaration by supervisors

We confirm that the work in this thesis has been submitted with our approval as the University Supervisors

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DEDICATION

This thesis is dedicated to my son, Liam Bradley and my daughter, Hailey Avery, who gave me the strength to keep working hard each day. May this thesis serve as motivation for them to achieve even higher heights.

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LIST OF ABBREVIATIONS AND SYNONYMS

ADC	Agricultural Development Corporation
AfFOResT	African Farmers Organic Research and Training
ANOVA	Analysis of Variance
ASDS	Agricultural Sector Development Strategy
CIP	International Potato Center
DAP	Diammonium Phosphate
EPN	Entomopathogenic Nematodes
EU	European Union
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization Statistics
GIZ-PSDA	Gesellschaft fur Internationale Zusammenarbeit (GIZ) - Promotion
IPM	Integrated Pest Management
KA LRO	Kenya Agricultural and Livestock Research Organization
KEPHIS	Kenya Plant Health Inspectorate Service
KFA	Kenya Farmers Association
LSD	Least Significant Difference
MLND	Maize Lethal Necrosis Disease
MOA	Ministry of Agriculture
NCPK	National Potato Council of Kenya
NGO	Non- Governmental Organization
	of Private Sector in Agriculture (PSDA)
PPN	Plant-parasitic Nematodes
RKN	Root-knot nematodes
SDG	Sustainable Development Goals

SPSS	Statistical Software for the Social Sciences
UN	United Nations

ABSTRACT

Globally, potatoes, *Solanum tuberosum*, are a key staple food crop. In Kenya and East Africa, it is the second most important food crop after maize. Among the various constraints on potato production are plant-parasitic nematodes, RKNs are viewed as the most economically damaging group of plant-parasitic nematodes (PPNs) worldwide. Plant-parasitic nematodes are linked to reduced yields, low quality of crop produce, and high costs of production. The current study was undertaken to evaluate the efficacy of a lignocellulose fiber matrix (banana fiber paper) as a carrier for control agents in the management of RKN on potatoes in Kenya. The experiment was conducted in both field and pot trials over two consecutive cropping seasons. The experiment was conducted in Mwea, Kirinyaga County, in plots measuring 4x4 meters for two consecutive short rain cropping seasons and in pot trials in a screen-house at Kenyatta University. Mwea was chosen as the experimental site as there is a high prevalence of RKNs in the area brought about by continuous planting of RKN-susceptible crops such as tomatoes in the area. Effectively managing RKNs in Mwea may be essential in improving the yields and incomes of farmers in the region and also providing them with opportunities to successfully venture into potato farming; thus, improving food security in the country. Land preparation was done manually, and then 4x4 meters plots were marked. Treatments were distributed to the plots randomly using a completely randomized block design. The six treatments used in this study included (a) banana paper impregnated with abamectin, (b) abamectin alone, (c) *Trichoderma asperellum alone*, (d) banana paper impregnated with *Trichoderma asperellum*, (d) banana paper alone, and (e) untreated control. Seed potatoes sourced from the International Potato Centre (CIP) were planted after wrapping them with banana banana-paper. Data collection on plant height and number of stems began after the crops had germinated and was done after every two weeks throughout the cropping season (12 weeks). The data collected included a) plant height (cm), b) mass of tubers per plant (g), c) mass of the entire root system (g)/plant, d) number of stem/plant, e) number of tubers/plant, g) the reproduction factor of J2's/200cc of soil. Data were analyzed using R (Version 4.2.3) statistical software (R Core Team, 2023). Tukey's Honest Significant Difference (Tukey-HSD) test was done where the Analysis of Variances (ANOVA) indicated that there were significant differences ($p<0.05$) between the treatment means. Banana paper impregnated with abamectin (abamectin-paper) led to significantly increased crop growth, yield and the number of tubers compared to abamectin alone, paper-control and no treatment. The use of banana paper impregnated with abamectin also significantly reduced the nematode density at harvest compared with abamectin alone, paper-control, and absolute-control. However, the paper-control and abamectin alone also significantly improved potato production and nematode management compared to the untreated control. The use of abamectin-paper resulted in a 30% and 36% increase in the number of tubers per plant compared to the untreated control in Seasons 1 and 2, respectively. Additionally, abamectin-paper increased the mean tuber yield per plant by 83% in Season 1 and 148% in Season 2 compared to the untreated control. Additionally, abamectin-paper reduced nematode reduction by 96% in season 1 and 89% in season 2 compared to the untreated control. Consequently, this innovative technology, also known as 'Wrap&Plant,' provides a viable option for nematode management in potatoes under resource-constrained conditions in Sub-Saharan Africa.

CHAPTER ONE: INTRODUCTION

1.1 Background information

The potato (*Solanum tuberosum*) is among the most important staple food crops globally. In sub-Saharan Africa, the crop is valuable for food security and income generation, and in Kenya, it stands as the second most important crop after maize, where it is produced primarily by smallholder farmers (McEwan et al., 2021). In Kenya, the area cropped to ware potato is over 192,000 ha with yields of 7.9 t/ha, a figure way below its potential of >40 t/ha (FAO, 2019). As a source of income, potatoes also contribute over $0.5 billion to the Kenyan economy annually (National Potato Council of Kenya [NPCK], 2021), employing around 2.5 million people across the value chain (International Potato Center [CIP], 2019). With their relatively short growing season, potatoes provide an ideal crop for food security regionally. Further, it can be planted year-round in some locations with 2-3 crops per annum, especially when planting early maturing cultivars such as the regionally popular cv. Shangi (Mburu et al., 2020). However, despite the regional importance of potato overall, production is declining, with Kenya alone witnessing a 61% decline within 10 years, even though the area cropped to potato is increasing (FAOSTAT, 2019). This steady decline in productivity is due to several factors (Sigrid et al., 2014), such as pests and diseases, including potato cyst nematodes (PCN; *Globodera* spp.) and root-knot nematodes (RKN; *Meloidogyne* spp.) (Niere & Karuri, 2018). Although PCN was first reported in Kenya in 2015 (Mwangi *et al*., 2015) and has recently been shown to be highly damaging to Kenyan and regional potato production (Mburu et al., 2020), RKNs are also a significant threat to production (Lima et al., 2018; Sikandar et al., 2020). RKN are viewed as the most economically damaging group of plant-parasitic nematodes worldwide (Coyne *et al*., 2018a). The main species affecting potatoes in Africa and across the sub-tropics include

M. incognita, M. arenaria. M. javanica and, *M. hapla,* although there are an increasing number of records of other species, such as *M. chitwoodi* (Coyne *et al*., 2018a, b). RKN are highly polyphagous with exceptionally broad host ranges, making it challenging to establish suitable and effective management options. Previously, RKN management has relied heavily on synthetic chemical pesticides (Renčo and Kováčik, 2012). However, due to the withdrawal of the most effective of these pesticides for environmental and safety reasons (Onkendi et al., 2014), there is a great need for alternative management options for these pervasive pests. Techniques such as host resistance, sanitation, soil tillage, cover crops, trap crops and green manures, among others, have been utilized in the management of RKN, but effective management remains elusive, especially in the tropics and sub-tropics (Coyne et al., 2018a). Consequently, interest in biologically based options has grown considerably, with some products showing promising results, including the use of antagonistic fungi such as *Trichoderma* species (Poveda et al., 2020). In Kenya, *Trichoderma asperellum* strain TR900 has been produced and marketed for effective use against RKN on a range of crops (RealIPM, 2021).

Abamectin is a nematicide with strong activity against a wide range of plant parasitic nematodes and is marketed for use on a range of crops (Cao *et al*., 2016). Abamectin is derived from the natural fermentation of the soil bacterium *Streptomyces avermitilis* (Ōmura & Shiomi, 2007; Pitterna et al., 2007). It has relatively low toxicity to non-target beneficial arthropods, increasing its acceptance in relation to environmental safety (Khalil, 2013). However, abamectin's efficacy is limited by its poor solubility in water and lipophilic nature, which causes it to bind to organic matter, resulting in poor distribution and mobility in the soil (Cao et al., 2016). These characteristics can result in limited protection because the compound may not reach the root zone, or the radicle may be rendered unprotected following germination when used as a seed coating (Cao

et al., 2016; Khalil et al., 2019). As a result, delivering abamectin to the target root zone via an effective carrier would aid in improving efficacy and prolonging activity in the soil, thereby extending protection against plant parasitic nematodes.

A nutrient-rich biodegradable lignocellulose matrix made from banana fiber was identified and developed for delivering nematicide microdosages to the target rhizosphere zone (Pirzada et al., 2020a, b; Ochola et al., 2022). The high lignin content of the banana fiber paper made it suitable for loading abamectin, followed by a slow, sustained release over weeks. The 'Wrap & Plant' [W&P] technology delivers high relative concentrations of nematicides to the rhizosphere while minimizing environmental contamination and non-target effects (Ochola et al., 2022). It is being tested primarily on clonally propagated crops, with preliminary results against PCN indicating great promise for nematode management (Ochola et al., 2020; Ochola et al., 2022). The current study was designed to evaluate the efficacy of banana fiber paper against RKN on potatoes in the field and its potential as a carrier for products such as the chemical nematicide abamectin and the fungal antagonist *T. asperellum*.

The 'Wrap&Plant' technology represents a significant advancement in agricultural pest management by combining traditional methods with innovative delivery systems. The banana fiber paper used in W&P technology not only supports the environment by being biodegradable but also enhances the bioavailability of applied nematicides and biological agents. This ensures a more consistent and targeted approach to pest control. In addition, the slow-release mechanism reduces the need for frequent applications, cutting down on labor and material costs for smallholder farmers. As W&P technology is refined and adapted, it holds the potential to revolutionize nematode management in

potatoes and other crops, especially in regions where pest pressure is high and resources are limited.

1.2 Statement of the Problem

The foundation of the study lies in addressing the gaps in knowledge regarding effective management strategies for RKNs, which pose a significant threat to crop production in Kenya and globally. Because of their wide host range, short generation times, high reproductive rates, and endoparasitic nature, RKNs are difficult to control (Trudgill & Blok, 2001). Although nematicides that have been banned can effectively manage nematodes, their use is limited due to their short-term effects, high costs, non-availability, nematode resistance development, health and environmental hazards, residual toxicity, and adverse effects on beneficial microflora and fauna in the soil, in addition to phytotoxic effects on crops (Abd-Elgawad, 2020; Azlay et al., 2023; Mukhtar, 2018). The surge in interest in developing appropriate biological control methods stems from the urgent need to address the threat to food security while ensuring environmental sustainability and cost-effectiveness for farmers. Despite the potential of nematicides, their drawbacks necessitate exploration of alternative approaches. Thus, the utilization of banana paper as a carrier for nematicides represents a novel avenue for research, aiming to bridge the gap in knowledge regarding effective and environmentally friendly control of RKNs.

1.3 Justification of the Study

The justification of the study lies in addressing the gaps in knowledge regarding effective strategies for suppressing RKNs, which pose a significant threat to potato production in Kenya and globally. Because of their wide host range, short generation times, high reproductive rates, and endoparasitic nature, RKNs are notoriously difficult to control (Coyne et al., 2018a; Jagdale et al., 2021; Lima et al., 2018; Sikandar et al.,

2020). Traditional nematicides, though effective, come with numerous limitations, such as short-term effects, high costs, limited availability, the development of nematode resistance, health and environmental hazards, residual toxicity, and adverse effects on beneficial soil microflora and fauna, as well as phytotoxic effects on crops (Abd-Elgawad, 2020; Azlay et al., 2023; Mukhtar, 2018). The surge in interest in developing appropriate biological control methods stems from the urgent need to address the threat to food security while ensuring environmental sustainability and cost-effectiveness for farmers. Despite the potential of nematicides, their drawbacks necessitate exploration of alternative approaches (Abd-Elgawad, 2020; Azlay et al., 2023). Thus, the utilization of banana paper as a carrier for control agents such as abamectin and *Trichoderma* represents a novel avenue for research, aiming to bridge the gap in knowledge regarding effective and environmentally friendly control of RKNs.

In addition, the selection of study sites, particularly Mwea, was deliberate and based on previous research indicating a high RKN challenge in the area, particularly in tomato fields. This decision was made with the aim of establishing sites where RKN pressure was known to be significant. Building upon previous work in the region, the study sought to extend the proof of concept from tomatoes to potatoes, demonstrating the efficacy of the novel approach against RKN in a different crop. Hence, the selection of study sites and the strategic focus on proof of concept in the field not only enhanced the scientific rigor of the research but also aligned with the practical objectives of addressing nematode challenges in Kenyan agriculture. Through this approach, the study was aimed at generating actionable insights that can inform future efforts to combat nematode infestations and promote sustainable potato production practices.

1.4 Significance of the study

The significance of the study lay in its potential to address several critical issues in potato farming, particularly in regions heavily impacted by PPNs such as RKNs. These nematodes had been linked to significant crop yield reductions in Kenya, exacerbating food security concerns (Waceke, 2007). Despite their destructive nature, PPNs were often overlooked, and farmers' awareness of their presence and management remained low (Maina et al., 2010). With the increasing reliance on potatoes as a stable source of starch and food security for small-scale farmers, especially in the face of challenges such as maize lethal necrosis disease (MLND) and the fall armyworm, there was a pressing need to develop effective and sustainable pest management strategies. The study was aimed at filling this gap by evaluating various control strategies that could be integrated into integrated pest management (IPM) packages to manage RKN in potato farming, ultimately leading to increased yields.

One of the key benefits of the control strategies utilized in this project is their potential to improve the working environment for smallholders. By reducing the reliance on synthetic chemical pesticides, which could be costly and hazardous to both human health and the environment, the study's findings contributed to creating safer and more sustainable agricultural practices. Additionally, by providing effective control measures for RKN, the study helped alleviate the economic burden on small-scale farmers, who often bear the brunt of crop losses due to nematode infestations.

In addition, the precision in the application of nematode control agents facilitated by the use of banana fiber paper as a carrier offered several advantages. It ensured targeted delivery of the nematicides to the root zone, maximizing their efficacy while minimizing environmental contamination and non-target effects. This precision

application approach not only enhanced the effectiveness of pest control but also reduced the need for frequent applications, resulting in cost savings for farmers. Overall, the findings of the study have significant implications for potato farming in Kenya and other regions grappling with similar nematode infestations. By providing practical and sustainable solutions for suppressing RKN populations, the study's findings will contribute to improving food safety, increasing yields, and enhancing the livelihoods of smallholder farmers, ultimately contributing to broader agricultural sustainability and food security goals.

1.5 Research Objectives

1

.5.1 General Objectives

To improve potato production through the management of RKN using banana paper as a carrier for control agents.

