POTENTIAL OF POTASSIUM SALTS OF FATTY ACIDS AND INTEGRATED PEST MANAGEMENT STRATEGIES IN THE MANAGEMENT OF SNAP BEAN PESTS

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DECLARATION

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

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DEDICATION

To my mother Evelyn for her endless support and encouragement throughout the period of this study.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
CIAT	International Centre for Tropical Agriculture
EU	European Union
GAP	Good Agricultural Practices
GDP	Gross Domestic Product
HCDA	Horticultural Crops Development Authority
IPM	Integrated Pest Management
KAPAP	Kenya Agricultural Productivity and Agribusiness Project
KEPHIS	Kenya Plant Health Inspectorate Service
KHCP	Kenya Horticulture Competitiveness Project
KSHS	Kenya Shillings
MRLs	Maximum Residue Limits
MOA	Ministry of Agriculture
PCPB	Pest Control Products Board
PHI	Pre-Harvest Interval
PIPs	Plant-Incorporated Protectants
SPS	Sanitary and Phytosanitary
TBT	Technical Barriers to Trade
USAID	United States Agency for International Development
WAE	Weeks After Emergence

GENERAL ABSTRACT

Production of snap beans for the export market in Kenya is mainly by small scale farmers but insect pests remain a major constraint to production. Farmers rely mainly on synthetic chemical pesticides to manage insect pests. Overreliance on chemical pesticides has led to adverse effects on the environment and high chemical pesticide residues on fresh produce resulting in noncompliance with the strict maximum residue level (MRLs) requirements for export vegetables by European markets. This has led to rejection of export produce causing high economic losses to farmers. Therefore, this study was carried out to develop sustainable options of managing snap bean pests with the aim of reducing chemical residues on snap bean produce. Two field experiments were carried out in farmers' fields in Mwea and Embu under irrigated conditions over two cropping cycles from July 2013 to January 2014. The first experiment was to determine the effectiveness of potassium salts of fatty acids in the management of whiteflies and thrips in snap beans. Different concentrations of potassium salts of fatty acids evaluated were potassium salts of fatty acids at 0.5%, 1% and 1.5% spray solution. Applications of potassium salts of fatty acids were carried out starting from two weeks after emergence then weekly until early podding. The collected data included thrips and whitefly populations, yield and pest damage on the harvested produce.

The second experiment evaluated pest management options that included: i) seed dressing only, ii) seed dressing followed by three neem sprays, iii) seed dressing followed by two pyrethroid sprays and one neem spray, iv) seed dressing followed by three pyrethroid sprays and intercropping snap bean with maize, v) seed dressing followed by two pyrethroid sprays plus one spray with a biological product, vi) seed dressing followed by two neem sprays plus one spray with a biological product, and vii) two pyrethroid sprays and one neem spray only. The data collected included plant emergence, nodulation, the bean stem maggot population, thrips population, whitefly population, yield and pest damage. Potassium salts of fatty acids were effective in reducing whiteflies and thrips population. The application of potassium salts of fatty acids at the rate of 1.5% of spray solution significantly ($P<0.05$) reduced white fly and thrips populations by up to 65% and 60% respectively. Pod damage due to thrips was also significantly ($P<0.05$) reduced and the yield was significantly ($P<0.05$) increased. The untreated control and potassium salts of fatty acids at the rate of 0.5% did not have significant ($P>0.05$) effect.

The integration of seed dressing, two pyrethroid sprays and a neem spray applied at the vegetative stage, early flowering and early podding respectively and the integration seed dressing, intercropping with maize plus three pyrethroid sprays applied at the vegetative stage, early flowering and early podding, reduced the bean stem maggot, white fly and thrips population by up to 59%, 57% and 60%, respectively. These options also increased emergence, reduced pod damage and increased yield of extra-fine and fine pods. The above results show that potassium salts of fatty acids at 1.5% are effective in the management of thrips and whitefly in snap beans and can be integrated in a pest management system for snap beans. Similarly, the integration of seed dressing, foliar sprays and intercropping with maize is effective in the management of the bean stem maggots, thrips and whitefly in snap beans and can be integrated in a pest management system for snap beans. Potassium salts of fatty acids and the integration of seed dressing, foliar sprays and intercropping with maize would therefore be viable alternatives to synthetic chemical pesticides thereby enabling farmers meet the strict maximum chemical residue level requirements set by European markets.

Key words: *Phaseolus vulgaris* L, chemical pesticide residues, potassium salts of fatty acids, seed dressing, foliar sprays, intercropping

CHAPTER ONE: INTRODUCTION

1.1 Background

Snap bean (*Phaseolus vulgaris* L.) is bean grown specifically for the immature green pods primarily for export market to the European Union (EU) and elite local urban markets (Infonet-Biovision, 2012). The production of snap beans, one of Kenya's most important export vegetable crops, is steadily rising (HCDA, 2013). Snap beans from Kenya are exported to United Kingdom, France, Holland, Germany, United Arab Emirates and South Africa (HCDA, 2013). Local consumption of snap beans has also increased over the last few years, providing a domestic market (HCDA, 2013). Production of snap beans in Kenya is constrained by insect pests (Nderitu et al., 2007). Insect pests cause both direct damage during feeding and indirect damage through transmission of viruses in snap beans. Some of the most important pests in snap bean production include: thrips, whiteflies, bean flies and aphids. These insect pests cause considerable yield loss of snap beans. For instance, Thrips, mainly western flower thrips (*Frankliniella occidentalis* (Pergande) and legume flower thrips (*Megalurothrips sjostedti* Trybom) (Thysanoptera: Thripidae), have been reported to cause over 60% loss of marketable pods in Kenya (Michalik et al., 2006).

In Kenya, farmers rely on insecticides to control sucking insect pests in snap beans. However, chemical pesticide contamination poses significant risks to the environment and non-target organisms ranging from beneficial soil microorganisms to insects, plants, fish, and birds (Aktar et al., 2009). At present the introduction of maximum residue levels (MRLs) for export vegetables (including snap beans) by European retailers, the main consumers of Kenyan snap beans poses a challenge to the use of pesticides (Nderitu et al., 2009). Sustainable pest management measures are therefore key to sustainable snap bean production systems that will meet the current market demand for snap beans in terms of both quality and quantity.

The use of new pest control technologies that lead to little reliance on chemical pesticides and use of environmentally friendly insect pest control measures is a major step towards sustainable pest management (Nderitu et al., 2009). Some of these technologies include: reduced pesticide application frequency and use of environmentally friendly pesticides such as seed dressers, bio-pesticides and modified cropping systems (Nderitu et al., 2009). Alternative pest control options for example potassium salts of fatty acids also referred to as insecticidal soaps are also an option.

1.2 Problem statement

Snap beans which are produced in Kenya are reputed to be the world's finest (Ndung'u, 2013). However, insect pests are a major constraint to snap bean production (Nderitu et al 2007; Monda et al., 2003) and they cause both direct and indirect damage to snap beans which results in reduced productivity and losses to farmers (Michalik et al., 2006). Direct feeding by pests causes stunting, colour changes, deformation and, in severe infestation, death of the plants (Infonet-Biovision, 2013).

In order to manage insect pests, snap bean farmers rely on chemical pesticides (Monda et al., 2003). However, excessive and over reliance on chemical pesticides by farmers is counterproductive and poses significant risks to the environment and non-target organisms ranging from beneficial soil microorganisms, to insects, plants, fish, and birds due to contamination (Aktar et al., 2009; Kumar et al., 2012; Leila et al., 2013; Nderitu et al., 2010). The result of this has been loss of biodiversity in agrosystems leading to upsurge of insect pests (Das et al., 2010).

Additionally, resistance to chemical insecticides by pests for example whiteflies and thrips has been reported making it difficult to sustainably manage these pests with chemicals only (Cardona, 2012; Gorman et al., 2007; Nderitu et al., 2010). The improper use of chemical pesticides also results in high chemical residue on fresh vegetable produce (Al-Samarrai et al., 2012). The introduction of strict maximum residue limits (MRLs) for fresh vegetables including snap beans (Ndung'u, 2013) has led to rejections of Kenyan produce at the export markets. In some cases some chemicals have been withdrawn from the options that a farmer is allowed to use on his crops (Al-Samarrai et al., 2012). There is need to address these challenges through use of new pest control technologies that lead to little reliance on chemical pesticides and use of environmentally friendly insect pest control measures.

1.3 Justification

The recent strict enforcement of food safety and quality measures by the EU which is the main export market for Kenyan snap beans poses a threat to snap bean exports (Belder, 2012; EU, 2013; Mwangi, 2013). The measures are with regards to maximum residue levels (MRLs) which have been changed from 0.2 to 0.02 parts per million (Ndung'u, 2013). Farmers and exporters of fresh vegetables as a result are incurring losses through product rejects and bills passed to them after the MRL tests (Ndung'u, 2013; Munene, 2013). Non-compliance to the regulations has also led to Kenya Plant Health Inspectorate Service (KEPHIS) suspending export licences of some exporters (Mwangi, 2012).

There are several pest control methods available for insect pest management in Kenya apart from the use of chemical pesticides. These include biological control methods, cultural control methods and host plant resistance. Integrated pest management is regarded as the best approach and is slowly gaining ground among large scale growers (Koppert, 2013). There is need to promote integrated pest management technologies among the small scale growers who mostly rely on foliar chemical pesticide sprays to manage insect pests (Nderitu et al., 2007). The use of new pest control technologies and alternative non chemical pest control options that lead to little reliance on chemical pesticides and use of environmentally friendly insect pest control measures is a major step towards sustainable pest management. Some of these technologies include: reduced pesticide application frequency, use of environmentally friendly pesticides and bio-pesticides and modified cropping systems (Nderitu et al., 2009).

1.4 Objectives of the study

The broad objective of the study was to effectively manage insect pests and reduce chemical residues on snap bean produce through adoption of alternative and integrated pest management practices.

The specific objectives were:

1. To determine the efficacy of potassium salts of fatty acids in the management of snap bean pests.

2. To determine the effectiveness of integrating seed dressing, foliar sprays and intercropping in the management of snap bean pests.

1.5 Hypotheses

1. Varying concentrations of potassium salts of fatty acids affect the efficacy of potassium salts of fatty acids in controlling snap bean pests.
2. Integration of seed dressing, foliar sprays and intercropping is more effective in the management of snap bean pests than the current chemical control practices among snap bean farmers.

CHAPTER TWO: LITERATURE REVIEW

2.1 Snap bean production in Kenya

Production of snap beans in Kenya is mainly for the fresh export market (HCDA, 2014) and small scale farmers in the rural areas from the biggest percentage of snap bean producers (Kinyuru et al., 2011). The production of snap beans has been steadily rising and the crop is grown under both rain-fed and irrigation conditions (Biovision-infonet, 2013). Kenya exported over 31,973 tons of snap beans last year up from 22,553 tons in the year 2012 (HCDA, 2014). The main export markets include: the United Kingdom, France, Holland, Germany, United Arab Emirates and South Africa (HCDA, 2013).

Snap beans grow best on well drained, silty loams to heavy clay soils high in organic matter with a PH of between 5.5-6.5 (Infonet-Biovision, 2012). The optimum temperature range for growing snap beans is 20-25°C, but can be grown in areas with temperatures ranging between 14 and 32°C (Infonet-Biovision, 2012). Rain-fed cultivation is possible in areas with well distributed, medium to high annual rainfall (900-1200 mm) but irrigation is essential to maintain a continuous production (Infonet-Biovision, 2012).

Production of snap beans in Kenya is constrained by insect pests and diseases (Infonet-Biovision, 2013). Insect pests cause both direct damage during feeding and indirect damage through transmission of viruses in snap beans. Some of the most important pests in snap bean production include: thrips, whiteflies, bean flies and aphids. These insect pests cause considerable yield loss of snap beans. Farmers rely mainly on insecticides to control insect pests in snap beans (Monda et al., 2003). However, chemical pesticide contamination poses significant risks to the environment and non-target organisms ranging from beneficial soil microorganisms to insects, plants, fish, and birds (Kumar et al., 2012; Leila et al., 2013;

Srinivasan, 2012). Resistance to chemical insecticides by pests, for example whiteflies and thrips, has been reported making it difficult to sustainably manage these pests with chemicals only (Cardona et al., 2012).