1

.5.2 Specific Objectives

i. To evaluate the effect of banana paper as a carrier for abamectin or *Trichoderma* on potato yield.
ii. To evaluate the effect of banana paper as a carrier for abamectin or *Trichoderma* on potato growth.
iii. To evaluate efficacy of banana paper as a carrier for abametcin or *Trichoderma* to suppress RKN populations on potato.

1

.5.3 Research hypotheses

i. Banana paper as a carrier for abamectin and *Trichoderma* is effective in improving potato yield.

ii. Banana paper as a carrier for abamectin or *Trichoderma* is effective in improving potato growth.

iii. Banana paper as a carrier for abamectin or *Trichoderma* is effective in suppressing RKN populations on potato.

1.6 Conceptual Framework

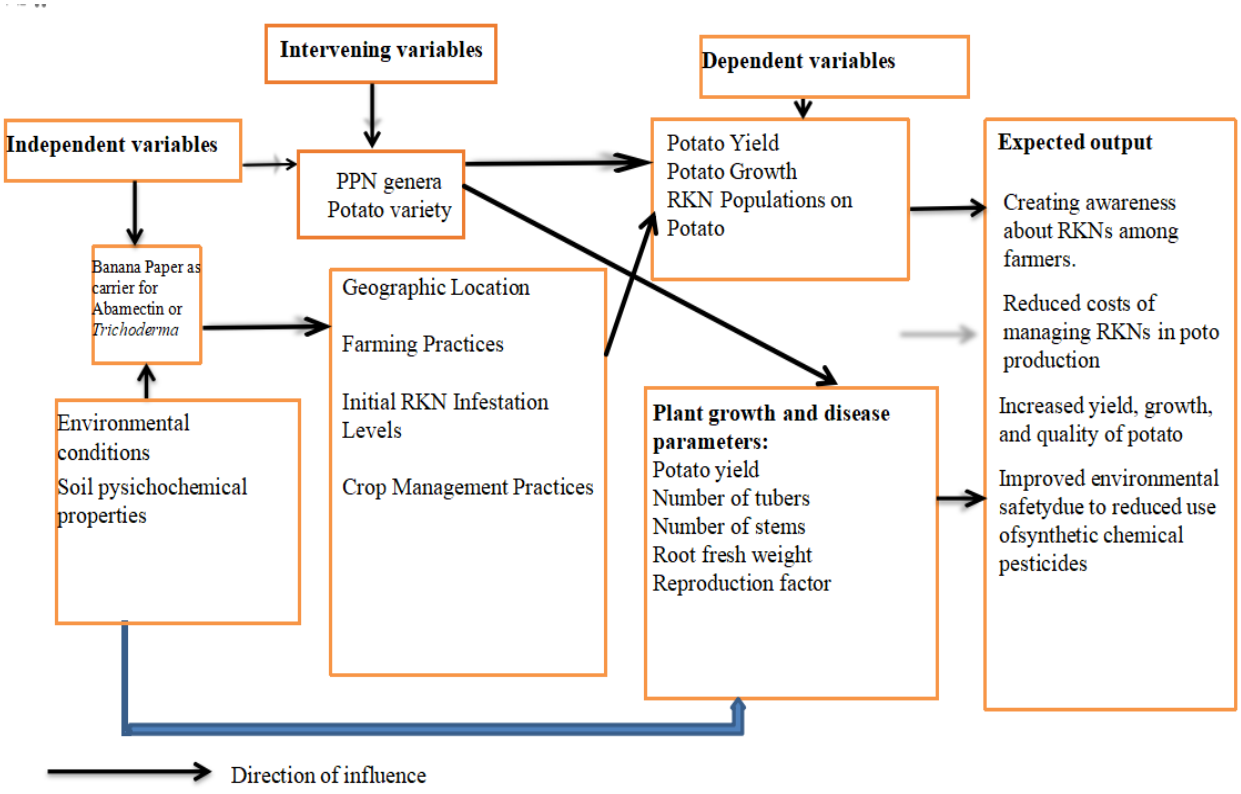

Figure 1.1: Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Potato Production in Kenya

Potato production in Kenya began in the late 19th century when European settlers introduced the Irish potato (Solanum tuberosum) in Kiambu, Murang'a, and Nyeri counties, initially for domestic use and later for export. Native Kenyan farmers started cultivating potatoes in 1920 and entered the export market by 1923. The National Agricultural Laboratories in Kabete introduced new potato varieties and seed production in 1903, followed by plant breeding in Njoro in 1927, with Kerr's Pink being the primary variety at the time (Ministry of Agriculture, Livestock, and Fisheries [MoALF], 2020). Traditionally, potatoes were grown at high altitudes (1500-3000 meters above sea level) on the slopes of Mount Kenya, the Mau escarpment, Mount Elgon, the Aberdare range, Kericho, Kisii, Cherangani hills, and patches of Taita hills. However, due to increasing demand, cultivation has expanded to non-traditional areas like Kirinyaga, Tana River, and Naivasha (MoALF, 2020). Potatoes grow best in temperatures between 15-24 degrees Celsius with 1200-1800 mm of rainfall and prefer loam soils with a pH of 5.5-7.0 (National Potato Council of Kenya [NPCK], 2016).

Over 800,000 farmers, mostly small-scale, grow potatoes in Kenya, with 83% of the land under potato cultivation managed by small-scale farmers (0.2-0.4 ha) and 17% by large-scale farmers (2-10 ha) (Janssens et al., 2013). The average yield is 7-10 tons per hectare, below the global average of 17 tons per hectare (FAOSTAT, 2014), and the per capita consumption is about 25-30 kg annually (FAO, 2019). Kenya grows over 60 potato varieties, with Shangi and Tigoni being the most popular due to market preferences. Shangi is particularly favored for its short cooking time, rapid growth

(about three months), and low tuber dormancy (about one month), making it suitable for low-income households. Despite its popularity, Shangi is highly susceptible to pests and diseases, which can negatively impact yields (Kaguongo et al., 2014; Sinelle, 2018).

2.2 Potato Production Constraints in Kenya

2

.2.1 Root-knot nematode (*Meloidogyne* spp.)

Root-knot nematodes (*Meloidogyne* spp.) are globally significant, polyphagous plant parasites that affect many flowering plants, including economically important crops (Khan et al., 2023). These nematodes are ubiquitous, sedentary endoparasites thriving in moist sandy soils and warm temperatures. Optimal plant penetration by RKN occurs between 10 and 35 °C, with the highest activity at around 27 °C. Eggs are not laid at temperatures below 14.2°C or above 31.7°C. Typically, a female RKN can produce 300 to 800 eggs, with a new generation arising within 25 to 40 days, depending on environmental conditions. The life cycle includes six developmental stages: Eggs, four juvenile stages, and adults (Jagdale et al., 2021; Khan et al., 2023; Yigezu Wendimu, 2021).

The *Meloidogyne* species exhibit sexual dimorphism, where females are pear-shaped and males are vermiform. Females range from 350 µm to 3 mm in length, while males are about 1.2 to 1.5 mm long and have a cylindrical body (Yigezu Wendimu, 2021). The second-stage juvenile, which is the infective stage, is annulated and vermiform, measuring between 250 and 600 µm. These nematodes use a stylet to puncture plant cells, with the stylet containing an opening near the tip leading to a lumen continuous with the esophageal tube (Yigezu Wendimu, 2021).

Root-knot nematodes infect young feeder roots, causing gall-like swellings due to stimulated cell division and enlargement. Reproduction occurs mainly during the short and long rainy root-growth periods. Root-knot nematodes secrete various effectors, including enzymes and proteins, from their esophageal glands, which alter the host's cellular processes to form giant cells (GCs) essential for nematode feeding and development (Jagdale et al., 2021; Yigezu Wendimu, 2021). By understanding RKN biology, lifecycle, and plant interactions, effective strategies may be established to help mitigate their impact on potato production.

2

.2.2 Root-knot nematode life cycle

Root-knot nematodes exhibit a life cycle (see Fig. 2.1) and population dynamics that are influenced by several environmental factors. The length of their life cycle and population growth rate depend on soil temperature, host suitability, and soil type. At the optimal temperature of 27 °C, a generation can be completed in about 21 to 25 days on a suitable host, but this period extends to at least 87 days at 19 °C. Less suitable hosts also lengthen the nematode's life cycle. Sandy, organic muck, and peat soils are more conducive to nematode population growth compared to heavier clay soils (Jagdale et al., 2021).

Root-knot nematodes lay between 300 and 800 eggs in gelatinous sacs that protect the eggs from dehydration. These nematodes primarily reproduce through mitotic parthenogenesis. The eggs hatch based on temperature conditions, releasing second-stage juveniles (J2s) that migrate through the soil to locate and penetrate host plant roots, typically in the soft tissue behind the root tip (Jagdale et al., 2021). During penetration, J2s release cell wall-breaking enzymes such as cellulases and pectinases, which make it

easier for them to get into the roots. Once it gets inside the root, the J2 makes a permanent feeding site by activating the formation of giant cells (GCs) by injecting proteins made by their esophageal glands (Jagdale et al., 2021). These proteins manipulate the plant cells to form multinucleate structures that provide nutrients to the nematode (Jagdale et al., 2021). J2s can survive in the soil for up to a month and need to penetrate the root to develop into adults. The effectors secreted by RKNs, primarily from the sub-ventral and dorsal esophageal glands, are crucial for manipulating host cell biology and establishing feeding sites (Jagdale et al., 2021). Effectors play a significant role in RKN parasitism, helping nematodes evade plant defenses and alter plant cell function to create and maintain GCs. These effectors include enzymes and proteins that degrade cell walls, suppress host immune responses, and modify plant cell cycles and metabolism. Additionally, RKNs undergo moulting as part of their life cycle, which involves shedding their cuticles to grow. In some cases, RKNs can exhibit sex reversal, where females can transform into males under certain environmental conditions. Understanding these aspects of the nematode life cycle is crucial in establishing effective strategies to manage RKNs, contributing to improved potato production.

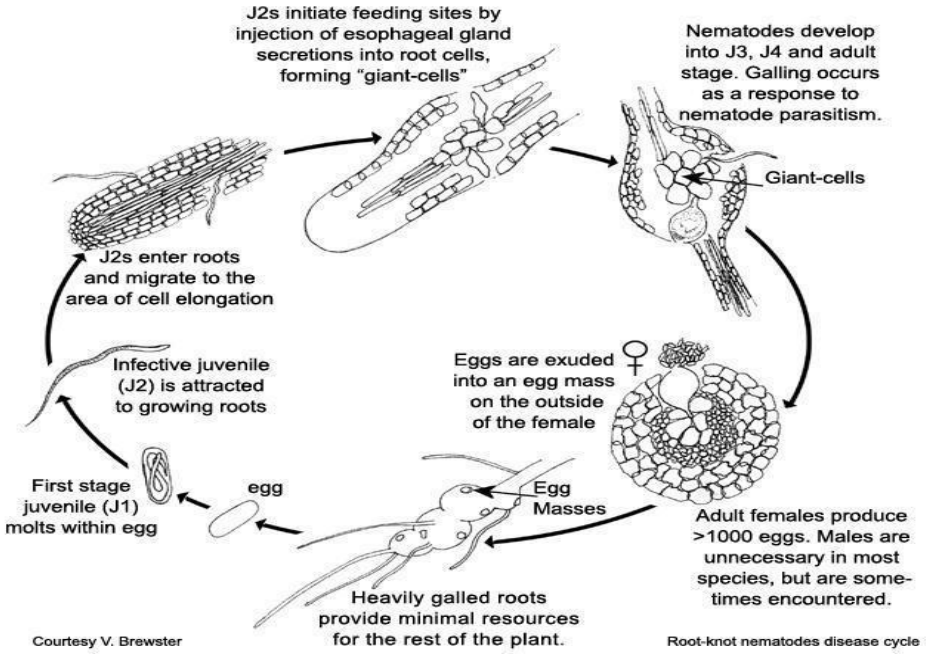

Figure 2. 1: Root-knot nematode life cycle

(Source: www.aspnet.org)

2

.2.3 Damages

Nematode feeding and penetration of roots may cause direct or indirect damage. Direct attacks occur when the nematodes penetrate plant roots, inducing the formation of GCs and disrupting the normal physiological functions of the roots (Jagdale et al., 2021). According to Cao et al. (2023), indirect attacks involve the alteration of soil microbial communities and nutrients cycling, leading to further stress on the host plants. Root-knot nematodes interact with other pathogens, such as *Ralstonia solanacearum* and plant symbionts like *Rhizobium spp*., by creating entry points and stress conditions that facilitate pathogen infection and colonization (Costa et al., 2021; Sundaresh et al., 2017). The nematode-induced damage to root tissues can enhance the susceptibility of plants to Ralstonia solanacearum, a bacterial pathogen that causes bacterial wilt, by providing entry sites and conducive conditions for the bacteria to thrive (Sundaresh et

al., 2017). In addition, the presence of nematodes can disrupt the beneficial symbiotic relationship between plants and Rhizobium spp., which is crucial for nitrogen fixation (Costa et al., 2021). This disruption can impair the plant's nitrogen uptake and overall health, exacerbating the damage caused by nematode infestation and leading to reduced plant growth and productivity.

Fig. 2.1 demonstrates hyperplasia or hypertrophy of the root tissue surrounding the nematode feeding site, resulting in galls or root knots, depending on the nematode species, host species, and cultivar of the host crop. The infestation of RKN kills the affected roots. Consequently, the plant will show signs of dehydration, including wilting, stunted growth, and chlorosis, and this will result in lower yields over time (Abd-Elgawad, 2020). Small pimple-like swellings cover the surface of infected tubers, which leads to higher production costs and a lower income for the farmers (NPCK, 2016). According to Kardani (2024), field symptoms of tuber infected by RKN include yellowing, stunting, wilting, brown spots, and tuber rot. Heavily infected plants show stunted growth and early maturity. Unlike in tomatoes, galling on potato roots is usually very small but severe, often escaping growers' notice (Kardani, 2024). In addition, Kardani (2024) noted that the number and size of galls vary based on the cultivar's susceptibility, population density, and favorable temperatures. RKN-infected roots alter nutrient and water uptake, leading to significantly poor growth, reduced tuber quality, and decreased yield (Kardani, 2024). As such, there is a need to mitigate RKNs to improve potato growth, enhance tuber quality, and achieve better yields.

2

.2.4 Management Practices for Root-knot Nematodes

The first step in determining the most appropriate crop management control measure is to identify the *meloidogyne* spp. (Abd-Elgawad, 2020). Different methods have been developed to reduce and manage the impact of *Meloidogyne* spp. on crop yield (Abd-Elgawad, 2020). Soil treatment with nematicides has allowed for moderate management of RKNs and increased yields. However, nematicides are increasingly being banned from the world market, leading to an increased need for alternative control tactics that are safe, economically attractive, and can be used in integrated pest management programs (IPM) (Abd-Elgawad, 2020; Azlay et al., 2023). The control of various *Meloidogyne* spp. in the soil aims to protect the crop from attack, cushion it from being predisposed to secondary infections, and achieve maximum crop yields at the end of the growing season at reduced costs (Coyne *et al*., 2006).

2

.2.4.1 Cultural control methods

Cultural practices can also be used to control *Meloidogyne* spp. The practices include developing and using resistant crop cultivars, planting clean planting material, intercropping and crop rotation, and cleaning farm implements (Azlay et al., 2023; Sikandar et al., 2020). Various mustards (e.g., *Brassica juncea var. integrifolia* or *Brassica juncea var. juncea)* can also be used as intercrops on infested fields (Ntalli et al., 2020). Continuous use of these fertilizers can decrease soil pH; thus, affecting crop growth and yields (Liliane & Charles, 2020). In their study, Subedi et al. (2020) confirmed that amending the soil with green manure and crop residues in the field would significantly reduce PPN populations. A possible reduction of these populations can be

attributed to the release of toxic compounds during the decomposition of these materials (Briar *et al*., 2016).

Crop rotation is also a cultural practice that can be used to control RKN Sikandar et al., 2020). Rotate with onions, maize, cassava, baby corn, sweet corn, millet, sorghum, sesame, or Sudan grass. A rotation system called "STRong," developed by African farmers' organic research and training (AfFOResT), an NGO in Zimbabwe, is recommended to manage RKNs (Infonet Biovision, 2022). The rotation system involves planting in rotation of a susceptible crop (e.g., tomatoes), followed by a tolerant crop (e.g., cabbage) and then a resistant crop (e.g., onions) before a return to a susceptible crop (e.g., tomatoes) (Infonet Biovision, 2022). Nevertheless, on many occasions, these techniques have limited ability to help farmers suppress RKN populations in the soil, as farmers in Kenya tend to have a typical crop rotation system, where alternate crops are also hosts of these nematode species (e.g., maize-potato rotation) or they leave volunteer potato crops in the field for one season to another. The emergence of resistant-breaking RKN has partly rendered this pest management practice ineffective; hence, designing sustainable control methods based on plant resistance remains a significant challenge (Abd-Elgawad, 2020; Azlay et al., 2023). The use of resistant cultivars to control *Meloidogyne* spp. relies on knowing precisely which species is being targeted. These resistant cultivars are also not readily available to farmers in developing countries (Sikora et al., 2018).

2

.2.4.2 Physical control methods

Physical methods such as heat treatment and solarization have been practiced in the management of RKNs but have their limitations. In protected cropping systems and intensive field crops with continuous monocultures, farmers often employ physical soil

disinfestation techniques such as steam or hot water treatments. These methods, as well as microwave soil radiation, are typically costly (Sasanelli et al., 2021; Yahaya et al., 2021). In contrast, soil solarization is more cost-effective, environmentally friendly, and therefore more popular, particularly in warmer regions.

Soil solarization is an environmentally friendly technique that increases soil temperature using solar energy and plastic films. As such, soil solarization is an effective method in controlling PPNs (Sasanelli et al., 2021; Yahaya et al., 2021). The effectiveness of soil solarization is attributed to the sensitivity of PPNs to high temperatures. Specifically, RKNs are effectively controlled, especially in plastic-covered environments where soil temperatures in the top 30 cm can be 3-5°C higher than in open fields, resulting in higher nematode mortality (Sasanelli et al., 2021). For the best results, the soil should be irrigated to reach optimal field capacity, plowed after 3-4 days, and then covered with a 30-50 µm plastic film (PE, LDPE, PVC, or EVA), with the edges sealed (Sasanelli et al., 2021; Yahaya et al., 2021). The solarization period ranges from 4 to 8 weeks, depending on solar intensity, geographical location, and soil type, with temperatures at a depth of 30-40 cm ranging from 38 to 52 °C (Sasanelli et al., 2021). The success of solarization in controlling PPNs is related to soil temperature and exposure duration. According to Sasanelli et al. (2021), this technique can be enhanced by combining it with other agronomic practices such as soil amendments, biofumigation, or anaerobic soil disinfestation. As much as physical control methods are effective in controlling PPNs such as *Meloidogyne* spp., it is essential to consider cost-effective control methods to manage RKNs; thus, lowering their negative impact on potato production.

.2.4.3 Biological control methods

Numerous antagonistic microbes have been proven to be efficient bio-control agents against RKNs (Topalović et al., 2020; Sikora et al., 2018). However, only a few of these organisms have been developed into commercial products for field application. The commercial use of bio-control agents is often limited because they show inconsistent performance in the field, tackle a narrow range of soil pests, are slower compared to synthetic pesticides, and sometimes do not complete their activity compared to synthetic pesticides. The production costs of these bio-control agents often exceed those of existing synthetic chemicals (Ayaz et al., 2023). The damage caused by RKN can be managed by applying microorganisms or compounds produced by microbes antagonistic to *Meloidogyne* spp. (Mulusa, 2021). A nematode egg parasite fungus, *Purpureocillium lilacinum,* has been used as a biological control agent for various PPNs, particularly *P. lilacinum* strain 251, for which a commercial formulation is available (Patil et al., 2022; Rajendran et al., 2020). The fungus *P. lilacinum* penetrates nematode eggs and cuticles by producing the lytic enzymes protease and chitinase. *P. lilacinum* has been proven to successfully control *M. javanica* and *M. incognita* on tomato and other vegetable crops (Khan et al., 2022) and in potato under field conditions.

Environmental pollution and the risk of developing resistance to chemical pesticides in the pathogen make it necessary to use biological agents. Major limitations in utilizing biological agents are the inconsistency, unreliable efficacy, and short shelf life of the living entities used in the formulation (Ayaz et al., 2023). Biocontrol agents such as *Pseudomonas* and *Trichoderma* have been well established in agricultural

practices for many decades. Nevertheless, research is still ongoing in inoculant production to find methods to improve advanced formulation and application in fields. Biofungicides have emerged as effective alternatives, with ongoing research exploring antifungal biomaterials and mechanisms (Mollah & Hassan, 2023). *Trichoderma harzianum* has been formulated as bio-fungicides in various carrier materials, including wheat bran, rice bran, maize bran, and sawdust (Mollah & Hassan, 2023); rice straw, chickpea bran, grass pea bran, rice coarse powder, and black gram bran (Sinha et al., 2022); cow dung, poultry manure, ground nutshell, black ash, coir waste, spent straw from mushroom bed, talc, and vermiculite (Mollah & Hassan, 2023). Other inert solid carriers that can also be used in the formulations are bentonite, kaolin, perlite, phytosil, talc, vermiculite, and zeolite (Ayaz et al., 2023). Conventionally used solid and liquid formulations encompass several problems with respect to the low viability of microorganisms during storage and field application. However, there is also a lack of knowledge regarding the best carrier in conventional formulations. Immobilization of microorganisms improves their shelf-life and field efficacy (Khan et al., 2023). The carrier material should have some properties, such as being non-toxic, eco-friendly, cheap, having no harmful effect on plant health, being a biocontrol agent, and being easily available. Fungal spores of biocontrol agents like *Beauveria bassiana*, *Metarhizium anisopliae*, and *Trichoderma* spp. can be encapsulated using natural polymers such as starch.

The utilization of a field-deployable, nutrient-rich, biodegradable lignocellulose matrix derived from banana fiber represents a significant innovation in the delivery of nematicides to the rhizosphere. This approach, as outlined by Cao et al. (2016), offers several noteworthy advantages. Firstly, the high lignin content of the banana fiber paper

makes it an ideal substrate for loading abamectin, facilitating a slow and sustained release of the nematicide over an extended period, as corroborated by Pirzada et al. (2020a, b). This controlled release mechanism ensures that the nematicide remains active in the soil for weeks, enhancing its efficacy in combating nematode infestations. Additionally, the use of banana paper as a carrier for nematicides offers environmental benefits. Its organic nature and biodegradability render it eco-friendly, aligning with sustainable agricultural practices. Additionally, the ready availability of banana fiber makes this technology easily accessible for farmers, potentially contributing to its widespread adoption.

One of the most compelling aspects of this approach is its ability to deliver nematicides at significantly lower dosages than in commercially recommended applications. By utilizing microdosages of abamectin, up to 1000 times lower than conventional methods, Cao et al. (2016) demonstrate the potential for effective nematode management while minimizing the environmental impact and non-target effects associated with excessive chemical usage. The technology, known as Wrap & Plant (W&P), has garnered attention for its targeted delivery of nematicides to the rhizosphere zone. This targeted approach ensures that high relative concentrations of the nematicide reach the root zone, where nematode activity is most prevalent, maximizing efficacy while minimizing off-target effects and environmental contamination. The application of Wrap & Plant is particularly promising for clonally propagated crops, as noted by Ochola et al. (2020). Preliminary results against PCN demonstrate significant potential for nematode management, indicating that this technology could offer a sustainable and effective solution for nematode control in agriculture.

In summary, the utilization of banana fiber-based matrices for the delivery of nematicides represents a novel and promising approach in agricultural pest management. With its eco-friendly nature, controlled release mechanism, and targeted delivery system, the 'Wrap & Plant' technology has the potential to revolutionize nematode control strategies, offering farmers an effective and sustainable solution for nematode management while minimizing environmental impact. Further research and field trials are warranted to fully assess the efficacy and practicality of this innovative technology across different crops and farming systems.

2

.2.2.4 Chemical control methods

Chemical control methods use various inorganic mixtures to either kill RKNs or stop them from reproducing in soils where they are present. In RKN control programs, nematicides are usually the most effective method of controlling high levels of RKNs on various farms. Although chemical nematicides effectively manage RKN (Desaeger et al., 2020), they are usually expensive, of limited availability, challenging to store, and have adverse health and environmental effects (Touray et al., 2021). Besides, these can lose their efficacy after prolonged use. The continued use of chemical nematicides can lead to some level of resistance to the target nematode species (Desaeger et al., 2020). The resistance may be because of selection pressure on the parasitic nematodes that are already in the RKN populations' genetic pool (Páez, 2023). Most attention should be directed towards optimizing sustainable nematode management strategies to increase crop yield and quality while reducing reliance on synthetic pesticides (Shrestha, 2023). Abamectin, a natural soil bacterium *Streptomyces avermitilis* fermentation product, is

used to control mites and insects' pests of citrus, nut tree crops, pear, leafy vegetables, fruiting vegetables, plum, prune, avocado, mint, and basil (Khalil & Darwesh, 2019).

Abamectin is also a promising nematicide with strong activity against a wide variety of PPNs and is marketed for use on a range of crops (Cao et al., 2020). Therefore, a new formulation is used as seed treatment under the trade name Tervigo®, and it is essential in protecting plants from insects and plant-parasitic nematodes, which attack the root system in the initial growing phase and are mainly used on ornamental crops. Abamectin was evaluated against plant-parasitic nematodes as a seed treatment, soil drench application, and root dipping against several genera of nematodes such as *Meloidogyne incognita, M. arenaria, M. javanica, Tylenchulus semipenetrans, and Rotylenchulus reniformi*s (Khalil & Darwesh, 2019). Abamectin (Vertemic 1.8% EC) as soil application proved its nematicidal activity suppressing *Meloidogyne* spp., on different vegetable crops (Liu et al., 2023). Avermectin B1 was found to reduce *Hoplolaimus galeatus* significantly and *Tylenchorhynchus dubius* after 14 and 28 days of treatment (Sasanelli et al., 2020). The gall rating and egg counts of *M. javanica* were reduced when different concentrations of abamectin were injected into the pseudostem of the banana. El-Saadony et al. (2021) proved the activity of abamectin against bud and leaf nematodes (*Aphelenchoides ritzemabosi*) in vitro and in vivo. Abamectin utilized as a seed treatment to coat cucumber seeds reduced the penetration of *Meloidogyne incognita* juveniles within the roots at 0.3 mg a.i./seed (approximately 20 g/ha) (El-Marzoky et al., 2022).

The objectives of the current study include (a) evaluating the effect of banana paper as a carrier for abamectin and *Trichoderma* on potato yield, (b) evaluating the effect of banana paper as a carrier for abamectin and *Trichoderma* on potato growth, and (c)

evaluating the efficacy of banana paper as a carrier for abametcin and *Trichoderma* to manage RKN populations on potato. The methodology utilized to examine the efficacy of banana paper as a carrier for abamectin and *Trichoderma* is discussed in the next chapter. Chapter 3 will contain details on the field area, experimental procedures, establishment of trials, the test host plant, treatments, data collection, and data analysis.

CHAPTER THREE: MATERIALS AND METHODS

The research activities were conducted both in the field (field trials) and in the screen-house (pot trials). Chapter two contained a discussion of pertinent literature on the topic. Chapter 3 contains details on the field area, experimental procedures, establishment of trials, the test host plant, treatments, data collection, and data analysis.

3.1 Study Site

The field trials were conducted in Mwea sub-county (Kirinyaga County), located at the foothills of Mount Kenya, approximately 90.5 km from Nairobi. The study area is characterized by a tropical climate with an annual average temperature of 20.9° C (minimum average) and 21.2° C (maximum average) and an annual average rainfall of 900-1200 mm with 285-300 rainy days throughout the year (Jaetzold & Schmidt, 1983). Mwea soils are predominantly black cotton soils. Under these agro-ecological conditions, the experiment was conducted under rain fed conditions during the long rains between April and July (2017); Two field trials were conducted in the long rain season (2018). The precise location of the experimental farm (latitude, longitude and altitude) that was selected to conduct the trials was determined using a GPS device.

The experiment in pots was conducted in a screen-house placed at Kenyatta University (KU) farm (Nairobi County). The KU campus is located in the central highlands of Kenya in the former Central Province, at approximately 18 km from Nairobi (1.14618º E and 36. 96649º S) at 1300-1500 m above sea level. The mean annual temperature in the county is 26° C with temperatures ranging from 7° C (average minimum) to 34° C (average maximum) (Kenyatta University, 2022). Pot trials were conducted from October to December 2017.

3.2 Experimental procedures

3

.2.1. Site selection

The suitability of a field to be used for experimental purposes was based on the presence and abundance of infective juveniles of *Meloidogyne* spp. in the soil. The overall area under research was demarcated, and six composite samples were collected randomly within and across this area. To assess the presence of root-knot nematodes in the soil, 10 soil samples were collected using a hand trowel at a depth of 20- 30 cm. Soil was collected from random points within the experimental area with the aim of producing a 1 kg composite soil sample that was placed in a transparent Ziploc® bag. Each soil sample was labeled carefully and stored in a portable cooling box to avoid desiccation.