In the recent past, the EU which is the major market for Kenyan snap bean farmers and exporters has enforced stringent food safety and quality measures (Belder, 2012; EU, 2013; Mwangi, 2013; Ndung'u, 2013). There are several chemical pesticides used by snap bean farmers that are currently targeted by the stringent safety and quality measures (Mwangi, 2013). This include: acephate, chlopylifos, dimethoate, indoxacarb, methamidophos, methomyl and diafenthiuron. The measures are with regards to Maximum Residue Levels (MRLs) which have been changed from 0.2 to 0.02 parts per million (Ndung'u, 2013). Farmers and exporters of fresh vegetables as a result are incurring losses through product rejects and bills passed to them after the MRL tests (Mwangi, 2012; Ndung'u, 2013). Non-compliance to the regulations has also led to KEPHIS suspending export licences of some exporters (Mwangi, 2012).

2.2 Major insect pests in snap bean production

Insect pests remain a major constraint in agricultural production systems. They cause damage to crops both directly through feeding and indirectly through transmition of viruses and contamination leading to low productivity (Degri, 2013). Snap bean production is faced by this constraint. The main pests in snap bean production systems include thrips, bean stem maggots, whiteflies, aphids, thrips, cut worms, pod porers, foliage beetles and red spider mites (Infonet-Biovision, 2013).

Thrips are important pests of snap beans and pose a challenge to snap bean production (Nderitu et al., 2010). They cause the highest damage of up to 40% due to bud abscission and flower abortion and up to 20% loss due to pod damage (Nderitu et al., 2008) Thrips cause direct damage through feeding which causes scars and blemishes on leaves and pods (Infonet-Biovision, 2013). Thrips feed on all the development stages of the crop including young leaves, flower buds and young pods (Nderitu et al., 2010). Heavy thrips feeding causes flower abortion and flower malformation (Infonet-Biovision, 2013). The affected snap bean pods consequently become scarred and malformed and are not marketable (Infonet-Biovision, 2013). Thrips cause damage to the plant by piercing the cells of the surface tissues and sucking out their contents, causing the sorrounding tissue to die (Malais et al., 2003)

Whiteflies are also important pests of snap beans and pose a challenge to snap bean production. Both larvae and adults pierce and suck the sap from leaves, which may cause reduced plant growth, yellowing of leaves, and wilting of the plant when present in large numbers (Infonet-Biovision, 2013). Whitefly larvae need a lot of protein for growth, and thus consume a large quantity of plant sap (Malais et al., 2003). The plant sap contains a high proportion of sugar, and the excess is excreted as honey dew (Malais et al., 2003). The honey dew on the surface of leaves encourages growth of fungal mould. Heavy growth of sooty mould reduces photosynthesis affecting plant growth. Snap bean pods contaminated with sooty mould are unmarketable (Infonet-Biovision, 2013). In addition, whiteflies are vectors of various viruses that cause disease in many crops in agricultural production systems. There are three species of whitefly that have been shown to transmit viruses including *Trialeurodes vaporariorum* and *Bemisia tabaci* (Malais et al., 2003). Resistance by whitefly species to insecticides has been reported which make it difficult to manage the pest in snap bean production systems (Gorman et al., 2007)

The bean fly also called bean stem maggots is a serious pest in snap bean production in Africa (Infonet-Biovision, 2013). The adult is a tiny fly, shiny black-bluish in colour. The female fly pierces the young leaves to lay eggs and sucks the exuding sap. This leaves yellow blotches on the leaves, which are the first signs of bean fly attack. Maggots mine their way from the leaves down to the base of the stem, where they complete their development (Infonet-Biovision, 2013). Maggot feeding destroys the tissue causing the steam to swell and split and reduce formation of lateral roots. The attack disrupts nutrient transportation, causing the tap root to die. The plant attempts to recover by forming adventitious roots above the damaged area (CIAT, 2010). Maggots and pupae can often be seen through the stem splits (Infonet-Biovision, 2012). Young seedlings and plants under stress wilt and die when attacked by bean flies (CIAT, 2010; Infonet-Biovision, 2012).

Aphids are a big problem in the horticultural sector and in snap bean production (Infonet-Biovision, 2013). Through their enormous reproductive capability, aphids can cause severe damage to several crops (Koppert, 2013). Resistance to pesticides by aphid populations is increasing due to overreliance on chemical pesticides (Silva et al., 2012). Nymphs and adults feed on plant sap and this halts growth, causing curled leaves. Sometimes yellow spots appear. Aphids excrete honeydew. Sooty moulds can develop under heavy infestations causing reduction in photosynthesis and consequently reducing growth and production (Infonet-Biovision, 2013).

Snap beans are also affected by spider mites (Acari: Tetranychidae), these are phytophagous pests and their population outbreaks can cause serious damage and yield losses (Marčić et al., 2012). The symptoms for spider mite attack are usually clusters of yellow spots on the upper surface of leaves, which may also appear chlorotic. Continued feeding by spider mites leads to a change of leaf colour and the attacked leaves turn bronze or a rusty, purple or yellow brown colour. Spider mites and webbing are present on the lower leaf surface, which may appear tan or yellow and have a crusty texture (Infonet-Biovision, 2013).

Pod borers are also important pests in snap beans and consist of mainly of caterpillars. The most common in snap beans are the African bollworm (*Helicoverpa armigera*) and the legume pod borer (*Maruca testulalis*) (Infonet-Biovision, 2013). Pod borers feed on leaves, flowers, pods and seeds although they do not cause significant yield reduction (Infonet-Biovision, 2013).

2.3 Pest management in snap bean production in Kenya

Insect pests cause a lot of damage in crops and as a result, their management is a very important aspect of crop production. Currently, the most common pest management strategy employed in snap bean production, is the use of chemical pesticides (Nderitu et al., 2007). Some of the chemical pesticides currently used for insect pests include: Confidor (Imidacloprid), Thunder (Imidacloprid 100g/L + Betacyfluthrin 45g/L), dimethoate (sold in over 25 products), and Karate (Lambda Cyhalothrin 25g/Kg) (Nderitu et al., 2008; Ndung'u, 2013). Currently, most farmers still use the chemical pesticides on calender spray regimes (Nderitu et al., 2008). Chemical pesticides when applied in the right way and properly are effective and reduce the damage caused by insect pests on crops (Al-Samarrai et al., 2012).

However, excessive and overreliance by farmers is counterproductive and has led to loss of biodiversity in agrosystems leading to upsurge of insect pests (Das et al., 2010). Additionally, resistance to chemical insecticides by pests for example whiteflies and thrips has been reported making it difficult to sustainably manage these pests with chemicals only (Cardona, 2012; Gorman et al., 2007; Nderitu et al., 2010).

The improper use of chemical pesticides and failure to observe the pre-harvest intervals (PHIs) for the chemical pesticides also results in high chemical residue on the produce (Al-Samarrai et al., 2012). The introduction of strict maximum residue limits (MRLs) for fresh vegetables including snap beans (Ndung'u, 2013) has led to rejections of Kenyan produce at the export markets. In some cases some chemicals have been withdrawn from the options that a farmer is allowed to use on his crops (Munene, 2013). Therefore, the use of chemical pesticides in an integrated manner that leads to reduced chemical applications can offer an alternative to the snap bean farmers (Nderitu et al., 2009).

Apart from the use of chemical pesticides, other pest management strategies exist. This include use of biological control, physical pest control measures and cultural control measures (Infonet-Biovision, 2013). These pest management options can be incoporated the integrated approach which entails the use of chemical pesticides together with other pest management strategies for instance biological control, mechanical control and cultural control.

2.4 Current market requirements and their impact on fresh vegetable production

In the recent past, market access for exporters of fresh produce is guided by the consumer requirements which the exporters must comply with during production and handling of the produce. The requirements are spelt out in the EU reguratory framework that sometimes goes beyond the beyond the international requirements set under the sanitary and phytosanitary (SPS) and technical barriers to trade (TBT) agreements (Graffham, 2006). This requirements include among others adherehence to the global good agricultural practice (Global GAP) standards which covers all stages of production of fresh produce, from pre-harvest activities such as soil management and plant protection product application to post-harvest produce handling, packing and storing by producers (Global GAP, 2014).

Global GAP has trained inspectors and auditors working for accredited cerfication bodies that certify fresh produce (Global GAP, 2014). To get the GAP certification, farmers have to invest in facilities such as facilities for storage of produce, grading, cooling, safe handling of chemical pesticides and handwashing (hygiene) (Global GAP, 2014). This has resulted in increased cost of production to farmers and as such some farmers opt not to go through the certification process and therefore locked out of the market because of non-compliance.

The Global GAP standard is standard is primarily designed to reassure consumers about how food is produced on the farm through minimising detrimental environmental impacts of farming operations, reducing the use of chemical inputs and ensuring a responsible approach to workers and other non-target organisms safety (Global GAP, 2014).Apart from the Global GAP requirements, producers and exporters have to meet the EU regulations that stipulate stringent food safety and quality measures with regards to Maximum Residue Limits (MRLs) for various pest control products (Belder, 2012; EU, 2013; Mwangi, 2013; Ndung'u, 2013).

Non-compliance to the above standards has led to enhanced scrutiny on the Kenyan produce at the market with 10% of all Kenyan bean produce being sampled (Mwangi, 2012) and suspension of export licences of some exporters by KEPHIS (Mwangi, 2012). Farmers and exporters of fresh vegetables as a result, are incurring losses through product rejects and bills passed to them after the MRL tests whose average cost per sample is Ksh 21,000 (Mwangi, 2012; Ndung'u, 2013).

2.5 Bio-pesticides as alternatives to synthetic chemicals in vegetable production

Biopesticides are naturally occurring substances that control pests, these include biochemical (botanical) pesticides, macrobial pest control products, microbial pesticides and pesticidal substances produced by plants containing added genetic material Plant-Incorporated Protectants (PIPs) (Gašić et al., 2013; Gupta et al., 2010). Unlike sythethic chemicals, biopesticides are readily degradable and pose no risk of residues on produce making them a suitable alternative to sythethic chemicals (Al-Samarrai et al., 2012). Biopesticides also pose little risk to non-target organisms and therefore play an important role in an integrated pest management system (Gašić et al., 2013).

Biopesticides have been reported to be just as effective as sythethic chemical pesticides and as such can be used as an alternative to chemical pesticides in an integrated pest management system once their efficacy is validated (Degri et al., 2013; Mandi et al., 2009; Marčić et al., 2012). Macrobial biopesticides include live macro-organisms such as: predatory mites and parasitic wasps, botanical biopesticides include products based on plant extracts for example neem while microbial biopesticides include products based on micro-organisms for example *Verticillium lecanii* and *Bacillus subtilis* (Gupta et al 2010; PCPB, 2013)

In Kenya, some macrobial pest control products such as *Phytoseiulus persimilis* and *Amblyseius californicus* are already registered and are currently widely used for the control of red spider mites in greenhouses (Koppert, 2014; PCPB, 2013). In the category of botanical pest control products, some of the products registered include neem based products such as Nimbecidine while in microbial category some of the products registered include *Beauveria bassiana* among others (Infonet-Biovision, 2013; PCPB, 2013). Most of the registered biopesticides are currently only used on a small scale by large scale professional growers while on the other the use of biopesticides by smale scale farmers is very low because of lack of awareness about their efficacy (Monda et al., 2003).