After collection, the presence/absence of RKN (and any other PPN species) and the actual infestation levels of the soil (J2/g of soil) were assessed by extracting the mobile-infective J2s from 200 cc of soil using a modified Baerman tray (extraction tray method) following protocols by Coyne *et al.* (2007). Samples were sieved using a 1 mm mesh sieve to remove non-soil particles and eliminate soil clods. To set up a modified Baerman tray, a plastic sieve, a paper towel and a plate were required. The sample is spread on a paper towel and immersed halfway in water to collect motile juveniles after 48 hours. The nematode suspension containing the second stage juveniles (J2s) collected in the Modified Baerman trays was poured into a 25 µm sieve and backwashed using a running water source into a beaker. The initial suspension was then concentrated from 40 ml to 10 ml by backwashing the nematodes with a test sieve with running water.

An aliquot of 2 ml of the concentrated nematode suspension was then be pipetted into a gridded nematode counting dish and placed under a dissecting microscope (Olympus-

CX 22) at ×40 magnification and viewed to identify the nematodes and their diversity. Counting of the nematodes was done in a systematic manner, following the gridlines on the dish Nematodes were identified and counted from three aliquots per sample, and the mean was calculated for the combined aliquot score. After identification and counting, the nematodes were returned to the suspension. Based on the results, and upon confirmation that the selected site has the target nematode genus (*Meloidogyne* spp.) and significant infestation levels (>50 J2/200 cc soil), one experimental farm was selected for the implementation of the trial in Mwea. Further to this, farmer(s) were interviewed to establish the cropping history of the field (e.g., prior crops planted in the site), the agronomic practices applied (e.g., use of chemical pesticides, type of labor) and to have a better understanding of the farmer's knowledge of nematodes and their control.

The field trials were conducted before the pot trials, primarily because field trials provide a more realistic and representative environment for assessing the performance of the treatments. In the field, plants are subjected to natural conditions such as varying weather, soil types, and pest pressures, which can significantly influence treatment efficacy and plant growth. By conducting field trials first, the treatments' performance under real-world conditions and their practical applicability in agricultural settings were effectively assessed.

3

.2.2. Establishment of trials

3

.2.2.1. Field trials

In the field trials, treatments were arranged in a complete randomized block design (CRBD) with four replications per treatment. Plots were prepared by hand-hoe and measured 4 x 4 m with a 1 m buffer between blocks and between plots within a block. Each plot contained 65 plants, spaced 30 cm within a row, with rows spaced 75 cm apart (see Plate 2.1). A pre-plant application of diammonium phosphate (DAP) fertilizer was thoroughly mixed into the soil at a rate of 800 g per plot (500 kg/ha).

Prior to the establishment of each treatment in the experimental field, every individual plot was sampled to determine its (Pi) before the onset of the trials, following the procedures described in Section 3.2.1. Soil samples were collected from each plot using a random sampling technique. Specifically, soil was taken from five random points within each plot to form a composite sample weighing 200 grams per plot. Soil samples were labeled carefully, stored in a cool box, and transferred directly to the NemAfrica laboratory, Nairobi, for processing. Samples were thoroughly mixed and sieved through a 1 mm mesh sieve before removing a 200 ml soil sub-sample from each sample for nematode extraction over 48 h using a modified Baermann tray method (Coyne et al., 2018b). Nematode suspensions were concentrated to 10 ml in plastic beakers using a 25 qm aperture sieve, identified to genus level, and counted from a 2 ml aliquot in a counting dish under a dissecting microscope (Olympus-CX 22) at × 40 magnification. In addition, the characteristics of the soils in both field site were established prior to planting (see Appendix 1 and 2).

Plate 2. 1: Potatoes wrapped in banana paper planted in 4x4m plots

3

.2.2.2. Pot trials

The pot trial included ten replicate plants (cv. Shangi) per treatment, with a single seed tuber planted per 5 L capacity pot filled with autoclaved soil: sand (1:1). The six treatments, as used in the field trials, were arranged in a complete randomized design on the floor of the screen house. All treatments were administered in the same manner and at the same application rates as for the field trials. One day before treatment application, all pots were moistened to their carrying capacity. Diammonium phosphate (DAP) was applied at planting with 12.5 g/pot (500 kg/ha) by mixing into the soil prior to planting. The *Meloidogyne* spp. inoculum was sourced from infested tomato roots obtained from the field. For the inoculum, galled roots were uprooted from an infested crop in the field. Roots were transported to the laboratory and were gently washed free of soil. The roots were surface sterilized using 1.5% sodium hypochlorite (NaOCl) to

ensure that no other nematodes were on the surface of the roots. The roots were blended and macerated using a food blender at 1,000 rpm for 5 minutes. The macerated roots were then incubated for one week in the laboratory at room temperature, using modified Baerman trays aimed at collecting the J2s. The freshly hatched J2s obtained from the RKN cultures were pooled and recovered daily into fresh tap water for 23 days until enough inoculum was available for all 60 pots. The inoculum was counted under the dissection microscope, pooled and diluted to 250 J2/20 ml. Species were not identified, although the predominant species tend to be M. incognita and M. javanica (dos Santos et al., 2019). Each pot was inoculated at planting with 250 freshly hatched *Meloidogyne* spp. by pipetting 20 ml aqueous suspension into two small holes of 0.5 cm diam. and 5 cm deep. Following planting, pots received no irrigation for two days to enable treatments and nematodes to settle, commencing with irrigation on the third day with 500 ml/pot daily until harvest. The trial was conducted once.

3.3 Application of Treatments

The study included six treatments: (1) banana paper impregnated with 100 ng abamectin/sheet (~0.8 ng/cm^2 of abamectin), (2) banana paper impregnated with *T. asperellum,* (1×10^9 cfus /ml), (3) untreated banana paper, (4) soil drenching with commercial abamectin at the recommended rate of 8 L abamectin/ha (12.8 ml/20 L water) (5), soil drenching with commercial *T. asperellum* applied at the recommended rate of 4 ml/L ($4x10^9$ cfu/ml) water and 200 ml/ha, (6) untreated control (farmer practice) (Table 3.1). For banana fiber paper treatments, potato seed tubers (cv. Shangi) were wrapped in sheets (220 x 170 mm) and planted directly into the soil. Abamectin was applied to banana paper by spraying a water suspension with 12.8 ml/20 L of abamectin to deliver 100 ng of abamectin/sheet. *T. asperellum* was applied to banana paper using 4 ml/L per plant, which delivered 1×109 cfu/ml of *T. asperellum*/ml/plant.

Abamectin was applied directly to the soil around the potato seed, with half applied into the planting hole, and the remainder onto the surface after covering the seed with soil to ensure a homogeneous distribution. *T. asperellum* was applied into the planting hole at planting to deliver 4 ml of the treatment before being covered with soil. The untreated control reflected regular farmer planting conditions without paper or treatment.

Table 3.1: Treatments and their Application Modes

Paper presence	Active ingredient	Treatment	Application mode	Application dose
With paper	Paper	Control paper	Wrapping	Ø
	Abamectin	Impregnated paper	Wrapping	100 ng/sheet
	Trichoderma asperellum (TR900)	TR900+ paper	Wrapping and treating with *Trichoderma*	0.2 l/ha
Without paper	Abamectin	Tervigo®	Deliver treatment to the seed directly	8 l/ha
	Trichoderma asperellum	TR900	Deliver treatment to the seed directly	0.2 l/ha
	Untreated control	None	No treatment	Ø

3.4 Experimental layout

The field was divided into 4 x 4 m plots (16 m^2) with 1 m of buffer area around each plot. There were a total of 24 plots for the field. The treatments were then applied in a complete randomized block design (CRBD) to control any variation in the trials by

accounting for spatial effects in the field, e.g., differences in fertility or drainage in the field.

3.5 Data collection

At harvest, the number of stems per plant, tuber number and root and tuber fresh weights were recorded per pot and per plant for each field plot. Nematode soil densities were assessed at harvest (Pf) for each plot in field trials from a 200 ml sub-sample of soil samples removed from each plot, as above for Pi. Nematode multiplication (reproductive factor) was calculated for the field and pot soils by dividing soil Pf by Pi. Freshly harvested roots from five plants per plot were rinsed under water, dabbed dry and chopped into small pieces before removing a 5 g sub-sample for nematode extraction. Nematodes were examined under the compound microscope, identified to genus level, and counted as above.

3.6 Data analysis

All data were analysed using R (Version 4.2.3) statistical software (R Core Team, 2023). For the field trials, data for: RKN (Pi and RF), tuber weight, tuber number, and stem number were subjected to a two-way analysis of variance (ANOVA) to investigate the main and interaction effects of season and treatment on each parameter (see Appendix 3-8). Prior to analysis, tuber weight data were square-transformed to conform to the requirements for normality (Shapiro-wilk test:$p \leq 0.05$) and homogeneity of variances (Levene's test: $p \leq 0.05$); data for other parameters were not transformed. When significant effects were detected at $p \leq 0.05$, group means were separated using Tukey's Honest Significant Difference (Tukey-HSD) test.

CHAPTER FOUR: RESULTS

4.1. Evaluation of the Efficacy of Banana Paper Impregnated with abmectin or *Trichoderma* on Potato Yield

4

.1.1 Field trials

In the field trials, *Trichoderma*-paper consistently had the highest tuber weights ($p \leq 0.05$) (6.8), followed by *T. asperellum* (6.6) and abamectin-paper (6.5), while the untreated control yielded the lowest (5.0) ($p \leq 0.05$) in season 1 (Table 4.1). Notably, there was no significant difference in the number of tubers per plant among the *Trichoderma*-paper, *T. asperellum*, and abamectin-paper treatments. However, the untreated control significantly lagged behind all other treatments in terms of tuber count per plant.

In season 2, abamectin-paper had the highest number of tubers, followed by *Trichoderma*-paper and *T. asperellum* (Table 4.1). Similar to season 1, no significant difference was observed in the number of tubers per plant among the abamectin-paper, *Trichoderma*-paper, and *T. asperellum* treatments, with the untreated control consistently displaying the lowest tuber count per plant (Table 4.1).

In season 1, *Trichoderma*-paper (594.1) recorded the highest tuber yield, followed by T. asperellum (596.5). Contrastingly, the untreated control yielded significantly fewer tubers compared to all other treatments (Table. 4.1). In season 2, *Trichoderma*-paper (579.7), abamectin-paper (585.5), and *T. asperellum* (526.2) demonstrated a significantly higher tuber yield ($p \leq 0.05$) compared to all other treatments. Similar to

season 1, the untreated control displayed a markedly lower tuber yield compared to all other treatments in season 2 (Table 4.1).

Table 4.1: The Effect of Banana Paper Impregnated with Abamectin or Trichoderma on Potato Yield in the Field Trials

Treatments	Mean tubers number per plant (field trial)		Mean tuber yield per plant (g) (field trial)	
	Season 1	**Season 2**	**Season 1**	**Season 2**
Untreated control	5.0b	5.3b	271. 2d	236.1d
Paper-control	5.9ab	5.7b	430.9c	443.5c
Trichoderma asperellum	6.6a	6.7a	596.5a	526.2b
Trichoderma-paper	6.8a	6.9a	594.1a	579.7a
Abamectin	5.8ab	5.4b	467.3bc	468.4c
Abamectin-paper	6.5a	7.2a	495.9b	585.5a
LSD	0.95	0.96	54.16	36.55

Means with the same letter in a column are not significantly different. Means were separated using the LSD method at $p \leq 0.05$.

4

.1.2 Pot trials

In the pot trials, abamectin-paper had the highest tuber number, followed by *Trichoderma*-paper, and *Trichoderma asperellum* (Table 4.2). The untreated control had a significantly lower number of tubers compared to all other treatments. In addition, abamectin had a significantly high tuber yield ($p \leq 0.05$), followed by *Trichoderma*-paper (Table 4.2). The untreated had the lowest tuber yield compared to all other treatments. However, there were no significant differences between the untreated control, paper control, abamectin, and *Trichoderma asperellum*.

Table 4.2: The Effect of Banana Paper Impregnated with Abamectin or Trichoderma on Potato Yield in the Pot Trials

Treatments	Tuber Number	Tuber yield
Untreated control	2.0c	4.2c
Paper-control	4.4b	16.8bc
Trichoderma asperellum	4.8ab	9.9c
Trichoderma-paper	5.3ab	40.6a
Abamectin	2.8c	23.6b
Abamectin-paper	5.9a	49.2a
LSD	2.21	10.38

Means with the same letter in a column are not significantly different. Means were separated using the LSD method at $p \leq 0.05$.

4.2 To evaluate the efficacy of Banana paper impregnated with Abamectin or Trichoderma on potato growth

4

.2.1 Field Trials

In the field, no differences ($p \leq 0.05$) were observed in root fresh weight between treatments in season 1, while in season 2, root fresh weight was significantly higher in the abamectin-paper treatment than all other treatments (Table 4.3). The untreated control had a significantly low root fresh weight compared to all other treatments.

The number of stems per plant in season 1 was significantly ($p \leq 0.05$) higher in the *Trichoderma*-paper treatment, followed by abamectin-paper (Table 4.3). The untreated control had the lowest number of stems, which was not a significant difference from the *Trichoderma asperellum* treatment. In season 1, the untreated control treatment had the lowest number of stems per plant compared to all other treatments. In season 2, the *Trichoderma*-paper treatment had the highest number of stems per plant compared to all other treatments, while the untreated control had the least (Table 4.3).

Table 4.3: The Effect of Banana Paper Impregnated with Abamectin or Trichoderma on Potato Growth in the Field Trials

Treatments	Root fresh weight/plant (g) (Season 1)	Root fresh weight/plant (g (Season 2)	Mean number of stems/plan (Season 1)	Mean number o stems/plant (Season 2)
Untreated control	2.5a	3.1c	5.60b	5.73b
Paper-control	2.6a	6.1b	6.43a	5.79b
Trichoderma asperellum	2.5a	5.6b	6.27ab	6.89a
Trichoderma paper	2.7a	6.1b	6.84a	7.04a
Abamectin	2.7a	5.4b	6.46a	5.80b
Abamectin-paper	2.7a	9.2a	6.55a	6.07b
LSD	0.38	1.50	0.82	0.64

Means with the same letter in a column are not significantly different. Means were separated using the LSD at $p \leq 0.05$.