2.6 Use of seed dressing in the management of crop pests

Seed dressing which falls under chemical control is an important technology which has been found to be effective for the management of sucking insect pests (Hossain et al., 2012; Pons and Albajes, 2002). This technology entails the treating of seeds with a systemic insecticide before sowing (Hossain et al., 2013). The chemical paste for seed dressing is first prepared in a container and the seeds are the poured in the container with the chemical and stirred for 10 to 15 minutes to allow the chemical to adhere, the seeds are then removed and spread on papers to dry before sowing (Hossain et al., 2012). Seed dressing can be carried out manually especially for small scale growers or by using a seed dressing machine.

A seed dressing chemical is usually taken up by the plant at the root zone and translocated to other parts of the plant (Mazzanti et al., 2011) and as a result, the effect of the seed dressing chemical on pests is usually through systemic and residual toxicity (Zhang *et al*., 2011). This technology has been employed successfully for the management of sucking pests such as whitefly and thrips in cotton (Hossain et al., 2012), management of rice water weevil in rice (Mazzanti et al., 2011) and the management of red spider mites and beanfly in beans (Allah, 2010). Some of the chemicals used as seed dressers include: Imidacloprid which is a neonicotinoid chemical that shows systemic and residual toxicity in several crops and interferes with the transmission of stimuli in the nervous system of insect herbivores giving good control against sucking insect pests (Hossain et al., 2013; Zhang et al., 2011) and Thiamethoxam which is a second generation neonicotinoid with systemic action on insect pests (Mazzanti et al., 2011). The treatments with these chemicals are usually carried out before sowing.

There are also non-chemical seed dressing products for example *Trichoderma harzianum* that have been reported to protect seedlings and enhance germination (Mastouri et al., 2010; Okoth et al., 2011). *Trichoderma harzium* also when used as a seed dresser alleviates abiotic and biotic stress leading to good germination and emergence (Mastouri et al., 2010).

Compared to foliar spraying of chemical insecticides, seed dressing has leads to many benefits that include: reduced use of the chemical making it cost effective, there is reduced chances of drift leading to less adverse effects on the environment and the systemic activity of the seed dressing chemical leads to reduced or no effect on non-target organisms by the seed dressing chemical (Hossain et al., 2013, Mazzanti et al., 2011; Moser et al., 2009). Seed dressing therefore can be used as an alternative to foliar chemical pesticides in an integrated pest management (IPM) system.

2.7 The use of intercrops to manage pests

Intercropping is a cultural practice that entails planting two or more plant species in a field. This technology commonly employed by small scale farmers, has been reported to contribute greatly in the management of various insect pests (Abd-Rabou et al., 2012; Rahnama et al., 2013; Theunissen et al., 1996). Intercropping reduces insect pests through the increasing of the biodiversity in the ecosystem which leads to a build up of natural enemies that contribute to the management of pests (Rao et al., 2012; Usmanikhail et al., 2012).

Intercropping systems have been shown to result in reduced pest incidences compared to monocropping systems (Rao et al., 2012). This technology has been successfully used in Kenya in the management of lepidopteran stem borers on maize and thrips in bulb onions (Gachu et al., 2012; Songa et al., 2007). Other pests whose populations have been shown to be reduced through intercropping include: semilooper (*Achaea janata* L.), leaf hopper (*Empoasca flavescens* Fabricius), shoot and capsule borer (*Conogethes punctiferalis* Guenee) and whitefly (Abd-Rabou et al., 2012; Rao et al., 2012). Some of the crops commonly used in intercropping systems include beans, maize, onions, cowpea, ground nuts, sunflower, sorghum, spider plant and clover (Gachu et al., 2012; Kitonyo et al., 2013; Rao et al., 2012).

In an intercropping system, spatial arrangement of plants, planting rates and maturity dates must be considered because of coexistence of positive and negative interactions among different intercrops (Ghosh, 2004; Sarkodie-Addo et al., 2012). Some intercopping systems can lead to reduction in yield (Sarkodie-Addo et al., 2012). The intecropping components in such a systems should be suitable and economically viable to ensure increased productivity (Gachu et al., 2012; Sarkodie-Addo et al., 2012). The use of intercrops can therefore also play a part in an IPM system as an alternative to chemical pesticides.

2.8 Use of insecticidal soaps in the management of pests

Developing sustainable pest management systems remains a challenge to many small scale snap bean farmers. Pest control technologies that result in higher agricultural production, a safer environment and better quality agricultural produce are key to addressing this challenge (Dheeraj et al., 2013).

The use of alternative non-chemical pest control products such as potassium salts of fatty acids also commonly referred to as soap salts which can be used in the management of various pests (Ciancio et al., 2010; Osborne, 1984), is one such technology. Fatty acids are naturally occurring in animals and vegetables as such fatty acid based insecticides are readily biodegradable with little or no adverse effects on the environments (Dheeraj et al., 2013)

Potassium salts of fatty acids work only on direct contact with the pest. They wash away the protective coating on the insect surface and penetrate the cell membrane causing disruption of its permeability which leads to desiccation of the insects (Dheeraj et al., 2013; Mohamad et al., 2013). Potassium salts of fatty acids work on most soft-bodied insect pests (Koppert, 2013) and have been successfully used in the management of aphids, whiteflies, scales and mealy bugs (Dheeraj et al., 2013; Hollingsworth, 2005; Mohamad et al., 2013) with very good efficacy.

Unlike synthetic chemical pesticides, potassium salts of fatty acids are fast acting with a quick knock down effect on the pests and break down quickly after application leaving no residues (Dheeraj et al., 2013). Insecticidal soaps are also easy to handle because of their low toxicity to human beings and therefore are user friendly (Dheeraj et al., 2013). As a result potassium salts of fatty acids have no MRL or PHI requirements (Koppert, 2013).

The use of potassium salts of fatty acids for management of insect pests is a new concept which has not been exploited. At the moment no pest control product based on potassium salts of fatty acids is registered for the management of insect pests (PCPB, 2013). This could be as result of availability of other insecticides which are already registered for pest management (PCPB, 2013). With the increasing challenges in the use chemical pesticides in vegetables, more and more farmers will embrace and demand availability of non-chemical pest control products such as potassium salts of fatty acids. However, in other countries such as countries in the EU, potassium salts are allowed for use and have been in use for a long time (Ciancio et al., 2010; Osborne, 1984)

CHAPTER THREE: EFFICACY OF POTASSIUM SALTS OF FATTY ACIDS IN THE MANAGEMENT OF THRIPS AND WHITEFLIES ON SNAP BEANS

3.1 Abstract

Farmers mainly rely on chemical pesticides to manage insect pests and diseases in snap bean but the introduction of maximum residue levels (MRLs) for export vegetables by European markets pose a challenge to the use of pesticides. Alternative pest management options that do not result in chemical residue on produce for example potassium salsts of fatty acids have not been widely explored. This study was carried out to determine the efficacy of potassium salts of fatty acids in the management of snap bean pests. Field experiments were carried out in farmers' fields in Mwea and Embu in 2013 for two cropping cycles. Different concentrations of potassium salts of fatty acids evaluated were 0.5%, 1% and 1.5% spray solution. Application of potassium salts of fatty acids was carried out weekly starting from 3 weeks after emergence (WAE) until early podding.

The data collected included data on: thrips population, whitefly population, yield and pod damage. The application of potassium salts of fatty acids at 1% and 1.5% of spray solution significantly ($P<0.05$) reduced white fly and thrips populations by up to 61% and 69% respectively. Pod damage due to thrips was also significantly ($P<0.05$) reduced by up to 83% and the yield was significantly ($P<0.05$) increased by up to 151%. Application of potassium salts of fatty acids at the concentration of 0.5% did not significantly ($P>0.05$) reduce whitefly and thrips population. This demonstrates that potassium salts of fatty acids are a viable alternative to chemical pesticides thereby enabling farmers to meet the strict maximum chemical residue level requirements set by European markets.

Key words: *Phaseolus vulgaris* L., potassium salts of fatty acids, pesticide residues

3.2 Introduction

Snap bean (*Phaseolus vulgaris* L.) is grown specifically for the immature green pods primarily for export market to European Union and elite local urban markets (Infonet-Biovision, 2014). The production of snap beans, one of Kenya's most important export vegetable crops, is steadily rising (HCDA, 2014). Snap beans from Kenya are exported to United Kingdom, France, Holland, Germany, United Arab Emirates and South Africa (HCDA, 2013). Local consumption of Snap beans has also increased over the last few years, providing a domestic market (HCDA, 2013). In the year 2013, Kenya exported over 31,973 tons of snap beans valued at over KSh. 9 billion (HCDA, 2014)

Snap bean production is mainly by small scale farmers and it is estimated that over 50,000 smallholder families are involved in snap bean production in Kenya contributing to the larger agricultural sector (Infonet-Biovision, 2014). The agricultural sector plays an important role in Kenya's economy contributing directly and indirectly to the countries GDP by upto 24% and 27% in the year 2011 (MOA, 2012). Production of snap beans in Kenya is constrained by insect pests and diseases (Nderitu et al., 2007). Some of the most important pests in snap bean production include thrips, whiteflies, bean flies and aphids (Monda et al., 2003).

In Kenya, farmers rely on insecticides to control sucking insect pests in snap beans. However, at present the introduction of maximum residue levels (MRLs) for export vegetables (including snap beans) by European retailers, the main consumers of Kenyan snap beans poses a challenge to the use of pesticides (Nderitu et al., 2009). The measures are with regards to maximum residue levels (MRLs) which are set for various insecticides (EU, 2013; Ndung'u, 2013). Over-reliance on sythethic chemicals pesticides has often led to non compliance by Kenyan exporters leading losses that are passed over to farmers (Mwangi, 2012; Ndung'u, 2013).

Non-compliance to the above standards has also led to enhanced scrutiny of Kenyan produce at the market with 10% of all Kenyan bean produce being sampled (Mwangi, 2012). Farmers and exporters of fresh vegetables are as a result, incurring losses through product rejects and financial bills passed to them after the MRL tests whose average cost per sample is KSh.21,000 (Mwangi, 2012; Ndung'u, 2013). These maximum residue levels (MRLs) for export vegetables (including snap beans) by European retailers, the main consumers of Kenyan snap beans poses a challenge to the use of pesticides (Nderitu et al; 2009).

The use of pest control technologies that lead to reduced reliance on chemical pesticides and use of environmentally friendly insect pest control measures is a major step towards sustainable pest management (Nderitu et al., 2009). Alternative pest control methods such as potassium salts of fatty acids also referred to as insecticidal soaps can be an option to overcome this challenge (Ciancio et al., 2010). Potassium salts of fatty acid work only on direct contact with the pest. They wash away the protective coating on the insect surface and penetrate the cell membrane causing disruption of its permeability which leads to desiccation of the insects (Dheeraj et al., 2013; Mohamad et al., 2013). Potassium salts of fatty acids work on most soft-bodied insect pests (Koppert, 2013) and have been successfully used in the management of aphids, whiteflies, scales and mealy bugs with very good efficacy (Dheeraj et al., 2013; Hollingsworth, 2005; Mohamad et al., 2013).

Unlike synthetic chemical pesticides, potassium salts of fatty acids are fast acting with a quick knock down effect on the pests and break down quickly after application leaving no residues (Dheeraj et al., 2013). Theyare also easy to handle because of their low toxicity to human beings and therefore are user friendly (Dheeraj et al., 2013). As a result, potassium salts of fatty acids have no MRL or PHI requirements (Koppert, 2013). This study was undertaken to determine the efficacy of potassium salts of fatty acids in the management of snap bean pests

3.3 Materials and methods

3.3.1 Description of the experimental sites

The experiments were carried out in farmers' fields in Mwea, Kirinyaga South district, Kirinyaga County and Embu East district, Embu County. Mwea is situated in a region with a good transport network and therefore is easily accessible. There is an irrigation infrastructure that allows year round production and therefore faster implementation of the project. The experimental site was in a lower midland zone 4 (LM4), a semiarid area with soils classified as nitosols. The average rainfall is about 850 mm with a range of 500 - 1250 mm divided into long rains (March – June with an average of 450 mm) and short rains (Mid-October to December with an average of 350 mm). The rainfall is characterized by uneven distribution in total amounts, time and space. The temperature ranges from 15.6º C to 28.6º C with a mean of about 22ºC.

Embu East is located in Embu County and Snap bean is a recently introduced crop to this area but its cultivation is spreading fast and therefore the area is likely to have a high uptake of new technologies. It is located in Upper Midland 2 (UM2) agro-ecological zone and receives high amounts of rainfall. The annual average high temperature is 28.8 °C while the annual average low temperature 9.6 °C. The area receives an average annual precipitation of 1206 mm.

The production of snap beans in both sites is mainly for export and is carried out by small scale farmers organized into self-help groups within the irrigation scheme.

3.3.2 Description of experimental materials

Potassium salts of fatty acids are non-chemical insecticidal soaps derived from naturally occurring fatty acids (Dheeraj et al., 2013). They work on direct contact with the pest and break down quickly after application leaving no residues (Dheeraj et al., 2013). Application of potassium salts in this study was at 5, 10 and 15 litres potassium salts per ha in 1000 litres water.

The chemical treatment using Confidor (Imidacloprid) was applied at the rate of 0.33kg confidor per ha in 1000 litres of water. The farmer practice was carried out by alternate application of Thunder at the rate 0.5 litres product per ha in 1000 litres of water and Karate 17.5 EC at the rate of 325ml product per ha in 1000 litre of water. The control was sprayed with water only during application of the other treatments (Table 3.0).

Table 3.0: Description of experimental materials

Product	AI	Description
Potassium salts	Potassium salts of fatty acids	Application rates at 5ml per litre of water (0.5%), 10 ml per litre (1%) and 15ml per litre of water (1.5%)
Confidor WG	Imidacloprid 700g/Kg	Application rate at 5g per 15 Litres of water
Thunder	Imidacloprid 100 g/L + Betacyfluthrin 45g/L	Application rate at 10 ml in 20 litres of water
Karate	Lambda Cyhalothrin 25 g/kg	Application rate at 6.5 ml in 20 litres of water

3.3.3 Experiment layout and setup

Snap beans were planted under irrigation in plots measuring 3 m by 2 m with 1 m alleys between the plots and 1.5 m alleys between the blocks and was replicated four times. The experiment was laid out in a randomized complete block design. The snap bean variety used for the trial was Serengeti planted in single rows with a spacing of 10 cm x 30 cm. Fertilizer application was done once at planting using diammonium phosphate (18%N and 46% P_2O_5)

applied just before seed placement at the rate of 490 kg per ha. Top dressing was done at 21 days after emergence with calcium ammonium nitrate at the rate of 490 kg per ha .

The first weeding was done two weeks after emergence (WAE) followed by a second weeding two weeks later. Diseases were controlled using chemical pesticides - Kocide (Copper Hydroxide 61.4%) against rust and rots, Mancozeb against leaf spots and Ortiva (Azoxystrobin 250g/L) against mildews.

Experimental treatments consisted of different concentrations of potassium salts of fatty acids as follows:

i. 0.5 % potassium salts applied weekly from 3 WAE until early podding
ii. 1 % potassium salts applied weekly from 3 WAE until early podding
iii. 1.5 % potassium salts applied weekly from 3 WAE until early podding
iv. Chemical pesticide confidor (Imidacloprid) applied every two weeks
v. Farmer practice –application of Thunder (Imidacloprid 100 g/L + Betacyfluthrin 45g/L) and Karate (Lambda Cyhalothrin 25 g/kg) on pest detection
vi. Control. Spray with water only

3.3.4 Assessment of pest population

The main pests assessed in these experiments were whiteflies and thrips. The population of whiteflies was assessed by use of yellow sticky trap counts and leaf counts. A yellow sticky trap was placed at the centre of each plot. The adult whitefly on the yellow sticky trap placed at the centre of each trial plot was counted and recorded bi-weekly (Hirano et al.,1995; Hoelmer et al., 1998). This was done at two, four, six and eight weeks after emergence (WAE). Bi-weekly sampling at two, four, six and eight WAE of ten lower leaves from ten plants in a zig-zag manner from inner rows of each plot was carried out and the nymphs of the whitefly were counted and recorded (Soto et al., 2002).

Thrips population was assessed on ten flowers from ten plants per plot by sampling from the inner rows weekly from the start of flowering and kept in 70% ethanol. This was carried out three times at six, seven and eight weeks after emergence. The flowers were taken to the laboratory where each flower was placed in a petri dish, dissected and washed to make sure that no thrips were lost with the debris (Nderitu, et al., 2009). The thrips were then counted under a dissecting microscope using a tally counter. All thrips stages (adults and larvae) were counted and identified based on their morphological characteristics and recorded.

3.3.5 Assessment of pod yield and quality

Harvesting and grading mainly immature pods was done twice every week for two weeks. Pods were harvested from three inner rows in each plot. The pods were then graded into marketable and non-marketable yields. The yield was further graded into extra-fine and fine yield as follows: all pods that were 6.5 to 9 mm in diameter and 10 to 13 cm long were classified as fine pods while all pods that were 6 to 7.5 mm in diameter and 8 to 12 cm long were classified as extra-fine pods (USAID-KHCP, 2011).

The pod diameter was determined using a vernier caliper. The weight of the marketable extra-fine and fine pods per treatment was determined using an electronic scale and recorded. The non-marketable extra-fine and fine yield was further graded into pest damaged pods and other rejects. Pest damaged pods were identified using damage symptoms on pods that included feeding marks, scarring and malformation (Infonet-Biovision, 2013)

3.3.6 Cost benefit analysis

The cost benefit analysis was assessed by addition of all the marketable yield for each treatment multiply by the average price per kg minus the total costs to get the net returns for the farmer. The cost benefit ratio was calculated by dividing the total cost by the net return. This can be summarised in the formula below:

Total marketable= Total extra-fine + Total fine

Average price = (Price for extra-fine + Price for fine)/2

Total cost =Land preparation cost + Labour + Cost of inputs

Gross returns= Total marketable x Average price

Net returns= Gross returns – Total cost

Cost-benefit ratio= Total cost/ Net returns

3.3.7 Statistical data analysis

Analysis of variance (ANOVA) was carried out on the data from the two seasons using GenStat Edition 13 software and tested for significance using F-test at 95% level of significance. The treatment means were then compared using the least significant difference (LSD) test at P=0.05 where the F-test was significant (Mead et al., 2003)

3.4 Results

3.4.1 Effect of potassium salts of fatty acids on the number of whitefly population

Potassium salts of fatty acids had an effect on the whitefly population. These fatty acids at the rate of 1% and 1.5% significantly ($P<0.05$) reduced the whitefly population. There was a general reduction in whitefly population in all the treated plots compared to the control which had an increase in the whitefly population (Tables 3.1, 3.2, 3.3 and 3.4). During the first planting in Mwea, potassium salts of fatty acids at the rates of 1 % and 1.5% potassium salts of spray solution had the highest reduction (38% and 44% reduction respectively) of the population of adult whiteflies (Table 3.1). Similar results were observed in the population of whitefly nymphs with potassium salts at the rate of 1.5% potassium salts in spray solution causing higher reduction (46% reduction) of whitefly nymphs than in the control (Table 3.3).

During the second planting, the chemical treatment (Imidacloprid) and potassium salts of fatty acids at rate 1.5% potassium salts in spray solution had the highest reduction (65% and 61% reduction respectively) of the population of adult whiteflies (Table 3.2). Potassium salts at the rates of 1% and 1.5% of spray solution caused a higher reduction (56% and 64% reduction) of whitefly nymphs than the control (Table 3.4). The level of whitefly population was higher in planting one than in planting two (Tables 3.1, 3.2, 3.3 and 3.4). No whitefly was recorded in Embu in the first and second season of the trial.

Table 3.2: Mean number of adult whitefly per sticky card for different rates of potassium salts per sampling in snap beans for 1st planting July-Oct 2013 in Mwea

Treatment	Sampling 1	Sampling 2	Sampling 3	Mean	(%Reduction)
0.5 % Potassium salts	84.0bc	97.7b	94.3b	92.0c	17.1
1 % Potassium Salts	74.1ab	68.2a	63.1a	68.4ab	38.2
1.5 % Potassium Salts	62.9ab	64.8a	60.2a	62.6a	44.0
Confidor	70.3ab	84.1ab	92.9b	82.4bc	25.8
Thunder + Karate	57.2a	87.4ab	85.1b	76.6b	31.0
Control (Water only)	101.6c	112.5bc	119.4c	110.9d	0
P-value	0.031	0.006	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	26.2	23.6	24.1	13.6	
C.V%	7.1	5.5	4.1	1.7	

Treatments with different letters in the same column are significantly different at 5% probability

Table 3.2: Mean number of adult whiteflies per sticky card for different rates of potassium salt per sampling in snap beans for 2nd planting Oct 2013 – Jan 2014 in Mwea

Treatment	Sampling 1	Sampling 2	Sampling 3	Mean	(%Reduction)
0.5 % Potassium salts	59.1a	70.0b	77.2b	68.7b	12.7
1 % Potassium Salts	54.2a	28.3a	17.7a	33.4a	57.6
1.5 % Potassium Salts	55.5a	23.5a	13.3a	30.7a	60.9
Confidor	52.8a	17.2a	13.6a	27.9a	64.5
Thunder + Karate	64.1a	21.8a	14.4a	33.4a	57.6
Control (Water only)	59.3a	79.7b	97.0c	78.7b	0.0
P-value	0.766	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	18.3	13.7	13.6	16.4	
C.V%	12.2	15.8	6.1	8.4	

Treatments with different letters in the same column are significantly different at 5% probability.

Table 3.3: Mean number of whitefly nymphs per leaf for different rates of potassium salts per sampling in snap beans for 1st planting July-Oct 2013 in Mwea

Treatment	Sampling 1	Sampling 2	Sampling 3	Mean	(%Reduction)
0.5 % Potassium salts	31.0bc	27.2a	39.4b	32.5bc	12.4
1 % Potassium Salts	29.9bc	29.3a	32.4b	30.5b	17.8
1.5 % Potassium Salts	18.7a	22.4a	18.5a	19.9a	46.4
Confidor	24.5ab	20.9a	19.3a	21.6a	41.8
Thunder + Karate	18.2a	25.9a	19.6a	21.2a	42.8
Control (Water only)	31.2bc	36.2a	43.8bc	37.1c	0.0
P-value	0.003	0.055	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	7.4	9.8	9.9	5.4	
C.V%	5.3	5.5	14.3	8.4	

Treatments with different letters in the same column are significantly different at 5% probability.

Table 3.4: Mean number of whitefly nymphs per leaf for different rates of potassium salts per sampling in snap beans for 2nd planting Oct 2013 – Jan 2014 in Mwea

Treatment	Sampling 1	Sampling 2	Sampling 3	Mean	% Reduction
0.5 % Potassium salts	34.5a	32.2b	38.0b	34.9b	9.8
1 % Potassium Salts	30.0a	13.1a	8.7a	17.3a	55.2
1.5 % Potassium Salts	27.1a	13.3a	4.4a	14.9a	61.4
Confidor	31.3a	14.2a	10.1a	18.5a	52.2
Thunder + Karate	32.2a	18.4a	9.3a	20.0a	48.3
Control (Water only)	28.6a	36.3b	51.1b	38.7b	0.0
P-value	0.930	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	15.4	10.0	13.1	9.7	
C.V%	10.6	11.9	20.4	11.9	

Treatments with different letters in the same column are significantly different at 5% probability

3.4.2 Effect of potassium salts of fatty acids on thrips population

Potassium salts of fatty acids had an effect on thrips population in Mwea and Embu in the first and second season (Tables 3.5, 3.6, 3.7 and 3.8). The salts at the rates of 1% and 1.5% significantly ($P<0.05$) reduced the thrips population compared to the control. Generally, there were no significant ($P > 0.05$) differences between the chemical treated plots and plots with potassium salts at 1% and 1.5% (Tables 3.5, 3.6, 3.7 and 3.8). Similarly, all the treated plots had a reduction in the thrips population compared to the control. Potassium salts of fatty acids at rate of 1% and 1.5% potassium salts had the highest reduction (44% and 47% reduction respectively) of thrips population in planting one in Mwea (Table 3.5). During the second season, Potassium salts of fatty acids at rate of rates of 1% and 1.5% potassium salts in spray solution had the higher reduction (37% and 41% reduction respectively) of thrips population (Table 3.6).