4.2.2 Pot trials

No differences ($p \leq 0.05$) were observed in root fresh weight between treatments in the pot trial (Table 4.4). Abamectin-paper had the highest root fresh weight compared to all other treatments. Contrastingly, the untreated control had the lowest root fresh weight compared to all other treatments (Table 4.4).

In the pot trial, the abamectin-paper had a significantly higher ($p \leq 0.05$) number of stems per plant compared to all other treatments (Table 4.4). The untreated control had a significantly lower number of stems per plant ($p \leq 0.05$) compared to all other treatments (Table 4.4).

Table 4.4: The Effect of Banana Paper Impregnated with Abamectin or Trichoderma on Potato Growth in the Pot Trial

Treatments	Root fresh weight/pot (g) (Pot trials)	Mean number of stems/pots (Pot trials)[2]
Untreated control	1.5c	1.8d
Paper-control	3.3b	2.4cd
Trichoderma asperellum	3.5b	2.6bcd
Trichoderma paper	4.7a	3.4abc
Abamectin	3.2b	3.65ab
Abamectin-paper	5.3a	4.25a
LSD	1.61	1.61

Means with the same letter in a column are not significantly different. Means were separated using the LSD at $p \leq 0.05$.

4.3 To evaluate the efficacy of banana paper impregnated with Abamectin or *Trichoderma* in managing RKN populations

4.3.1 Field trials

In the field trials, abamectin paper had the lowest RKN populations compared to all other treatments (Table 4.5). Contrastingly, the untreated control had a significantly high RKN population ($p \leq 0.05$) compared to all other treatments (Table 4.5).

Table 4.5: The effect of banana paper impregnated with Abamectin or Trichoderma in managing RKN populations

Treatments	Reproduction factor (Season 1)	Reproduction factor (Season 2)
Untreated control	1.40a	1.90a
Paper-control	0.38b	0.55b
Trichoderma asperellum	0.21b	0.28c
Trichoderma paper	0.42b	0.27c
Abamectin	0.25b	0.31c
Abamectin+paper	0.06b	0.20c
LSD	0.50	0.28

Means with the same letter in a column are not significantly different. Means were separated using the LSD method at p≤0.05.

4

.3.2 Pot Trials

In the pot experiment, the RKN multiplied in all treatments. However, the abamectin-paper had a significantly low RKN population (p≤0.05) compared to all other treatments. (Table 4.6). Contrastingly, the untreated control had a significantly high (p≤0.05) RKN population compared to all other treatments.

Table 4.6: Root knot nematode densities and reproduction factor on potato at harvest of pot trials in Kenya

Treatments	Reproduction factor (Pot trials)
Untreated control	12.7a
Paper-control	4.5cd
Trichoderma asperellum	8.3b
Trichoderma paper	7.1bc
Abamectin	7.6b
Abamectin+paper	1.7e
LSD	5.56

Means with the same letter in a column are not significantly different. Means were separated using the LSD method at p≤0.05.

CHAPTER FIVE: DISCUSSIONS

5.1 Evaluation of the Efficacy of Banana Paper Impregnated with abmectin or Trichoderma on Potato Yield

The results from both field and pot trials provide valuable insights into the efficacy of different treatments in influencing potato tuber production. In the field trials, *Trichoderma*-paper consistently demonstrated superior performance in terms of tuber weights, with significantly higher values compared to *T. asperellum*, abamectin-paper, and the untreated control in season 1. This suggests that the application of Trichoderma incorporated into paper matrices effectively enhanced tuber growth. Similarly, in season 2, while abamectin-paper exhibited the highest number of tubers, *Trichoderma*-paper still maintained competitive tuber weights, indicating its sustained efficacy across seasons. Notably, the untreated control consistently yielded the lowest tuber weights and counts, highlighting the importance of treatment interventions in promoting potato productivity.

The pot trial results further corroborate the positive impact of treatments on tuber production. Abamectin-paper emerged as the most effective treatment, yielding the highest tuber numbers and significantly outperforming the untreated control. Additionally, both abamectin-paper and *Trichoderma*-paper treatments demonstrated significantly higher tuber yields compared to the untreated control, underscoring the potential of these interventions in improving potato crop productivity. However, there were no significant differences observed between the untreated control, paper control, abamectin, and *Trichoderma asperellum* in terms of tuber yield, suggesting that these treatments may have had limited impact on tuber production under the specific conditions of the pot trials

Based on the findings of this project, applying either abamectin or *Trichoderma* through the Wrap & Plant platform resulted in a doubling of potato yields in RKN infested fields. A particularly appealing feature of the banana fiber paper is its ability to adsorb ultra-low dosages of chemical compounds, such as abamectin, enabling the slow release of much lower field application levels of nematicides than recommended application rates (Cao et al., 2016). This approach enables the delivery of a low, but effective dosage of abamectin. For example, it is estimated that the field delivery of abamectin using banana fiber paper is approximately 1000 times lower than the recommended application rates of the commercial product (Ochola et al., 2020; Ochola et al., 2022). In the current trials, abamectin-paper was similarly effective as the recommended application rates of abamectin-alone at reducing nematodes but led to better tuber yields than abamectin alone. This provides a much more cost effective and environmentally sensitive management option for RKN than the conventional application of synthetic pesticides. Also, banana paper is an organic material and is made from the leftovers of the banana plant, mainly the rachis, therefore it also acts as a soil amendment when used. Banana residues being organic in nature are a rich source of macro and micronutrients. Banana residues also improves soil texture, structure, water holding capacity, permeability and productivity of the soil (ElNour *et al.,* 2015). This can explain why the tubers though not many in number were well nourished and large in size when banana paper impregnated with abamectin was used as compared to when abamectin alone was applied. Korayem *et al*. (2008) also found that apart from abamectin significantly reducing most nematode parameters at the tested concentrations, it also enhanced plant growth parameters.

5.2 To evaluate the the efficacy of banana paper impregnated with Abamectin or Trichoderma on potato growth

The findings suggest that abamectin-paper may have resulted in a sustained release of the treatment over a long time, leading to better root growth compared to the other treatments. Additionally, the presence of *Trichoderma asperellum* on the banana paper may have contributed to improved nutrient uptake and overall plant health. The findings of this project are consistent with those of El-Marzoky et al. (2022), who found that abamectin treatment led to increased plant growth and stem production in similar plant species. These results suggest that abamectin may have a positive impact on plant growth and development, potentially due to its effects on pest control and overall plant health.

In addition, the results are consistent with those of Harman et al. (2004), who found that *Trichoderma* enhances root proliferation, therefore enhancing the growth of the plant. The results obtained in this project also uphold the results observed by Waghunde et al. (2016), who observed that *Trichoderma* improves photosynthetic activity of the plant, alleviates uptake of nutrients in plants, enhances plant growth and also promotes nitrogen-use efficiency.

5.3 To evaluate the the efficacy of banana paper impregnated with Abamectin or *Trichoderma* in suppressing RKN populations

The abametin-paper may have been effective in suppressing RKN by disrupting chemical communication between the nematode and the plant. The high lignin of the banana paper make it suitable for loading abamectin followed by a slow, sustained release over weeks. Upon hatching from the eggs in the soil, J2s must successfully locate a host plant to invade and infect for them to survive and complete

their life cycle. Root exudates from the host plant attract J2s to the host plant. As such, the banana paper may have acted as a barrier between the nematodes and the plant, preventing the RKN from sensing the root exudates. By disrupting the chemical communication between the nematode and the plant, the banana paper could potentially hinder the J2s from locating and infecting a host plant, ultimately reducing their survival rate.

Previous findings indicate that banana paper as a carrier for control agents is effective in the management of plant-parasitic nematodes such as potato cyst nematodes (PCN) (Globodera spp.) on potato (Ochola et al., 2022). These findings further underscore the efficacy of abamectin-paper in controlling RKN infestations, even under controlled conditions. The current study further supports earlier studies assessing the efficacy of abamectin impregnated banana fiber paper against *G. rostochiensis* on potato (Ochola et al., 2022). Similarly, Khalil and Darwesh (2019) argued that abamectin is an effective nematicide for significantly reducing PPNs in various crops. The rate of abamectin release is dependent on the paper's chemical compositions of lignin, hemicellulose, and cellulose, and the corresponding distribution of each component (Cao et al., 2016). The higher lignin content in the bulk of the banana paper enabled the slow and sustained release of loaded abamectin (Cao et al., 2016; Ochola et al., 2022). Abamectin has poor mobility in soil due to its hydrophobicity and because it has strong affinity to organic matter. Although it binds tightly to banana paper, it is slowly released over time from the lignocellulose matrix as the paper deteriorates and decomposes in the soil (Pirzada et al., 2020a,b; Ochola et al., 2022). While RKN can penetrate the banana paper quite readily (Pirzada et al., 2020a, b), when provided a choice in in vitro experiments, RKNs appear to avoid having to do

so. Additionally, roots and shoots readily pass through the paper, as its manufacture was designed with this trait in mind (Pirzada et al., 2020b). It has been observed that banana paper alone may help in the management of nematodes by disrupting chemical communication between the nematode and the potato plant, reducing the chances of infection and establishment in potato plants (Ochola et al., 2022). As a result, these findings emphasize the potential of abamectin-paper treatment as an effective, sustainable, and environmentally friendly approach to suppress RKNs in potato production, offering promising solutions for farmers grappling with nematode infestations in Kenya and beyond.

Trichoderma-paper significantly the reduced the number of J2s as compared to *Trichoderma* alone, paper-control and absolute-control. These results are in agreement with Sharon et al. (2007) who found that the potential ability to parasitize nematode life stages in planta was demonstrated with *Trichoderma asperellum*-203 which interacted with penetrating J2 in a sterile soil system, thereby interfering with the reproduction process. The potential parasitic capability of this isolate on the different nematode life stages may partially account for its high efficacy at reducing root galling and viable egg production in soil experiments. Apart from enhancing root proliferation and enhancing the growth of the plant, *Trichoderma* is also known to be effective against plant-parasitic nematodes. *Trichoderma* isolates have been used successfully to suppress J2 densities and egg production of Meloidogyne spp. in roots by parasitizing the egg masses and J2 within them (Sharon et al., 2007). Recent studies have shown that *T. asperellum* (isolate203) and *T. atroviridae* (previously *T. harzianum*) show suppressive activity against *M. javanica* (Viaene et al., 2013). In addition, Temitope et al. (2020) found that *T. asperellum* reduced the root-knot

nematode population and root gall index. The findings of this project indicate the potential use of banana fiber paper for delivering biologically based products such as *Trichoderma*.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The current study demonstrates that this novel technique provides an effective and environmentally sensitive mechanism to address sustainable and affordable management of RKN in Kenya. As a result, based on the objectives of this project, it is safe to conclude that banana paper as a carrier for abamectin or *Trichoderma* is effective in promoting potato yield. In addition, it may be concluded that banana paper as a carrier for abamectin or *Trichoderma* is effective in enhancing potato growth. Lastly, banana paper as a carrier for abamectin or *Trichoderma* is effective in the management of RKNs. Overall, the findings suggest that banana paper as a carrier for control agents such as abamectin and *Trichoderma* has the potential to revolutionize pest management practices in agriculture, particularly in Kenya, where RKNs pose a significant threat to potato production.

6.2 Recommendations

The take-home message for potato farmers in RKN infested areas in Kenya is that the use of banana paper as a carrier for control agents such as abamectin and *Trichoderma* shows great promise in managing RKN effectively and sustainably. This novel technique not only addresses the challenges of RKN management but also offers an environmentally sensitive solution. As a result, embracing the 'Wrap & Plant' technology could revolutionize pest management practices, potentially leading to increased yields and healthier crops for potato farmers in RKN-infested areas.

However, it is recommended that a pouch system for the Wrap & Plant platform that is more user-friendly and eases deployment in the field is developed. The advent of the pouch system will reduce labor inputs and the reduced application dosage of abamectin,

compared to commercial applications, will lower the chemical input costs. In addition, future studies should be aimed at determining why *Trichoderma* works so well in combination with banana paper. Understanding the synergistic effects of *Trichoderma* and banana paper could lead to further improvements in RKN management and plant health. Lastly, future studies should also be aimed at exploring the cost-effectiveness of the 'Wrap & Plant' technology in managing RKN. Analyzing the cost-effectiveness of this technology will provide valuable insights for farmers considering its implementation, helping them make informed decisions about adopting this innovative approach.

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APPENDICES

APPENDIX I: Soil analysis for Mwea site (2016)

SOIL TEST REPORT

Name	Laura Cortada
Address	IIRA- INT. TROP. AGRIC-ICIPE Campus
Location of farm	Mwea
Crop(s) to be grown	Potato
Date sample received	30/05/16
Date sample reported	22/06/16
Reporting officer (through Director NARL)	G.N. Gachini

	Soil Analytical Data							
Field	Mwea							
Lab. No/2016	5153							
Soil depth cm	Top							
Fertility results	value	class	value	class	value	class	value	class
* Soil pH	5.99	moderate acid						
Exch. Acidity me%								
* Total Nitrogen %	0.15	low						
* Total Org. Carbon %	1.42	moderate						
Phosphorus (Mehlich) ppm	20	low						
* Phosphorus (Olsen) ppm								
Potassium me%	1.32	adequate						
Calcium me%	13.8	adequate						
Magnesium me%	4.18	high						
Manganese me%	0.01	low						
Copper ppm	2.55	adequate						
Iron ppm	117.9	adequate						
Zinc ppm	5.88	adequate						
Sodium me%	0.90	adequate						
Elect. Cond. mS/cm	0.19	adequate						

* **ISO/IEC 17025 accredited**

Interpretation and Fertilizer Recommendation

The soil reaction (pH) is moderately acid and satisfactory for crops' growth. **Potatoes:** Apply 8 tons/acre of well decomposed manure or compost along the planting furrow mixed well with 500 kg/ha of N:P:K 23:23:0 and soil before placing the potato seeds.

NOTE: Test results are based on customer sampled sample(s).
Methods used: Information is given out on client's request.