In Embu, potassium salts of fatty acids had a significant ($P <0.05$) effect on thrips population (Tables 3.7 and 3.8). Potassium salts of fatty acids at the rates of 1% and 1.5% potassium salts had the highest reduction (49% and 51% reduction respectively) of thrips population compared to the control in planting one (Table 3.7). During the second season, potassium salts of fatty acids at the rate of 1.5% potassium salts and the chemical (Imidacloprid) treatment had the highest reduction (60% and 55% reduction respectively) of thrips population compared to the control (Table 3.8).

The level of thrips population was higher in Mwea than in Embu during both planting one and two (Tables 3.5, 3.6, 3.7 and 3.8). The thrips population in Mwea was almost similar in planting one and two (Tables 3.5 and 3.6). However, in Embu, the thrips population was lower in planting one than in planting two (Tables 3.7 and 3.8).

Table 3.5: Mean number of thrips per flower for different rates of potassium salts per sampling in snap beans for 1st planting July-Oct 2013 in Mwea

Treatment	Sampling 1	Sampling 2	Sampling 3	Mean	% Reduction
0.5 % Potassium salts	2.9b	4.0d	1.9ab	2.9b	19.4
1 % Potassium salts	2.1a	2.7ab	1.5a	2.0a	44.4
1.5 % Potassium salts	2.0a	2.1a	1.8ab	1.9a	47.2
Confidor	1.8a	2.4ab	2.1b	2.1a	41.7
Thunder + Karate	1.9a	2.9bc	2.3ab	2.3ab	36.1
Control	3.1b	3.7d	4.0c	3.6c	0.0
P-value	0.008	<0.001	0.020	<0.001	
LSD ($_{p\leq 0.05}$)	0.8	0.7	1.4	0.6	
C.V% (Water only)	7.8	16.7	25.5	15.8	

Treatments with different letters in the same column are significantly different at 5% probability

Table 3.6: Mean number of thrips per flower for different rates of potassium salts per sampling in snap beans for 2nd planting Oct 2013 – Jan 2014 in Mwea

Treatment	Sampling 1	Sampling 2	Sampling 3	Mean	%Reduction
0.5 % Potassium salts	2.7a	2.2a	2.3b	2.4cd	11.1
1 % Potassium salts	2.2a	1.5a	1.6ab	1.7ab	37.0
1.5 % Potassium salts	2.3a	1.4a	1.0a	1.6a	68.7
Confidor	2.4a	1.6a	1.4a	1.8ab	33.3
Thunder + Karate	2.2a	2.1a	2.4b	2.2bc	18.5
Control (Water only)	2.2a	2.6a	3.3c	2.7d	0.0
P-value	0.813	0.103	<0.001	<0.001	
LSD ($_{p\leq 0.05}$)	0.98	1.00	0.81	0.56	
C.V%	9.5	5.6	10.2	3.2	

Treatments with different letters in the same column are significantly different at 5% probability

Table 3.7: Mean number of thrips per flower for each for different rates of potassium salts per sampling in snap beans for 1st planting July-Oct 2013 in Embu

Treatment	Sampling 1	Sampling 2	Sampling 3	Mean	%Reduction
0.5 % Potassium salts	0.25bc	0.40a	0.33a	0.33b	5.7
1 % Potassium salts	0.18b	0.30a	0.33a	0.27ab	22.9
1.5 % Potassium salts	0.05a	0.20a	0.30a	0.18a	48.6
Confidor	0.05a	0.25a	0.20a	0.17a	51.4
Thunder + Karate	0.30c	0.28a	0.30a	0.29b	17.1
Control (Water only)	0.28c	0.33a	0.45a	0.35b	0.0
P-value	<0.001	0.576	0.308	0.006	
LSD ($_{p\leq 0.05}$)	0.09	0.23	0.21	0.11	
C.V%	34.8	21.1	13.6	14.4	

Treatments with different letters in the same column are significantly different at 5% probability

Table 3.8: Mean number of thrips per flower for each for different rates of potassium salts per sampling in snap beans for 2nd planting Oct 2013 – Jan 2014 in Embu

Treatment	Sampling 1	Sampling 2	Sampling 3	Mean	%Reduction
0.5 % Potassium salts	2.40b	1.48c	1.12bc	1.70bc	13.7
1 % Potassium salts	1.55a	0.53a	0.72ab	0.93a	52.8
1.5 % Potassium salts	1.50a	0.55a	0.33a	0.79a	59.9
Confidor	1.20a	0.90ab	0.53ab	0.88a	55.3
Thunder + Karate	1.68ab	1.23bc	0.93bc	1.27ab	35.5
Control (Water only)	1.35b	1.98cd	2.60d	1.97c	0.0
P-value	0.05	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	0.74	0.53	0.59	0.50	
C.V%	21.9	16.7	12.3	8.8	

Treatments with different letters in the same column are significantly different at 5% probability

3.4.3 Effect of potassium salts of fatty acids on yield

Potassium salts of fatty acids had an effect on the yield of snap beans in Mwea and Embu in planting one and two (Tables 3.9 and 3.10). Potassium salts of fatty acids at the rate of 1.5% potassium salts in spray solution caused the highest increase of extra-fine pods by 151% in planting one in Mwea (Table 3.9). Potassium salts at the rate of 0.5% of spray solution had the lowest increase in yield of extra-fine pods causing only an increase of 47% (Table 3.9). In the fine grade, Potassium salts of fatty acids had no significant (P >0.05) effect on the fine yield of snap beans (Table 3.9).

In the second season, potassium salts of fatty acids at the rate 1.5% potassium salts had the highest increase of 78% increase in extra-fine pods (Table 3.9). Potassium salts at the rate of 0.5% spray solution was not significantly (P>0.05) different from the control. In the fine grade, potassium salts of fatty acids had no significant (P >0.05) effect on the fine yield of snap beans (Table 3.9).

In both seasons potassium salts of fatty acids at the rates of 1% and 1.5% potassium salts in spray solution, were not significantly (P> 0.05) from the chemical (Imidacloprid) treatment and farmer practice (alternate spraying of Thunder and Karate) (Table 3.9). Generally, all treated plots had higher yield than the control in both the fine and extra-fine grades (Table 3.9). In Embu, potassium salts of fatty acids did not have any significant (P-value >0.05) effect on the extra-fine and fine yield of snap beans in the first season and second season (Table 3.10).

Table 3.9: Total yield (kg/ ha) of marketable snap bean pods for different rates of potassium salts in snap beans per 1st and 2nd plantings in Mwea

	1st planting (July- Oct 2013)				2nd Planting (Oct - Jan 2014)			
Treatment	Extra-fine	% Inc	Fine	% Inc	Extra-fine	% Inc	Fine	% Inc
0.5 % Potassium salts	2394ab	47	2654a	36	1529a	0	5679bc	39
1 % Potassium salts	2760bc	70	2754a	42	3049c	67	6055c	48
1.5 % Potassium salts	4072cd	151	2754a	42	3236c	78	5706c	39
Confidor	3138c	93	2974a	53	3099c	70	5658bc	38
Thunder + Karate	3748c	130	3898a	100	2355abc	29	4180ab	2.1
Control (Water only)	1624a	0	1946a	0	1821ab	0	4092a	0
P-value	0.002		0.291		0.033		0.048	
LSD ($_{p\leq0.05}$)	1052		1624		1203		1509	
C.V%	15.0		30.1		13.0		16.8	

Treatments with different letters in the same column are significantly different at 5% probability
% Inc= Percentage increase

Table 3.10: Total yield (kg/ ha) of marketable snap bean pods for different rates of potassium salts p in snap beans for per 1st and 2nd plantings in Embu

	1st planting (July- Oct 2013)				2nd Planting (Oct - Jan 2014)			
Treatment	Extra-fine	% Inc	Fine	% Inc	Extra-fine	% Inc	Fine	% Inc
0.5 % Potassium salts	5826a	6	6621a	64	1165a	5.7	1324a	56
1 % Potassium salts	7090a	27	6068a	50	1418a	29	1214a	43
1.5 % Potassium salts	7386a	34	5801a	43	1477a	34	1160a	37
Confidor	5936a	8	6271a	55	1187a	8	1254a	48
Thunder + Karate	6085a	10	5976a	48	1217a	10	1195a	41
Control (Water only)	5510a	0	4043a	0	1102a	0	847a	0
P-value	0.578		0.157		0.578		0.275	
LSD ($_{p\leq0.05}$)	2564		1983		513		27	
C.V%	12.7		12.4		12.7		12.5	

Treatments with different letters in the same column are significantly different at 5% probability
% Inc= Percentage increase

3.4.4 Effect of potassium salts of fatty acids on pest damaged pods

Potassium salts of fatty acids had an effect on pest damaged pods (Table 3.11 and 3.12). Potassium salts of fatty acids had a significantly ($P < 0.05$) reduced pest damaged extra-fine and fine pods (Tables 3.11 and 3.12). Potassium salts of fatty acids at the rate 1.5% potassium salts spray solution had the highest reduction of pest damage in the extra-fine grade by up to 59% during the first season in Mwea (Table 3.11). In the fine yield grade, potassium salts of fatty acids at the rate 1.5% potassium salts spray solution had the highest reduction of up to 50% (Table 3.11).

During the second season, potassium salts of fatty acids had a significant ($P < 0.05$) effect of pest damage on snap beans in Mwea (Table 3.11). Potassium salts of fatty acids at the rate 1.5% potassium salts spray solution had the highest reduction of 90% reduction in the weight of pest damaged extra-fine pods (Table 3.11). Similar results were observed in the fine yield grade with potassium salts of fatty acids at the rates of 1.5% potassium salts spray solution causing the highest reduction of 83% reduction in pest damaged fine pods (Table 3.11).

In Embu, potassium salts of fatty acids had significant ($P < 0.05$) effect on the pest damaged pods. Potassium salts of fatty acids at the rate of 1% potassium salts had the highest reduction (83% reduction) of pest damaged extra-fine pods compared to the control (Table 3.12). Similar results were observed in the fine yield grade with potassium salts of fatty acids at the rate of 1% potassium salts causing the highest reduction (70% reduction) of pest damaged fine pods (Table 3.12).

In the second season, potassium salts of fatty acids had significant ($P < 0.05$) effect on the pest damaged pods. Potassium salts of fatty acids at the rate of 1.5% potassium salts had the highest reduction (91% reduction) of pest damaged extra-fine pods. Similar results were observed in the fine grade yield with potassium salts of fatty acids at the rate of 1.5%

potassium salts causing the highest reduction (70% reduction) of pest damaged fine pods compared to the control (Table 3.12). Chemical (Imidacloprid) treatment also had significant ($P<0.05$) reduction in pest damage of snap beans. However, the chemical (Imidacloprid) treatment was not significantly ($P>0.05$) different from potassium salts at the rates of 1% and 1.5% of spray solution (Table 3.12).

Table 3.11: Total yield (kg/ ha) of pest damaged snap bean pods in each grade for different rates of potassium salts per 1st and 2nd plantings in Mwea

	1st planting (July- Oct 2013)				2nd Planting (Oct - Jan 2014)			
Treatment	Extra-fine	% dec	Fine	% dec	Extra-fine	% dec	Fine	% dec
0.5 % Potassium salts	149b	32	224ab	32	66a	76	265b	43
1 % Potassium salts	128ab	42	187a	43	69a	75	114a	75
1.5 % Potassium salts	90a	59	164a	50	28a	90	79a	83
Confidor	72a	67	156a	52	98a	64	110a	76
Thunder + Karate	203c	8	274bc	16	103a	62	328b	29
Control (Water only)	221c	0	328c	0	274b	0	465c	0
P-value	<0.001		<0.001		<0.001		<0.001	
LSD ($_{p\leq0.05}$)	57		70		89		106	
C.V%	11.6		28.4		24.8		10.0	

Treatments with different letters in the same column are significantly different at 5% probability
% dec= Percentage decrease

Table 3.12: Total yield (kg/ ha) of pest damaged snap bean pods in each grade for different rates of potassium salts for 1st and 2nd plantings in Embu in 2013

	1st planting (July- Oct 2013)				2nd Planting (Oct - Jan 2014)			
Treatment	Extra-fine	% dec	Fine	% dec	Extra-fine	% dec	Fine	% dec
0.5 % Potassium salts	234b	49	389b	34	91c	0	78b	34
1 % Potassium salts	84a	82	268a	55	47b	48	54a	55
1.5 % Potassium salts	115a	75	178a	70	23a	75	36a	70
Confidor	39a	91	246a	58	8a	91	49a	59
Thunder + Karate	288b	36	459b	22	59b	35	92b	23
Control (Water only)	456c	0	592c	0	91c	0	119c	0
P-value	<0.001		<0.001		<0.001		<0.001	
LSD ($_{p\leq0.05}$)	101		100		20		20	
C.V%	24.1		18.9		24.1		18.9	

Treatments with different letters in the same column are significantly different at 5% probability
% dec= Percentage decrease

3.4.5 Cost benefit analysis for different rates of potassium salts in snap beans in 2013

The cost benefit calculations showed that use of potassium salts at 1% and 1.5% of spray solution were more profitable compared to the other pest management options evaluated in this study with the cost benefit ratio at 1.6 and 1.7 (Table 3.13). The application of chemical pesticide (Imidacloprid) with a cost-benefit ratio at 1.6 was also profitable compared to the application of potassium salts at 0.5% and application of Thunder (Imidacloprid 100 g/L + Betacyfluthrin 45 g/L) and Karate (Lambda Cyhalothrin 25g/kg) on pest detection (Table 3.13). Potassium salts at the rate of 0.5% was the least cost effective pest management option (Table 3.13).

The highest input in terms of chemical costs was in the pest management strategy with potassium salts 1.5% followed by potassium salts at 1%. The net returns were however, also high in these particular pest management options leading to a higher cost-benefit ratio compared to other pest management options (Table 3.13). The labour costs remained the same across all the pest management options (Table 3.13).

Table 3.13: Cost benefit analysis for different concentrations of potassium salts of fatty acids in snap beans in 2013

Treatment	Total marketable/ ha (kg)	Average price/Kg (Ksh)	Returns (Ksh)	Labour cost (Ksh)	Chemical costs (Ksh)	Net returns (Ksh)	Cost benefit ratio
0.5 % Potassium salts	6798	40	271920	140,000	36000	95,920	1.8
1 % Potassium salts	7602	40	304080	140,000	40400	113,680	1.6
1.5 % Potassium salts	7898	40	315920	140,000	43800	111,120	1.7
Confidor	7379.25	40	295170	140,000	41,200	113,970	1.6
Thunder + Karate	7163.5	40	286540	140,000	41,200	105,340	1.7
Control	5246.25	40	209850	140,000	0	69,850	2.0

3.5 Discussion

Potassium salts of fatty acids significantly ($P < 0.05$) reduced the whitefly population in Mwea in plantings one and two. Potassium salts at the concentration of 1.5% was effective in the management of whitefly causing up to 65% reduction in whitefly population. There was no significant ($P > 0.05$) difference between the lowest rate of potassium salts 0.5% and the untreated control. These findings are consistent with reports by Mohamad et al., (2013) and Dheeraj et al., (2013) who the reported effect of potassium salts on aphids and whiteflies respectively. Similar results have been reported by Liu et al., (2000), Vavrina et al., (1995) and Ciancio et al., (2010). Hollingsworth, (2005) also reported the control of scales and mealybugs using potassium salts of fatty acids.

The effectiveness of potassium salts of fatty acids this study increased with the increase in their concentration in the spray solution. The lowest concentartion of 0.5% potassium salts in spray solution was less effective compared to the highest concentartion of 1.5% potassium salts in spray solution. This report agrees with the findings by Liu et al., (2000) where increase in the concentration of potassium salts resulted in higher mortalities in whitefly. These results demontrated that potassium salts are just as effective as synthetic chemical pesticides in the management of whitefly (Dheeraj et al., 2013).

Potassium salts of fatty acids work only on direct contact with the pest. Toxicity of potassium salts of fatty acids has been reported by Liu et al., (2000). Potassium salts of fatty acids work on most soft-bodied insect pests (Koppert, 2013) and have been successfully used in the management of aphids, whiteflies, scales and mealy bugs (Mohamad et al., 2013; Dheeraj et al., 2013; Hollingsworth, 2005).

The results obtained in this study showed that potassium salts of fatty acids at the concentration of 1.5% are effective in the management of thrips causing up to 68% reduction in their population. At both experimental sites, these salts at 1% and 1.5% resulted to having significant ($P<0.05$) reduction of thrips population. The results are consistent with the results by Clinton et al., (2011) who reported the management of thrips in onions using potassium salts of fatty acids. The results also agree with various studies by Heidi and Cullen, (2008); Ciancio et al., (2010); Mohamad et al., (2013) and Dheeraj et al., (2013) where use of potassium salts for the management of aphids and other arthropod pests has also been reported.When pests come in contact with the spray solution of the potassium salts, the potassium salts wash away the protective coating on the insect surface and penetrate the cell membrane causing disruption of the cell membrane permeability which leads to desiccation of the insects (Mohamad et al., 2013; Dheeraj et al., 2013; Ciancio et al., 2010).

The results obtained in this study showed that potassium salts of fatty acids when used at the rate of 1% and 1.5% for the management of whitefly and thrips led to higher yields compared to unsprayed plots resulting in up to 151% increase in yield. There were no significant ($P>0.05$) differences between the chemically treated plots and potassium salts at the concentration of 1% and 1.5% potassium salts in spray solution. These results concur with findings by Clinton et al., (2011) who reported an increase in yield with decrease in pest population after application of potassium salts of fatty acids. Studies by Nderitu et al., (2009); Delkhoshi et al., (2012) and El-Mohamedy et al., (2008) reported increased yields in various crops as a result of application of pest control measures to reduce pest populations. The results above contradicts the results by Vavrina et al., (1995) in which application of higher rates of potassium salts of fatty acids led to reduction in yield of tomato fruits.

Unlike synthetic chemical pesticides, potassium salts of fatty acids are fast acting with a quick knock down effect on the pests and break down quickly after application leaving no residues on the crop (Dheeraj et al., 2013). This results in better growth of the crop leading to higher yields. Chemical residues on the crop can lead to phytotoxicity which affects the growth of plants (Hollingsworth, 2005). Potassium salts of fatty acids are also very effective in the management of insect pests which reduce productivity in agricultural systems and therefore the use of these salts leads to higher yields (Dheeraj et al., 2013, Mohamad et al., 2013)

All the rates of potassium salts of fatty acids tested which were caused a significant ($P < 0.05$) reduction in pest damage in snap beans both in the extra-fine and fine grades. These salts at the rate of 1.5% caused the highest reduction in pest damage on snap bean pods of up to 91%. The present results agree with results by Clinton et al., (2011) who reported lower pest damage in onions in the treatments with higher rates of potassium salts. Mohamad et al., (2013); Dheeraj et al., (2013) and Hollingsworth, (2005) have all reported reduction of insect pest population on application of potassium salts of fatty acids. Potassium salts of fatty acids reduce insect pest populations leading to reduced pest damage on produce.

The cost benefit analysis showed that the use of potassium salts for management of thrips and whitefly was just as profitable as using the chemical pesticides. Potassium salts at 1% concentration had the was more profitable compared to potassium salts at the concentrations of 0.5% and 1.5%. However, potassium salts at 1.5% was the most effective concentration and was also profitable just as the chemical control. Potassium salts pose no risk of residues on the crop and therefore offer the best alternative to chemical pesticides.

The results above demonstrate that potassium salts of fatty acids at the concentration of 1.5% potassium salts in spray solution are effective in the management of thrips and whiteflies on snap beans and can be used as alternative to synthetic chemical pesticides in snap bean production.

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CHAPTER FOUR: EFFECTIVENESS OF INTEGRATING SEED DRESSING, FOLIAR SPRAYS AND INTERCROPPING IN THE MANAGEMENT OF SNAP BEAN PESTS

4.1 Abstract

Insect pests remain a major constratint in the production of snap beans and farmers mainly rely on chemical pesticides to manage the insect pests and diseases. However, the introduction of maximum residue levels (MRLs) for export vegetables by European markets pose a challenge to the use of pesticides. This study was carried out to develop sustainable options of managing snap bean pests and reducing chemical residues on snap bean produce.

Field experiments were carried out in farmers' fields in Mwea and Embu from July 2013 to January 2014 for two planting cycles under irrigation. The integrated pest management strategies evaluated included: i) seed dressing only, ii) seed dressing followed by three neem sprays, iii) seed dressing followed by two pyrethroid sprays and one neem spray, iv) seed dressing followed by three pyrethroid sprays and intercropping snap bean with maize, v) seed dressing followed by two pyrethroid sprays plus one spray with a biological product, vi) seed dressing followed by two neem sprays plus one spray with a biological product, and vii) two pyrethroid sprays and one neem spray only. The data collected included: emergence, plant stand, nodulation, thrips population, bean stem maggot population, whitefly population, yield and pest damage.

The combination of seed dressing, two pyrethroid sprays and neem applied at the vegetative stage, early flowering and early podding reduced white fly and thrips population by up to 54% and 60% respectively. Similar results were also observed on plots where seeds dressing was done before planting combined with intercropping with maize plus three pyrethroid sprays at the vegetative stage, early flowering and early podding. Seed dressing had a direct effect on the bean stem maggots that attack the seedling at a very young stage. Spraying with pyrethroid sprays had a quick knockdown effect on the population of whitefly and thrips while the maize intercrop also reduced the pest population. These options also reduced pod damage due to thrips by up to 75 and 93% and increased yield of extra-fine by up to 157 and 162% and fine pods by up to 148 and 133%. The results showed that seed dressing followed by two pesthrin sprays at the vegetative stage and early flowering stage plus a single spray with Nimbecidine at early podding, sprays and intercropping with maize were effective in managing snap bean pests. This demonstrates that integrated pest management options would be viable alternatives to chemical pesticides thereby enabling farmers meet the strict maximum chemical residue level requirements set by European consumers.

Key words: *Phaseolus vulgaris* L, seed dressing, bio-pesticides, intercropping, integrated pest management

4.2 Introduction

Snap bean (*Phaseolus vulgaris* L.) is grown specifically for the immature green pods primarily for export market to European Union and elite local urban markets (Infonet-Biovision, 2014). The production of snap bean, one of Kenya's most important export vegetable crops, is steadily rising (HCDA, 2013). Snap beans from Kenya are exported to United Kingdom, France, Holland, Germany, United Arab Emirates and South Africa (HCDA, 2013). Local consumption of snap beans has also increased over the last few years, providing a domestic market (HCDA, 2013). Snap bean production is mainly by small scale farmers and it is estimated that over 50,000 smallholder families are involved in snap bean production in Kenya contributing to the larger agricultural sector (Infonet-Biovision, 2014). The agricultural sector plays an important role in Kenya's economy contributing directly and indirectly to the countries GDP (MOA, 2012).