APPENDIX II: Soil analysis for Mwea site (2017)

Kenya Agricultural & Livestock Research Organization
National Agricultural Research Laboratories
P. O. Box 14733, 00800 NAIROBI
Tel: 0202464435
Email: soilabs@yahoo.co.uk

SOIL TEST REPORT

Name	Laura Cortada
Address	ICIPE Campus - Kasarani
Location of farm	Kirinyaga
Crop(s) to be grown	Potato
Date sample received	30/5/17
Date sample reported	9/6/17
Reporting officer (through Director NARL)	N. Gachini

	Soil Analytical Data							
Field	Mwea							
Lab. No/2017	3500							
Soil depth cm	top							
Fertility results	value	class						
* Soil pH	5.93	moderate acid						
Exch. Acidity me%								
* Total Nitrogen %	0.20	low						
* Total Org. Carbon %	1.90	moderate						
Phosphorus ppm	45.00	adequate						
Potassium me%	1.24	adequate						
Calcium me%	6.90	adequate						
Magnesium me%	2.92	adequate						
Manganese me%	0.59	adequate						
Copper ppm	0.11	low						
Iron ppm	26.67	adequate						
Zinc ppm	35.78	adequate						
Sodium me%	0.77	adequate						
Elect. Cond. mS/cm								

Interpretation and fertilizer recommendation

The soil reaction is acidic. Acidifying fertilizers like DAP, AS or ASN should be avoided due to their acidic reaction. Nitrogen and copper are low. Soil organic matter is moderate. Just before planting apply 6 t/ha of manure. The manure should be well ploughed in the soil to avoid close contact with potatoes. At planting apply 350 kg/ha of CAN as basal dressing. Just before flowering spray foliar fertilizer containing copper.

NOTE: Test results are based on customer sampled sample(s).
Methods used: Information is given out on client's request.

APPENDIX III: ANOVA for Plant Growth Parameters for Pot Trials

Dependent Variable		(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
NTP	LSD	Abamectin paper	Untreated control	3.9500*	.70692	.000	2.5496	5.3504
			paper control	1.5500*	.70692	.030	.1496	2.9504
			Abamectin	3.1500*	.70692	.000	1.7496	4.5504
			Trichoderma asperellum	.6500	.70692	.360	-.7504	2.0504
			Trichoderma-paper	1.1000	.70692	.122	-.3004	2.5004
		Untreated control	Abamectin paper	-3.9500*	.70692	.000	-5.3504	-2.5496
			paper control	-2.4000*	.70692	.001	-3.8004	-.9996
			Abanectin	-.8000	.70692	.260	-2.2004	.6004
			Trichoderma asperellum	-3.3000*	.70692	.000	-4.7004	-1.8996
			Trichoderma-paper	-2.8500*	.70692	.000	-4.2504	-1.4496
		paper control	Abamectin paper	-1.5500*	.70692	.030	-2.9504	-.1496
			Untreated-control	2.4000*	.70692	.001	.9996	3.8004
			Abamectin	1.6000*	.70692	.026	.1996	3.0004
			Trichoderma asperellum	-.9000	.70692	.206	-2.3004	.5004
			Trichoderma-paper	-.4500	.70692	.526	-1.8504	.9504
		Abamectin	Abamectin paper	-3.1500*	.70692	.000	-4.5504	-1.7496

			Untreated-control	.8000	.70692	.260	-.6004	2.2004
			paper control	-1.6000*	.70692	.026	-3.0004	-.1996
			Trichoderma asperellum	-2.5000*	.70692	.001	-3.9004	-1.0996
			Trichoderma-paper	-2.0500*	.70692	.004	-3.4504	-.6496
		Trichoderma asperellum	Abamectin paper	-.6500	.70692	.360	-2.0504	.7504
			Untreated control	3.3000*	.70692	.000	1.8996	4.7004
			paper control	.9000	.70692	.206	-.5004	2.3004
			Abamectin	2.5000*	.70692	.001	1.0996	3.9004
			Trichoderma-paper	.4500	.70692	.526	-.9504	1.8504
		Trichoderma-paper	Abamectin paper	-1.1000	.70692	.122	-2.5004	.3004
			Untreated control	2.8500*	.70692	.000	1.4496	4.2504
			paper control	.4500	.70692	.526	-.9504	1.8504
			Abamectin	2.0500*	.70692	.004	.6496	3.4504
			Trichoderma asperellum	-.4500	.70692	.526	-1.8504	.9504
MTP	LSD	Abamectin paper	Untreated control	45.0570*	3.31559	.000	38.4888	51.6252
			paper control	32.4800*	3.31559	.000	25.9118	39.0482
			Abamectin	43.8135*	3.31559	.000	37.2453	50.3817
			Trichoderma asperellum	31.5535*	3.31559	.000	24.9853	38.1217
			Trichoderma-paper	39.3850*	3.31559	.000	32.8168	45.9532
		Untreated control	Abamectin paper	-45.0570*	3.31559	.000	-51.6252	-38.4888
			paper control	-12.5770*	3.31559	.000	-19.1452	-6.0088
			Abamectin	-1.2435	3.31559	.708	-7.8117	5.3247

	Trichoderma asperellum	-13.5035*	3.31559	.000	-20.0717	-6.9353
	Trichoderma-paper	-5.6720	3.31559	.090	-12.2402	.8962
paper control	Abamectin paper	-32.4800*	3.31559	.000	-39.0482	-25.9118
	Absolute-control	12.5770*	3.31559	.000	6.0088	19.1452
	Abamectin	11.3335*	3.31559	.001	4.7653	17.9017
	Trichoderma asperellum	-.9265	3.31559	.780	-7.4947	5.6417
	Trichoderma-paper	6.9050*	3.31559	.040	.3368	13.4732
Abamectin	Abamectin paper	-43.8135*	3.31559	.000	-50.3817	-37.2453
	Untreated control	1.2435	3.31559	.708	-5.3247	7.8117
	paper control	-11.3335*	3.31559	.001	-17.9017	-4.7653
	Trichoderma asperellum	-12.2600*	3.31559	.000	-18.8282	-5.6918
	Trichoderma-paper	-4.4285	3.31559	.184	-10.9967	2.1397
Trichoderma	Abamectin paper	-31.5535*	3.31559	.000	-38.1217	-24.9853
asperellum	Untreated control	13.5035*	3.31559	.000	6.9353	20.0717
	paper control	.9265	3.31559	.780	-5.6417	7.4947
	Abamectin	12.2600*	3.31559	.000	5.6918	18.8282
	Trichoderma-paper	7.8315*	3.31559	.020	1.2633	14.3997
Trichoderma-	Abamectin paper	-39.3850*	3.31559	.000	-45.9532	-32.8168
paper	Untreated control	5.6720	3.31559	.090	-.8962	12.2402
	paper control	-6.9050*	3.31559	.040	-13.4732	-.3368
	Abamectin	4.4285	3.31559	.184	-2.1397	10.9967

			Trichoderma asperellum	-7.8315*	3.31559	.020	-14.3997	-1.2633
SPP	LSD	Abamectin-paper	Untreated control	2.4500*	.51461	.000	1.4306	3.4694
			Paper-control	1.8500*	.51461	.000	.8306	2.8694
			Abamectin	.8500	.51461	.101	-.1694	1.8694
			Trichoderma-paper	1.6000*	.51461	.002	.5806	2.6194
			Trichoderma asperellum	1.6500*	.51461	.002	.6306	2.6694
		Untreated control	Abamectin-paper	-2.4500*	.51461	.000	-3.4694	-1.4306
			Paper-control	-.6000	.51461	.246	-1.6194	.4194
			Abamectin	-1.6000*	.51461	.002	-2.6194	-.5806
			Trichoderma-paper	-.8500	.51461	.101	-1.8694	.1694
			Trichoderma asperellum	-.8000	.51461	.123	-1.8194	.2194
		Paper-control	Abamectin-paper	-1.8500*	.51461	.000	-2.8694	-.8306
			Untreated control	.6000	.51461	.246	-.4194	1.6194
			Abamectin	-1.0000	.51461	.054	-2.0194	.0194
			Trichoderma-paper	-.2500	.51461	.628	-1.2694	.7694
			Trichoderma asperellum	-.2000	.51461	.698	-1.2194	.8194
		Abamectin	Abamectin-paper	-.8500	.51461	.101	-1.8694	.1694
			Untreated control	1.6000*	.51461	.002	.5806	2.6194
			Paper-control	1.0000	.51461	.054	-.0194	2.0194
			Trichoderma-paper	.7500	.51461	.148	-.2694	1.7694

			Trichoderma asperellum	.8000	.51461	.123	-.2194	1.8194
		Trichoderma-paper	Abamectin-paper	-1.6000*	.51461	.002	-2.6194	-.5806
			Untreated control	.8500	.51461	.101	-.1694	1.8694
			Paper-control	.2500	.51461	.628	-.7694	1.2694
			Abamectin	-.7500	.51461	.148	-1.7694	.2694
			Trichoderma asperellum	.0500	.51461	.923	-.9694	1.0694
		Trichoderma asperellum	Abamectin-paper	-1.6500*	.51461	.002	-2.6694	-.6306
			Untreated control	.8000	.51461	.123	-.2194	1.8194
			Paper-control	.2000	.51461	.698	-.8194	1.2194
			Abamectin	-.8000	.51461	.123	-1.8194	.2194
			Trichoderma-paper	-.0500	.51461	.923	-1.0694	.9694
MRSP	LSD	Abamectin-paper	Untreated control	3.7135*	.51285	.000	2.6975	4.7295
			Paper-control	1.9325*	.51285	.000	.9165	2.9485
			Abamectin	3.2785*	.51285	.000	2.2625	4.2945
			Trichoderma-paper	1.4670*	.51285	.005	.4510	2.4830
			Trichoderma asperellum	1.7315*	.51285	.001	.7155	2.7475
		Untreated control	Abamectin-paper	-3.7135*	.51285	.000	-4.7295	-2.6975
			Paper-control	-1.7810*	.51285	.001	-2.7970	-.7650
			Abamectin	-.4350	.51285	.398	-1.4510	.5810
			Trichoderma-paper	-2.2465*	.51285	.000	-3.2625	-1.2305
			Trichoderma asperellum	-1.9820*	.51285	.000	-2.9980	-.9660

Paper-control	Abamectin-paper	-1.9325*	.51285	.000	-2.9485	-.9165
	Untreated control	1.7810*	.51285	.001	.7650	2.7970
	Abamectin	1.3460*	.51285	.010	.3300	2.3620
	Trichoderma-paper	-.4655	.51285	.366	-1.4815	.5505
	Trichoderma asperellum	-.2010	.51285	.696	-1.2170	.8150
Abamectin	Abamectin-paper	-3.2785*	.51285	.000	-4.2945	-2.2625
	Untreated control	.4350	.51285	.398	-.5810	1.4510
	Paper-control	-1.3460*	.51285	.010	-2.3620	-.3300
	Trichoderma-paper	-1.8115*	.51285	.001	-2.8275	-.7955
	Trichoderma asperellum	-1.5470*	.51285	.003	-2.5630	-.5310
Trichoderma-paper	Abamectin-paper	-1.4670*	.51285	.005	-2.4830	-.4510
	Untreated control	2.2465*	.51285	.000	1.2305	3.2625
	Paper-control	.4655	.51285	.366	-.5505	1.4815
	Abamectin	1.8115*	.51285	.001	.7955	2.8275
	Trichoderma asperellum	.2645	.51285	.607	-.7515	1.2805
TR9000	Abamectin-paper	-1.7315*	.51285	.001	-2.7475	-.7155
	Untreated control	1.9820*	.51285	.000	.9660	2.9980
	Paper-control	.2010	.51285	.696	-.8150	1.2170
	Abamectin	1.5470*	.51285	.003	.5310	2.5630
	Trichoderma-paper	-.2645	.51285	.607	-1.2805	.7515

Based on observed means.

The error term is Mean Square (Error) = 2.630.

APPEDIX IV: ANOVA for RKN reproduction (Pot trials)

Multiple Comparisons								
Dependent Variable		(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
RKN pf	LSD	Abamectin paper	Untreated control	-2730.000*	393.91698	.000	-3510.3465	-1949.6535
			paper control	-687.5000	393.91698	.084	-1467.8465	92.8465
			Abamectin	-1387.500*	393.91698	.001	-2167.8465	-607.1535

	Trichoderma asperellum	-1452.500*	393.91698	.000	-2232.8465	-672.1535
	Trichoderma-paper	-1641.250*	393.91698	.000	-2421.5965	-860.9035
Untreated control	Abamectin paper	2730.000*	393.91698	.000	1949.6535	3510.3465
	paper control	2042.500*	393.91698	.000	1262.1535	2822.8465
	Abanectin	1342.500*	393.91698	.001	562.1535	2122.8465
	Trichoderma asperellum	1277.500*	393.91698	.002	497.1535	2057.8465

	Trichoderma-paper	1088.7500*	393.91698	.007	308.4035	1869.0965
paper control	Abamectin paper	687.5000	393.91698	.084	-92.8465	1467.8465
	Untreated-control	-2042.5000*	393.91698	.000	-2822.8465	-1262.1535
	Abamectin	-700.0000	393.91698	.078	-1480.3465	80.3465
	Trichoderma asperellum	-765.0000	393.91698	.055	-1545.3465	15.3465
	Trichoderma-paper	-953.7500*	393.91698	.017	-1734.0965	-173.4035

Abamectin	Abamectin paper	1387.5000*	393.91698	.001	607.1535	2167.8465
	Untreated-control	-1342.5000*	393.91698	.001	-2122.8465	-562.1535
	paper control	700.0000	393.91698	.078	-80.3465	1480.3465
	Trichoderma asperellum	-65.0000	393.91698	.869	-845.3465	715.3465
	Trichoderma-paper	-253.7500	393.91698	.521	-1034.0965	526.5965
Trichoderma	Abamectin paper	1452.5000*	393.91698	.000	672.1535	2232.8465

asperellum	Untreated control	-1277.5000*	393.91698	.002	-2057.8465	-497.1535
	paper control	765.0000	393.91698	.055	-15.3465	1545.3465
	Abamectin	65.0000	393.91698	.869	-715.3465	845.3465
	Trichoderma-paper	-188.7500	393.91698	.633	-969.0965	591.5965
Trichoderma-paper	Abamectin paper	1641.2500*	393.91698	.000	860.9035	2421.5965
	Untreated control	-1088.7500*	393.91698	.007	-1869.0965	-308.4035

	paper control	953.7500*	393.91698	.017	173.4035	1734.0965
	Abamectin	253.7500	393.91698	.521	-526.5965	1034.0965
	Trichoderma asperellum	188.7500	393.91698	.633	-591.5965	969.0965

Based on observed means.
The error term is Mean Square (Error) = 1551705.866.
*. The mean difference is significant at the .05 level.

APPENDIX V: ANOVA for Plant Growth Parameters (Field Trials Season 1)

Multiple Comparisons								
Dependent Variable		**(I) Treatment**	**(J) Treatment**	**Mean Difference (I-J**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
							Lower Bound	**Upper Bound**
NTP	LSD	Abamectin paper	Untreated control	1.5000*	.27737	.000	.9544	2.0456
			paper control	.6250*	.27737	.025	.0794	1.1706
			Abamectin	.7679*	.27737	.006	.2222	1.3135
			Trichoderma asperellum	-.0893	.27737	.748	-.6349	.4564
			Trichoderma-paper	-.1250	.27737	.653	-.6706	.4206
		Untreated control	Abamectin paper	-1.5000*	.27737	.000	-2.0456	-.9544
			paper control	-.8750*	.27737	.002	-1.4206	-.3294
			Abanectin	-.7321*	.27737	.009	-1.2778	-.1865
			Trichoderma asperellum	-1.5893*	.27737	.000	-2.1349	-1.0436
			Trichoderma-paper	-1.6250*	.27737	.000	-2.1706	-1.0794
		paper control	Abamectin paper	-.6250*	.27737	.025	-1.1706	-.0794
			Untreated-control	.8750*	.27737	.002	.3294	1.4206
			Abamectin	.1429	.27737	.607	-.4028	.6885
			Trichoderma asperellum	-.7143*	.27737	.010	-1.2599	-.1686
			Trichoderma-paper	-.7500*	.27737	.007	-1.2956	-.2044
		Abamectin	Abamectin paper	-.7679*	.27737	.006	-1.3135	-.2222
			Untreated-control	.7321*	.27737	.009	.1865	1.2778
			paper control	-.1429	.27737	.607	-.6885	.4028

			Trichoderma asperellum	-.8571*	.27737	.002	-1.4028	-.3115
			Trichoderma-paper	-.8929*	.27737	.001	-1.4385	-.3472
		Trichoderma asperellum	Abamectin paper	.0893	.27737	.748	-.4564	.6349
			Untreated control	1.5893*	.27737	.000	1.0436	2.1349
			paper control	.7143*	.27737	.010	.1686	1.2599
			Abamectin	.8571*	.27737	.002	.3115	1.4028
			Trichoderma-paper	-.0357	.27737	.898	-.5814	.5099
		Trichoderma-paper	Abamectin paper	.1250	.27737	.653	-.4206	.6706
			Untreated control	1.6250*	.27737	.000	1.0794	2.1706
			paper control	.7500*	.27737	.007	.2044	1.2956
			Abamectin	.8929*	.27737	.001	.3472	1.4385
			Trichoderma asperellum	.0357	.27737	.898	-.5099	.5814
MTP	LSD	Abamectin paper	Untreated control	224.6614*	17.25925	.000	190.7094	258.6135
			paper control	64.9430*	17.25925	.000	30.9910	98.8951
			Abamectin	28.5036	17.25925	.100	-5.4485	62.4556
			Trichoderma asperellum	-100.6932*	17.25925	.000	-134.6452	-66.7412
			Trichoderma-paper	-96.5254*	17.25925	.000	-130.4774	-62.5733
		Untreated control	Abamectin paper	-224.6614*	17.25925	.000	-258.6135	-190.7094
			paper control	-159.7184*	17.25925	.000	-193.6704	-125.7664
			Abamectin	-196.1579*	17.25925	.000	-230.1099	-162.2058
			Trichoderma asperellum	-325.3546*	17.25925	.000	-359.3067	-291.4026

			Trichoderma-paper	-321.1868*	17.25925	.000	-355.1388	-287.2348
		paper control	Abamectin paper	-64.9430*	17.25925	.000	-98.8951	-30.9910
			Absolute-control	159.7184*	17.25925	.000	125.7664	193.6704
			Abamectin	-36.4395*	17.25925	.035	-70.3915	-2.4874
			Trichoderma asperellum	-165.6363*	17.25925	.000	-199.5883	-131.6842
			Trichoderma-paper	-161.4684*	17.25925	.000	-195.4204	-127.5164
		Abamectin	Abamectin paper	-28.5036	17.25925	.100	-62.4556	5.4485
			Untreated control	196.1579*	17.25925	.000	162.2058	230.1099
			paper control	36.4395*	17.25925	.035	2.4874	70.3915
			Trichoderma asperellum	-129.1968*	17.25925	.000	-163.1488	-95.2448
			Trichoderma-paper	-125.0289*	17.25925	.000	-158.9810	-91.0769
		Trichoderma asperellum	Abamectin paper	100.6932*	17.25925	.000	66.7412	134.6452
			Untreated control	325.3546*	17.25925	.000	291.4026	359.3067
			paper control	165.6363*	17.25925	.000	131.6842	199.5883
			Abamectin	129.1968*	17.25925	.000	95.2448	163.1488
			Trichoderma-paper	4.1679	17.25925	.809	-29.7842	38.1199
		Trichoderma-paper	Abamectin paper	96.5254*	17.25925	.000	62.5733	130.4774
			Untreated control	321.1868*	17.25925	.000	287.2348	355.1388
			paper control	161.4684*	17.25925	.000	127.5164	195.4204
			Abamectin	125.0289*	17.25925	.000	91.0769	158.9810
			Trichoderma asperellum	-4.1679	17.25925	.809	-38.1199	29.7842
MRSP	LSD	Abamectin-paper	Untreated control	.0979	.11465	.394	-.1277	.3234

	Paper-control	.1502	.11465	.191	-.0754	.3757
	Abamectin	-.0695	.11465	.545	-.2950	.1561
	Trichoderma-paper	.1361	.11465	.236	-.0895	.3616
	Trichoderma asperellum	-.0677	.11465	.555	-.2932	.1579
Untreated control	Abamectin-paper	-.0979	.11465	.394	-.3234	.1277
	Paper-control	.0523	.11465	.648	-.1732	.2779
	Abamectin	-.1673	.11465	.145	-.3929	.0582
	Trichoderma-paper	.0382	.11465	.739	-.1873	.2638
	Trichoderma asperellum	-.1655	.11465	.150	-.3911	.0600
Paper-control	Abamectin-paper	-.1502	.11465	.191	-.3757	.0754
	Untreated control	-.0523	.11465	.648	-.2779	.1732
	Abamectin	-.2196	.11465	.056	-.4452	.0059
	Trichoderma-paper	-.0141	.11465	.902	-.2397	.2114
	Trichoderma asperellum	-.2179	.11465	.058	-.4434	.0077
Abamectin	Abamectin-paper	.0695	.11465	.545	-.1561	.2950
	Untreated control	.1673	.11465	.145	-.0582	.3929
	Paper-control	.2196	.11465	.056	-.0059	.4452
	Trichoderma-paper	.2055	.11465	.074	-.0200	.4311
	Trichoderma asperellum	.0018	.11465	.988	-.2238	.2273
Trichoderma-paper	Abamectin-paper	-.1361	.11465	.236	-.3616	.0895
	Untreated control	-.0382	.11465	.739	-.2638	.1873

			Paper-control	.0141	.11465	.902	-.2114	.2397
			Abamectin	-.2055	.11465	.074	-.4311	.0200
			Trichoderma asperellum	-.2037	.11465	.076	-.4293	.0218
		Trichoderma asperellum	Abamectin-paper	.0677	.11465	.555	-.1579	.2932
			Untreated control	.1655	.11465	.150	-.0600	.3911
			Paper-control	.2179	.11465	.058	-.0077	.4434
			Abamectin	-.0018	.11465	.988	-.2273	.2238
			Trichoderma-paper	.2037	.11465	.076	-.0218	.4293
SPP	LSD	Abamectin-paper	Untreated control	.9643*	.24024	.000	.4917	1.4369
			Paper-control	.1250	.24024	.603	-.3476	.5976
			Abamectin	.0893	.24024	.710	-.3833	.5619
			Trichoderma-paper	.2679	.24024	.266	-.2047	.7405
			Trichoderma asperellum	-.3929	.24024	.103	-.8655	.0797
		Untreated control	Abamectin-paper	-.9643*	.24024	.000	-1.4369	-.4917
			Paper-control	-.8393*	.24024	.001	-1.3119	-.3667
			Abamectin	-.8750*	.24024	.000	-1.3476	-.4024
			Trichoderma-paper	-.6964*	.24024	.004	-1.1690	-.2238
			Trichoderma asperellum	-1.3571*	.24024	.000	-1.8297	-.8845
		Paper-control	Abamectin-paper	-.1250	.24024	.603	-.5976	.3476
			Untreated control	.8393*	.24024	.001	.3667	1.3119
			Abamectin	-.0357	.24024	.882	-.5083	.4369
			Trichoderma-paper	.1429	.24024	.552	-.3297	.6155

	Trichoderma asperellum	-.5179*	.24024	.032	-.9905	-.0453
Abamectin	Abamectin-paper	-.0893	.24024	.710	-.5619	.3833
	Untreated control	.8750*	.24024	.000	.4024	1.3476
	Paper-control	.0357	.24024	.882	-.4369	.5083
	Trichoderma-paper	.1786	.24024	.458	-.2940	.6512
	Trichoderma asperellum	-.4821*	.24024	.046	-.9547	-.0095
Trichoderma-paper	Abamectin-paper	-.2679	.24024	.266	-.7405	.2047
	Untreated control	.6964*	.24024	.004	.2238	1.1690
	Paper-control	-.1429	.24024	.552	-.6155	.3297
	Abamectin	-.1786	.24024	.458	-.6512	.2940
	Trichoderma asperellum	-.6607*	.24024	.006	-1.1333	-.1881
TR9000	Abamectin-paper	.3929	.24024	.103	-.0797	.8655
	Untreated control	1.3571*	.24024	.000	.8845	1.8297
	Paper-control	.5179*	.24024	.032	.0453	.9905
	Abamectin	.4821*	.24024	.046	.0095	.9547
	Trichoderma-paper	.6607*	.24024	.006	.1881	1.1333

Based on observed means.
The error term is Mean Square (Error) = 1.616.
***. The mean difference is significant at the .05 level.**

APPENDIX VI: ANOVA for RKN Reproduction (Pi and Pf) (Season 1)

Multiple Comparisons								
Dependent Variabl		(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
RKN pi	LSD	Abamectin paper	Untreated control	10.00	26.458	.710	-45.59	65.59
			paper control	.00	26.458	1.000	-55.59	55.59
			Abamectin	5.00	26.458	.852	-50.59	60.59
			Trichoderma asperellum	-10.00	26.458	.710	-65.59	45.59
			Trichoderma-paper	5.00	26.458	.852	-50.59	60.59
		Untreated control	Abamectin paper	-10.00	26.458	.710	-65.59	45.59
			paper control	-10.00	26.458	.710	-65.59	45.59
			Abanectin	-5.00	26.458	.852	-60.59	50.59
			Trichoderma asperellum	-20.00	26.458	.459	-75.59	35.59
			Trichoderma-paper	-5.00	26.458	.852	-60.59	50.59
		paper control	Abamectin paper	.00	26.458	1.000	-55.59	55.59
			Untreated-control	10.00	26.458	.710	-45.59	65.59
			Abamectin	5.00	26.458	.852	-50.59	60.59
			Trichoderma asperellum	-10.00	26.458	.710	-65.59	45.59

			Trichoderma-paper	5.00	26.458	.852	-50.59	60.59
		Abamectin	Abamectin paper	-5.00	26.458	.852	-60.59	50.59
			Untreated-control	5.00	26.458	.852	-50.59	60.59
			paper control	-5.00	26.458	.852	-60.59	50.59
			Trichoderma asperellum	-15.00	26.458	.578	-70.59	40.59
			Trichoderma-paper	.00	26.458	1.000	-55.59	55.59
		Trichoderma asperellum	Abamectin paper	10.00	26.458	.710	-45.59	65.59
			Untreated control	20.00	26.458	.459	-35.59	75.59
			paper control	10.00	26.458	.710	-45.59	65.59
			Abamectin	15.00	26.458	.578	-40.59	70.59
			Trichoderma-paper	15.00	26.458	.578	-40.59	70.59
		Trichoderma-paper	Abamectin paper	-5.00	26.458	.852	-60.59	50.59
			Untreated control	5.00	26.458	.852	-50.59	60.59
			paper control	-5.00	26.458	.852	-60.59	50.59
			Abamectin	.00	26.458	1.000	-55.59	55.59
			Trichoderma asperellum	-15.00	26.458	.578	-70.59	40.59
RKN pf	LSD	Abamectin paper	Untreated control	-40.00*	14.530	.013	-70.53	-9.47
			paper control	-20.00	14.530	.186	-50.53	10.53
			Abamectin	-15.00	14.530	.316	-45.53	15.53

	Trichoderma asperellum	-20.00	14.530	.186	-50.53	10.53
	Trichoderma-paper	-15.00	14.530	.316	-45.53	15.53
Untreated control	Abamectin paper	40.00*	14.530	.013	9.47	70.53
	paper control	20.00	14.530	.186	-10.53	50.53
	Abamectin	25.00	14.530	.102	-5.53	55.53
	Trichoderma asperellum	20.00	14.530	.186	-10.53	50.53
	Trichoderma-paper	25.00	14.530	.102	-5.53	55.53
paper control	Abamectin paper	20.00	14.530	.186	-10.53	50.53
	Absolute-control	-20.00	14.530	.186	-50.53	10.53
	Abamectin	5.00	14.530	.735	-25.53	35.53
	Trichoderma asperellum	.00	14.530	1.000	-30.53	30.53
	Trichoderma-paper	5.00	14.530	.735	-25.53	35.53
Abamectin	Abamectin paper	15.00	14.530	.316	-15.53	45.53
	Untreated control	-25.00	14.530	.102	-55.53	5.53
	paper control	-5.00	14.530	.735	-35.53	25.53
	Trichoderma asperellum	-5.00	14.530	.735	-35.53	25.53
	Trichoderma-paper	.00	14.530	1.000	-30.53	30.53

Trichoderma asperellum	Abamectin paper	20.00	14.530	.186	-10.53	50.53
	Untreated control	-20.00	14.530	.186	-50.53	10.53
	paper control	.00	14.530	1.000	-30.53	30.53
	Abamectin	5.00	14.530	.735	-25.53	35.53
	Trichoderma-paper	5.00	14.530	.735	-25.53	35.53
Trichoderma-paper	Abamectin paper	15.00	14.530	.316	-15.53	45.53
	Untreated control	-25.00	14.530	.102	-55.53	5.53
	paper control	-5.00	14.530	.735	-35.53	25.53
	Abamectin	.00	14.530	1.000	-30.53	30.53
	Trichoderma asperellum	-5.00	14.530	.735	-35.53	25.53

Based on observed means.

The error term is Mean Square (Error) = 422.222.