Production of snap beans in Kenya is constrained by insect pests and diseases (Nderitu et al., 2007). Insect pests cause both direct damage during feeding and indirect damage through transmission of viruses in snap beans. Some of the most important pests in snap bean production include thrips, whiteflies, bean flies and aphids. These insect pests cause considerable yield loss of snap beans. Currently, the most common pest management strategy employed in snap bean production, is the use of chemical pesticides (Nderitu et al., 2007). Some of the chemical pesticides currently used for insect pests include: Confidor (Imidacloprid), Thunder (Imidacloprid 100g/L + Betacyfluthrin 45g/L), dimethoate (sold in over 25 products), and Karate (Lambda Cyhalothrin 25g/Kg) (Nderitu et al., 2008; Ndung'u, 2013). Most farmers use the chemical pesticides on calender spray regimes (Nderitu et al., 2008). Improper and excessive use of chemical pesticides leads to contamination in the enevironment and chemical residues of fresh produce.

Chemical pesticide contamination poses significant risks to the environment and non-target organisms ranging from beneficial soil microorganisms, to insects, plants, fish, and birds (Aktar et al., 2009; Kumar et al., 2012; Leila et al., 2013). Resistance to chemical insecticides by pests such as whiteflies and thrips has been reported making it difficult to sustainably manage these pests with chemicals only (Cardona, 2012; Gorman et al., 2007). In the recent past, the European Union (EU) which is the major market for snap bean farmers and exporters has enforced stringent food safety and quality measures which in turn threaten the procurement of produce from small farmers in developing countries (Dolan, 2001). The measures are with regards to maximum residue levels (MRLs) which have been changed from 0.2 to 0.02 parts per million which is a limit for detection (Ndung'u, 2013). These maximum residue levels (MRLs) for export vegetables by European retailers, poses a challenge to the use of pesticides (Nderitu et al; 2009). Over reliance on chemicals has often led to non compliance by Kenyan exporters leading to losses that are passed over to farmers (Mwangi, 2012; Ndung'u, 2013).

The use pest control technologies that lead to reduced reliance on chemical pesticides and use of environmentally friendly pest control measures is a major step towards sustainable pest management (Nderitu et al; 2009). Some of these technologies include reduced pesticide application frequency and use of environmentally friendly pesticides such as seed dressers, bio-pesticides and modified cropping systems (Nderitu et al., 2009). Biopesticides have been reported to be just as effective as synthethic chemical pesticides and as such can be used to as an alternative to chemical pesticides in an integrated pest management system once their efficacy is validated (Degri et al., 2013; Mandi et al., 2009; Marčić et al., 2012). Macrobial biopesticides include live macro-organisms such as predatory mites and parasitic wasps, botanical biopesticides include products based on plant extracts such as neem and microbial biopesticides include products based on micro-organisms for example *Verticillium lecanii* and *Bacillus subtilis* (Gupta et al 2010; PCPB, 2013). The use of biopesticides in an integrated pest management system is also an alternative to over-reliance on chemical pesticides (Srinivasan, 2012).

Seed dressing is an important technology is effective for management of sucking insect pests (Hossain et al., 2012; Pons and Albajes, 2002). This technology entails treating of seeds with a systemic insecticide before sowing (Hossain et al., 2013). Intercropping is a cultural practice that has been reported to contribute greatly in the management of various insect pests (Abd-Rabou et al., 2012; Rahnama et al., 2013; Theunissen et al., 1996). Intercropping reduces insect pests through increasing of the biodiversity in the ecosystem which leads to a build up of natural enemies that contribute to the management of pests (Rao et al., 2012;

Usmanikhail et al., 2012). This study was undertaken to determine the effectiveness of integrating seed dressing, foliar sprays and intercropping in the management of snap bean pests.

4.3 Materials and methods

4.3.1 Description of the experimental sites

The experiment was carried out in farmers' fields in Mwea, Kirinyaga South district, Kirinyaga County and Embu East district, Embu County. It is situated in a region with a good transport network and therefore is easily accessible. There is an irrigation infrastructure that allows year round production and therefore faster implementation of the project. The experimental site was located in lower midland zone 4 (LM4), a semiarid area with soils classified as nitosols (Infonet-Biovision, 2013). The average rainfall is about 850 mm with a range of 500 - 1250 mm divided into long rains (March – June with an average of 450 mm) and short rains (Mid-October to December with an average of 350 mm). The rainfall is characterized by uneven distribution in total amounts, time and space. The temperature ranges from 15.6º C to 28.6º C with a mean of about 22ºC.

Embu East is located in Embu County which is located in Upper Midland 2 (UM2) agro-ecological zone and receives high amounts of rainfall (Infonet-Biovision, 2013). The annual average high temperature is 28.8 °C while the annual average low temperature 9.6 °C. The area receives an average annual precipitation of 1206 mm.

The production of snap beans in both sites is mainly for export and is carried out by small scale farmers organized into self-help groups within the irrigation scheme.

4.3.2 Description of experimental materials

Seed dressing was carried out using moncerine at the rate of 3 g product per Kg of seed. Pesthrin was applied at the rate of 5 Litres per ha in 1000liters of water. The farmer practice was carried out by alternate application of Thunder at the rate 0.5 litres product per ha in 1000 litres of water and Karate 17.5 EC at the rate of 325ml product per ha in 1000 litre of water. The control was sprayed with water only during application of the other treatments. Nimbecidine was applied at the rate of 3liters per ha in 1000 litres of water and Biocatch WP was applied at the rate of 4kg per ha in 1000 litres of water (Table 4.0)

Table 4.0: Description of experimental materials

Product	AI	Description
Moncerene	Imidacloprid 233g/L + Pencycuron 50g/L +Thiram 107g/L	Application rates at 3g ml per kg of seed
Nimbecidine	Azadirachtin 0.03%	Application rate at 3ml per litre of water
Pesthrin 6% EC	Pyrethrins 6%)	Application rate 5m per Litre of water
Biocatch 1.15WP	*Verticillium lecanii*	Application rate of 4kg per ha
Thunder	Imidacloprid 100 g/L + Betacyfluthrin 45g/L	Application rate at 10 ml in 20 litres of water
Karate	Lambda Cyhalothrin 25 g/kg	Application rate at 6.5 ml in 20 litres of water

4.3.3 Experimental layout and design

The experiment was carried out in a farmer's field under irrigated agriculture over two cropping cycles. Snap beans were planted in plots measuring 5 m by 4 m with 1m alleys between the plots and replicated four (4) times. The snap bean variety used for the trial was Serengeti planted in single rows with spacing of 10 cm x 30 cm. Maize in the intercrop treatment was planted at the same time with the snap beans at a spacing of 75 cm by 25 cm. The experiment was laid out in a randomized complete block design (RCBD) with 1.5 m alleys between the blocks. Fertilizer application was done once at planting using diammonium phosphate (18%N and 46% P_2O_5) applied just before seed placement at the rate of 490 kg per ha. Top dressing was done at 21 days after emergence with calcium ammonium nitrate at the rate of 490 kg per Ha. The first weeding was done two WAE followed by a second weeding two weeks later.

All the sprays were carried out using a hand knapsack sprayer which was first calibrated before treatment application begun. Diseases were controlled using chemical pesticides - Kocide (Copper Hydroxide 61.4%) against rust and rots, Mancozeb against leaf spots and Ortiva (Azoxystrobin 250g/L) against mildews.

The nine treatments in the experiment were applied as follows:

i. Seed dressing Moncerene (Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L) only. No other insect pest management practices
ii. Farmers practice. Application of Thunder (Imidacloprid 100g/L + Betacyfluthrin 45g/L) and Karate (Lambda Cyhalothrin 25g/Kg) on pest detection
iii. Seed dressing with Moncerene (Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L) followed by three Neem (Azadirachtin 0.03%) (Nimbecidine- Azadirachtin 0.03%) sprays at vegetative stage, beginning of flowering and early podding.
iv. Seed dressing with Moncerene (Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L) followed by two pyrethroid sprays using Pesthrin 6% EC (Pyrethrins 6%) at vegetative stage and beginning of flowering and a Neem (Azadirachtin 0.03%) spray (Nimbecidine- Azadirachtin 0.03%) at early podding

v. Seed dressing with Moncerene (Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L) and the snap beans planted as intercropped with maize (Baby corn); three prythroid sprays using Pesthrin 6% EC (Pyrethrins 6%)at vegetative stage, beginning of flowering and at early podding

vi. Seed dressing with Moncerene (Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L) followed by two pyrethroid sprays using Pesthrin 6% EC (Pyrethrins 6%)at vegetative stage and at beginning of flowering; one biological spray Biocatch 1.15WP (*Verticillium lecanii*) at early podding

vii. Seed dressing with Moncerene (Imidacloprid 233g/L+Pencycuron 50g/L +Thiram Ten7g/L) followed by two Neem (Azadirachtin 0.03%) (Nimbecidine- Azadirachtin 0.03%) sprays at the vegetative stage and at beginning of flowering; one a biological spray with Biocatch 1.15WP (*Verticillium lecanii*)

viii. No seed dressing; two pyrethroid sprays using Pesthrin 6% EC (Pyrethrins 6%) at vegetative and at beginning of flowering followed by one Neem (Azadirachtin 0.03%) (Nimbecidine- Azadirachtin 0.03%) spray at early podding.

ix. Control (-ve); No treatment at all. Sprayed with water only during application of other treatments.

4.3.4 Assessment of agronomic parameters

The agronomic data collected included: plant emergence at 10 days after planting and plant stand at two, four, six, seven and eight weeks after emergence (WAE). The plant emergence and plant stand were determined by counting number of plants in each plot. Nodulation was also assessed by destructively sampling five plants in each plot. The roots from the plants were taken to the laboratory where they were washed and the nodules removed and counted.

4.3.5 Assessment of pest population

The main pests assessed in these experiments were whiteflies, thrips and the bean stem maggot (bean fly). The population of whiteflies was assessed by use of yellow sticky trap counts and leaf counts. A yellow sticky trap was placed at the centre of each plot and the adult whiteflies on the yellow sticky trap were counted bi-weekly (Hirano et al.,1995; Hoelmer et al., 1998). This was done at two, four, six and eight WAE. Bi-weekly sampling at two, four, six and eight WAE of ten lower leaves from ten plants in a zig-zag manner from inner rows of each plot were carried out and the nymphs of the whitefly were counted and recorded (Soto et al., 2002).

Thrips population was assessed weekly from the start of flowering by sampling ten flowers from ten plants per plot from the inner rows and kept in 70% ethanol. This was carried out three times at six, seven and eight weeks after emergence. The flowers were taken to the laboratory where each flower was placed in a petri dish, dissected and washed to make sure that no thrips were lost with the debris (Nderitu et al., 2009). The thrips were then counted under a dissecting microscope using a tally counter. Both adults and nymphs were counted and identified based on their morphological characteristics and recorded.

Bean stem maggot (beanfly) incidence was assessed by checking and sampling of plants showing infestation. Ten plants from the outer rows of each plot were destructively sampled at two, four and six weeks after emergence. The sampled plants were dissected and the number of larvae and pupae of the bean fly identified using morphological characteristics and counted. The beanfly maggots are yellow in colour and the pupae are brown or black in colour- (Infonet-Biovision, 2013). This was then recorded. The main symptoms of beanfly to be used to recognize infestation were punctures and scarification on leaves, swelling at the base of the stem, development of longitudinal cracks on stems and yellowing of leaves that give a drought like appearance (Infonet-Biovision, 2013).