***. The mean difference is significant at the .05 level.**

APPENDIX VII: ANOVA for RKN reproduction (Pi and Pf) (Field Trial Season 2)

Multiple Comparisons

Dependent Variable		(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
RKN pi	LSD	Abamectin paper	Untreated control	160.00	104.735	.144	-60.04	380.04
			paper control	65.00	104.735	.543	-155.04	285.04
			Abamectin	-250.00*	104.735	.028	-470.04	-29.96
			Trichoderma asperellum	-125.00	104.735	.248	-345.04	95.04
			Trichoderma-paper	5.00	104.735	.962	-215.04	225.04
		Untreated control	Abamectin paper	-160.00	104.735	.144	-380.04	60.04
			paper control	-95.00	104.735	.376	-315.04	125.04
			Abanectin	-410.00*	104.735	.001	-630.04	-189.96

	Trichoderma asperellum	-285.00*	104.735	.014	-505.04	-64.96
	Trichodermapaper	-155.00	104.735	.156	-375.04	65.04
paper control	Abamectin paper	-65.00	104.735	.543	-285.04	155.04
	Untreated-control	95.00	104.735	.376	-125.04	315.04
	Abamectin	-315.00*	104.735	.008	-535.04	-94.96
	Trichoderma asperellum	-190.00	104.735	.086	-410.04	30.04
	Trichoderma-paper	-60.00	104.735	.574	-280.04	160.04
Abamectin	Abamectin paper	250.00*	104.735	.028	29.96	470.04
	Untreated-control	410.00*	104.735	.001	189.96	630.04
	paper control	315.00*	104.735	.008	94.96	535.04
	Trichoderma asperellum	125.00	104.735	.248	-95.04	345.04

			Trichoderma-paper	255.00*	104.735	.026	34.96	475.04
		Trichoderma asperellum	Abamectin paper	125.00	104.735	.248	-95.04	345.04
			Untreated control	285.00*	104.735	.014	64.96	505.04
			paper control	190.00	104.735	.086	-30.04	410.04
			Abamectin	-125.00	104.735	.248	-345.04	95.04
			Trichoderma-paper	130.00	104.735	.230	-90.04	350.04
		Trichoderma-paper	Abamectin paper	-5.00	104.735	.962	-225.04	215.04
			Untreated control	155.00	104.735	.156	-65.04	375.04
			paper control	60.00	104.735	.574	-160.04	280.04
			Abamectin	-255.00*	104.735	.026	-475.04	-34.96
			Trichoderma asperellum	-130.00	104.735	.230	-350.04	90.04
RKN pf	LSD	Abamectin paper	Untreated control	-740.00*	38.935	.000	-821.80	-658.20

	paper control	-185.00*	38.935	.000	-266.80	-103.20
	Abamectin	-150.00*	38.935	.001	-231.80	-68.20
	Trichoderma asperellum	-92.50*	38.935	.029	-174.30	-10.70
	Trichoderma-paper	-45.00	38.935	.263	-126.80	36.80
Untreated control	Abamectin paper	740.00*	38.935	.000	658.20	821.80
	paper control	555.00*	38.935	.000	473.20	636.80
	Abamectin	590.00*	38.935	.000	508.20	671.80
	Trichoderma asperellum	647.50*	38.935	.000	565.70	729.30
	Trichoderma-paper	695.00*	38.935	.000	613.20	776.80
paper control	Abamectin paper	185.00*	38.935	.000	103.20	266.80
	Absolute-control	-555.00*	38.935	.000	-636.80	-473.20

	Abamectin	35.00	38.935	.381	-46.80	116.80
	Trichoderma asperellum	92.50*	38.935	.029	10.70	174.30
	Trichoderma-paper	140.00*	38.935	.002	58.20	221.80
Abamectin	Abamectin paper	150.00*	38.935	.001	68.20	231.80
	Untreated control	-590.00*	38.935	.000	-671.80	-508.20
	paper control	-35.00	38.935	.381	-116.80	46.80
	Trichoderma asperellum	57.50	38.935	.157	-24.30	139.30
	Trichoderma-paper	105.00*	38.935	.015	23.20	186.80
Trichoderma asperellum	Abamectin paper	92.50*	38.935	.029	10.70	174.30
	Untreated control	-647.50*	38.935	.000	-729.30	-565.70
	paper control	-92.50*	38.935	.029	-174.30	-10.70
	Abamectin	-57.50	38.935	.157	-139.30	24.30

		Trichoderma-paper	47.50	38.935	.238	-34.30	129.30
	Trichoderma-paper	Abamectin paper	45.00	38.935	.263	-36.80	126.80
		Untreated control	-695.00*	38.935	.000	-776.80	-613.20
		paper control	-140.00*	38.935	.002	-221.80	-58.20
		Abamectin	-105.00*	38.935	.015	-186.80	-23.20
		Trichoderma asperellum	-47.50	38.935	.238	-129.30	34.30

Based on observed means.
The error term is Mean Square (Error) = 3031.944.
*. The mean difference is significant at the .05 level.

APPENDIX VIII: ANOVA for Plant Growth Parameters (Field trial Season 2)

Multiple Comparisons								
Dependent Variable		(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
NTP	LSD	Abamectin paper	Untreated control	1.8571*	.27843	.000	1.3094	2.4049
			paper control	1.4464*	.27843	.000	.8987	1.9941
			Abamectin	1.8036*	.27843	.000	1.2559	2.3513
			Trichoderma asperellum	.5179	.27843	.064	-.0299	1.0656
			Trichoderma-paper	.2500	.27843	.370	-.2977	.7977
		Untreated control	Abamectin paper	-1.8571*	.27843	.000	-2.4049	-1.3094
			paper control	-.4107	.27843	.141	-.9584	.1370
			Abanectin	-.0536	.27843	.848	-.6013	.4941
			Trichoderma asperellum	-1.3393*	.27843	.000	-1.8870	-.7916
			Trichoderma-paper	-1.6071*	.27843	.000	-2.1549	-1.0594
		paper control	Abamectin paper	-1.4464*	.27843	.000	-1.9941	-.8987
			Untreated-control	.4107	.27843	.141	-.1370	.9584
			Abamectin	.3571	.27843	.200	-.1906	.9049
			Trichoderma asperellum	-.9286*	.27843	.001	-1.4763	-.3809
			Trichoderma-paper	-1.1964*	.27843	.000	-1.7441	-.6487

		Abamectin	Abamectin paper	-1.8036*	.27843	.000	-2.3513	-1.2559
			Untreated-control	.0536	.27843	.848	-.4941	.6013
			paper control	-.3571	.27843	.200	-.9049	.1906
			Trichoderma asperellum	-1.2857*	.27843	.000	-1.8334	-.7380
			Trichoderma-paper	-1.5536*	.27843	.000	-2.1013	-1.0059
		Trichoderma asperellum	Abamectin paper	-.5179	.27843	.064	-1.0656	.0299
			Untreated control	1.3393*	.27843	.000	.7916	1.8870
			paper control	.9286*	.27843	.001	.3809	1.4763
			Abamectin	1.2857*	.27843	.000	.7380	1.8334
			Trichoderma-paper	-.2679	.27843	.337	-.8156	.2799
		Trichoderma-paper	Abamectin paper	-.2500	.27843	.370	-.7977	.2977
			Untreated control	1.6071*	.27843	.000	1.0594	2.1549
			paper control	1.1964*	.27843	.000	.6487	1.7441
			Abamectin	1.5536*	.27843	.000	1.0059	2.1013
			Trichoderma asperellum	.2679	.27843	.337	-.2799	.8156
MTP	LSD	Abamectin paper	Untreated control	349.4075*	10.72801	.000	328.3036	370.5114
			paper control	141.9952*	10.72801	.000	120.8913	163.0991
			Abamectin	117.1861*	10.72801	.000	96.0822	138.2900
			Trichoderma asperellum	5.8734	10.72801	.584	-15.2305	26.9773
			Trichoderma-paper	59.3459*	10.72801	.000	38.2420	80.4498
		Untreated control	Abamectin paper	-349.4075*	10.72801	.000	-370.5114	-328.3036
			paper control	-207.4123*	10.72801	.000	-228.5162	-186.3084

	Abamectin	-232.2214*	10.72801	.000	-253.3253	-211.1175
	Trichoderma asperellum	-343.5341*	10.72801	.000	-364.6380	-322.4302
	Trichoderma-paper	-290.0616*	10.72801	.000	-311.1655	-268.9577
paper control	Abamectin paper	-141.9952*	10.72801	.000	-163.0991	-120.8913
	Absolute-control	207.4123*	10.72801	.000	186.3084	228.5162
	Abamectin	-24.8091*	10.72801	.021	-45.9130	-3.7052
	Trichoderma asperellum	-136.1218*	10.72801	.000	-157.2257	-115.0179
	Trichoderma-paper	-82.6493*	10.72801	.000	-103.7532	-61.5454
Abamectin	Abamectin paper	-117.1861*	10.72801	.000	-138.2900	-96.0822
	Untreated control	232.2214*	10.72801	.000	211.1175	253.3253
	paper control	24.8091*	10.72801	.021	3.7052	45.9130
	Trichoderma asperellum	-111.3127*	10.72801	.000	-132.4166	-90.2088
	Trichoderma-paper	-57.8402*	10.72801	.000	-78.9441	-36.7363
Trichoderma	Abamectin paper	-5.8734	10.72801	.584	-26.9773	15.2305
asperellum	Untreated control	343.5341*	10.72801	.000	322.4302	364.6380
	paper control	136.1218*	10.72801	.000	115.0179	157.2257
	Abamectin	111.3127*	10.72801	.000	90.2088	132.4166
	Trichoderma-paper	53.4725*	10.72801	.000	32.3686	74.5764
Trichoderma-	Abamectin paper	-59.3459*	10.72801	.000	-80.4498	-38.2420
paper	Untreated control	290.0616*	10.72801	.000	268.9577	311.1655
	paper control	82.6493*	10.72801	.000	61.5454	103.7532
	Abamectin	57.8402*	10.72801	.000	36.7363	78.9441

			Trichoderma asperellum	-53.4725*	10.72801	.000	-74.5764	-32.3686
MRSP	LSD	Abamectin-paper	Untreated control	6.0682*	.44135	.000	5.2000	6.9364
			Paper-control	3.1000*	.44135	.000	2.2318	3.9682
			Abamectin	3.8596*	.44135	.000	2.9914	4.7279
			Trichoderma-paper	3.5550*	.44135	.000	2.6868	4.4232
			Trichoderma asperellum	3.4238*	.44135	.000	2.5555	4.2920
		Untreated control	Abamectin-paper	-6.0682*	.44135	.000	-6.9364	-5.2000
			Paper-control	-2.9682*	.44135	.000	-3.8364	-2.1000
			Abamectin	-2.2086*	.44135	.000	-3.0768	-1.3404
			Trichoderma-paper	-2.5132*	.44135	.000	-3.3814	-1.6450
			Trichoderma asperellum	-2.6445*	.44135	.000	-3.5127	-1.7763
		Paper-control	Abamectin-paper	-3.1000*	.44135	.000	-3.9682	-2.2318
			Untreated control	2.9682*	.44135	.000	2.1000	3.8364
			Abamectin	.7596	.44135	.086	-.1086	1.6279
			Trichoderma-paper	.4550	.44135	.303	-.4132	1.3232
			Trichoderma asperellum	.3237	.44135	.464	-.5445	1.1920
		Abamectin	Abamectin-paper	-3.8596*	.44135	.000	-4.7279	-2.9914
			Untreated control	2.2086*	.44135	.000	1.3404	3.0768
			Paper-control	-.7596	.44135	.086	-1.6279	.1086
			Trichoderma-paper	-.3046	.44135	.491	-1.1729	.5636

			Trichoderma asperellum	-.4359	.44135	.324	-1.3041	.4323
		Trichoderma-paper	Abamectin-paper	-3.5550*	.44135	.000	-4.4232	-2.6868
			Untreated control	2.5132*	.44135	.000	1.6450	3.3814
			Paper-control	-.4550	.44135	.303	-1.3232	.4132
			Abamectin	.3046	.44135	.491	-.5636	1.1729
			Trichoderma asperellum	-.1313	.44135	.766	-.9995	.7370
		Trichoderma asperellum	Abamectin-paper	-3.4238*	.44135	.000	-4.2920	-2.5555
			Untreated control	2.6445*	.44135	.000	1.7763	3.5127
			Paper-control	-.3237	.44135	.464	-1.1920	.5445
			Abamectin	.4359	.44135	.324	-.4323	1.3041
			Trichoderma-paper	.1313	.44135	.766	-.7370	.9995
SPP	LSD	Abamectin-paper	Untreated control	.6964*	.18733	.000	.3279	1.0649
			Paper-control	.6250*	.18733	.001	.2565	.9935
			Abamectin	.6429*	.18733	.001	.2743	1.0114
			Trichoderma-paper	-.4643*	.18733	.014	-.8328	-.0958
			Trichoderma asperellum	-.6071*	.18733	.001	-.9757	-.2386
		Untreated control	Abamectin-paper	-.6964*	.18733	.000	-1.0649	-.3279
			Paper-control	-.0714	.18733	.703	-.4399	.2971
			Abamectin	-.0536	.18733	.775	-.4221	.3149
			Trichoderma-paper	-1.1607*	.18733	.000	-1.5292	-.7922
			Trichoderma asperellum	-1.3036*	.18733	.000	-1.6721	-.9351

Paper-control	Abamectin-paper	-.6250*	.18733	.001	-.9935	-.2565
	Untreated control	.0714	.18733	.703	-.2971	.4399
	Abamectin	.0179	.18733	.924	-.3507	.3864
	Trichoderma-paper	-1.0893*	.18733	.000	-1.4578	-.7208
	Trichoderma asperellum	-1.2321*	.18733	.000	-1.6007	-.8636
Abamectin	Abamectin-paper	-.6429*	.18733	.001	-1.0114	-.2743
	Untreated control	.0536	.18733	.775	-.3149	.4221
	Paper-control	-.0179	.18733	.924	-.3864	.3507
	Trichoderma-paper	-1.1071*	.18733	.000	-1.4757	-.7386
	Trichoderma asperellum	-1.2500*	.18733	.000	-1.6185	-.8815
Trichoderma-paper	Abamectin-paper	.4643*	.18733	.014	.0958	.8328
	Untreated control	1.1607*	.18733	.000	.7922	1.5292
	Paper-control	1.0893*	.18733	.000	.7208	1.4578
	Abamectin	1.1071*	.18733	.000	.7386	1.4757
	Trichoderma asperellum	-.1429	.18733	.446	-.5114	.2257
TR9000	Abamectin-paper	.6071*	.18733	.001	.2386	.9757
	Untreated control	1.3036*	.18733	.000	.9351	1.6721
	Paper-control	1.2321*	.18733	.000	.8636	1.6007
	Abamectin	1.2500*	.18733	.000	.8815	1.6185
	Trichoderma-paper	.1429	.18733	.446	-.2257	.5114

Based on observed means.

The error term is Mean Square (Error) = .983.