4.3.6 Assessment of pod yield and quality of snap beans.

Harvesting and grading mainly immature pods was done twice every week for two weeks. Pods were harvested from three inner rows in each plot. The pods were then graded into marketable and non-marketable yield. This was further graded into extra-fine and fine yield as follows; all pods that were 6.5 to 9 mm in diameter and 10 to 13 cm long classified as fine pods while all pods that were 6 to 7.5 mm in diameter and 8 to 12 cm long extra-fine pods (USAID-KHCP, 2011). The weight of the marketable extra-fine and fine pods per treatment was determined using an electronic scale and recorded. The non-marketable extra-fine and fine yield was further graded into pest damaged pods and other rejects. Pest damage pods were identified using damage symptoms on pods that include feeding marks, scarring and malformation (Infonet-Biovision, 2013).

4.3.7 Cost benefit analysis

The cost benefit analysis was assessed by addition of all the marketable yield for each treatment multiply by the average price per kg minus the total costs to get the net returns for the farmer. The cost benefit ratio was calculated by dividing the total cost by the net return. This can be summarised in the formula below:

Total marketable= Total extra-fine + Total fine

Average price = (Price for extra-fine + Price for fine)/2

Total cost =Land preparation cost + Labour + Cost of inputs

Gross returns= Total marketable x Average price

Net returns= Gross returns – Total cost

Cost-benefit ratio= Total cost/ Net returns

4.3.8 Statistical data analysis

Analysis of variance (ANOVA) was carried out on the data from the two seasons using GenStat Edition 13 software and tested for significance using F-test at 95% level of significance. The treatment means were then compared using the least significant difference (LSD) test at P=0.05 where the F-test was significant (Mead et al., 2003)

4.4 Results

4.4.1 Effect of integrating seed dressing, foliar sprays and intercropping on plant emergence

Integrating seed dressing, foliar sprays and intercropping with maize had an effect on emergence of snap beans in Mwea and Embu (Tables 4.1, 4.2, 4.3 and 4.4). Seed dressing significantly ($P<0.05$) increased the emergence of snap beans in Mwea (Tables 4.1 and 4.2). Seed dressing with Moncerene (Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L) increased emergence of snap beans by 25% in Mwea in planting one compared to non-dressed plots (Table 4.1). During the second season, seed dressing increased emergence of snap beans by 23% compared to the non-dressed plots (Table 4.2).

In Embu, seed dressing significantly ($P<0.05$) increased the emergence of snap beans in planting one (Table 4.3). Seed dressing increased emergence of snap beans by 14% (Table 4.3). In the second season, seed dressing did not have a significant ($P>0.05$) effect on the emergence of snap beans. However, seed dressed plots had a higher emergence than the non-dressed plots (Table 4.4). The percent emergence at 10 days after planting however, was lower than the percent emergence at 2WAE. Similarly, the effect of seed dressing was lower in planting two than in planting one (Tables 4.1, 4.2, 4.3 and 4.4).

Table 4.1: Plant emergence for different integrated treatments per sampling in snap beans for 1st planting July-Oct 2013 in Mwea

Treatment	10 days after planting (%)	2WAE (%)	Mean (%)	% increase
Seed dressing only (Moncerene)	85b	94b	90b	25
Farmer practice (Thunder + Karate)	71a	72a	72a	0
Seed dressing + 3 Neem	84b	93b	88b	22
Seed dressing + 2 Pesthrin + 1 Neem	87b	95b	91b	26
Seed dressing + Intercrop + 3 Pesthrin	86b	94b	90b	25
Seed dressing+ 2 Pesthrin + 1 Biocatch	88b	95b	91b	26
Seed dressing + 2 Neem + 1 Biocatch	87b	94b	90b	25
2 Pesthrin+ 1 Neem	71a	74a	73a	0
P-value	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	4.7	5.3	5.1	
C.V%	1.3	3.1	2.1	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.2: Plant emergence for different integrated treatments per sampling in snap beans for 2nd planting Oct 2013- Jan 2014 in Mwea

Treatment	10 days after planting (%)	2WAE (%)	Mean (%)	(%) increase
Seed dressing only (Moncerene)	79a	95b	86bc	23
Farmer practice (Thunder + Karate)	69a	79a	73ab	0
Seed dressing + 3 Neem	77a	94b	85bc	21
Seed dressing + 2 Pesthrin + 1 Neem	71a	96b	82ab	17
Seed dressing + Intercrop + 3 Pesthrin	78a	93b	85bc	21
Seed dressing+ 2 Pesthrin + 1 Biocatch	77a	94b	86bc	23
Seed dressing + 2 Neem + 1 Biocatch	80a	95b	88bc	26
2 Pesthrin+ 1 Neem	66a	81a	72ab	0
Control (Water only)	66a	79a	70a	0
P-value	0.613	<0.001	0.022	
LSD ($_{p\leq0.05}$)	18	6.5	12.1	
C.V%	7.7	2.0	3.9	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.3: Plant emergence for different integrated treatments per sampling in snap beans for 1st planting July-Oct 2013 in Embu

Treatment	10 days after planting (%)	2WAE (%)	Mean (%)	% increase
Seed dressing only (Moncerene)	87b	92bc	90b	14
Farmer practice (Thunder + Karate)	93c	96cd	94c	19
Seed dressing + 3 Neem	88b	91b	90b	14
Seed dressing + 2 Pesthrin + 1 Neem	86b	93bc	90b	14
Seed dressing + Intercrop + 3 Pesthrin	88b	93bc	90b	14
Seed dressing+ 2 Pesthrin + 1 Biocatch	88b	92bc	90b	14
Seed dressing + 2 Neem + 1 Biocatch	88b	94c	91b	15
2 Pesthrin+ 1 Neem	76a	82a	79a	0
P-value	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	3.9	3.4	3.4	
C.V%	0.8	1.3	1.0	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.4: Plant emergence for different integrated treatments per sampling in snap beans for 2nd planting Oct 2013- Jan 2014 in Embu

Treatment	10 days after planting (%)	2WAE (%)	Mean (%)	(%) Increase
Seed dressing only (Moncerene)	73a	88b	78a	13
Farmer practice (Thunder + Karate)	70a	87b	79a	14
Seed dressing + 3 Neem	67a	89b	78a	13
Seed dressing + 2 Pesthrin + 1 Neem	72a	90b	81a	17
Seed dressing + Intercrop + 3 Pesthrin	70a	87b	79a	14
Seed dressing+ 2 Pesthrin + 1 Biocatch	74a	88b	79a	14
Seed dressing + 2 Neem + 1 Biocatch	68a	86b	77a	12
2 Pesthrin+ 1 Neem	62a	73a	67a	0
Control (Water only)	60a	78a	69a	0
P-value	0.256	<0.001	0.159	
LSD ($_{p\leq0.05}$)	12	6.3	11	
C.V%	4.6	3.8	3.4	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.4.2 Effect of integrating seed dressing, foliar sprays and intercropping on plant stand

Integrating seed dressing, foliar sprays and intercropping with maize had a significant ($P<0.05$) effect on the plant stand of snap beans in Mwea and Embu both in planting one and two (Tables 4.5, 4.6, 4.7 and 4.8). Seed dressing had a significant ($P<0.001$) positive impact on the plant stand of snap beans in Mwea.

Seed dressing increased the plant stand of snap beans by 37 to 40% in planting one in Mwea compared to the non- dressed plots (Table 4.5). In the second season, seed dressing increased the plant stand of snap beans by 23 to 27% compared to the non- dressed plots (Table 4.6).

In Embu, seed dressing with Moncerene (Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L) had a significant effect ($P<0.001$) on the plant stand of snap beans. Seed dressing increased the plant stand of snap beans by 15 to 20% in planting one compared to the non-dressed plots (Table 4.7).

In the second season, seed dressing increased the plant stand of snap beans by 20 to 31% compared to the non-dressed plots (Table 4.8). Overall, in Mwea the effect of seed dressing on the plant stand of snap beans was higher in the first season compared to the second season. In Embu, the effect of seed dressing on the plant stand of snap beans was higher in the second season compared to the first season.

Table 4.5: Plant stand for different integrated treatments per sampling in snap beans for 1st planting July-Oct 2013 in Mwea

Treatment	2WAE	4WAE	6WAE	8WAE	Mean	% increase
Seed dressing only (Moncerene)	405b	384b	368b	350b	376b	37
Farmer practice (Thunder + Karate)	311a	293a	265a	238a	277a	0
Seed dressing + 3 Neem	397b	375b	353b	338b	366b	34
Seed dressing + 2 Pesthrin + 1 Neem	408b	384b	364b	352b	377b	37
Seed dressing + Intercrop + 3 Pesthrin	403b	381b	366b	350b	375b	37
Seed dressing+ 2 Pesthrin + 1 Biocatch	408b	390b	376b	358b	383b	40
Seed dressing + 2 Neem + 1 Biocatch	403b	386b	371b	356b	379b	38
2 Pesthrin+ 1 Neem	319a	287a	256a	235a	274a	0
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	22.6	16.1	19.3	21.2	18.7	
C.V%	3.1	2.7	3.5	3.8	3.1	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.6: Plant stand for different integrated treatments per sampling in snap beans for 2nd planting Oct 2013- Jan 2014 in Mwea

Treatment	2WAE	4WAE	6WAE	8WAE	Mean	% Increase
Seed dressing only (Moncerene)	406b	395b	380b	369b	387b	27
Farmer practice (Thunder + Karate)	340a	311a	291a	301a	310a	0
Seed dressing + 3 Neem	402b	389b	369b	357b	379b	25
Seed dressing + 2 Pesthrin + 1 Neem	411b	389b	371b	359b	382a	26
Seed dressing + Intercrop + 3 Pesthrin	398b	382b	369b	351b	375b	23
Seed dressing+ 2 Pesthrin + 1 Biocatch	405b	390b	371b	358b	381b	25
Seed dressing + 2 Neem + 1 Biocatch	409b	388b	376b	363b	384b	26
2 Pesthrin+ 1 Neem	348a	317a	299a	267a	308a	0
Control (Water only)	340a	313a	291a	273a	304a	0
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	
LSD ($p\leq0.05$)	28.0	29.9	33.2	21.2	20.6	
C.V%	2.0	1.8	2.3	4.1	2.2	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.7: Plant stand for different integrated treatments per sampling in snap beans for for 1st planting July-Oct 2013 in Embu

Treatment	2WAE	4 WAE	6WAE	8WAE	Mean	% Increase
Seed dressing only (Moncerene)	395b	373b	371b	354b	376b	16
Farmer practice (Thunder + Karate)	411cd	385b	378b	365b	387b	20
Seed dressing + 3 Neem	392b	370b	365b	352b	372b	15
Seed dressing + 2 Pesthrin + 1 Neem	397b	374b	370b	355b	376b	16
Seed dressing + Intercrop + 3 Pesthrin	399bc	374b	369b	355b	376b	16
Seed dressing+ 2 Pesthrin + 1 Biocatch	395b	372b	367b	355b	374b	16
Seed dressing + 2 Neem + 1 Biocatch	403bc	379b	375b	361b	381b	18
2 Pesthrin+ 1 Neem	352a	320a	313a	294a	323a	0
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	14.4	17.3	13.8	13.7	13.4	
C.V%	1.3	1.3	1.2	1.3	1.3	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.8: Plant stand for different integrated treatments per sampling in snap beans for 2nd planting Oct 2013- Jan 2014 in Embu

Treatment	2WAE	4WAE	6WAE	8WAE	Mean	% Increase
Seed dressing only (Moncerene)	378b	364b	351b	339cd	358c	21
Farmer practice (Thunder + Karate)	375b	339b	347b	331bc	348bc	18
Seed dressing + 3 Neem	380b	366b	353b	338cd	359c	21
Seed dressing + 2 Pesthrin + 1 Neem	387b	376b	362b	348cd	368c	24
Seed dressing + Intercrop + 3 Pesthrin	374b	358b	345b	331bc	352bc	19
Seed dressing+ 2 Pesthrin + 1 Biocatch	376b	363b	349b	334cd	356bc	20
Seed dressing + 2 Neem + 1 Biocatch	367b	350b	336b	298bc	337b	14
2 Pesthrin+ 1 Neem	313a	293a	267a	250a	280a	0
Control (Water only)	333a	305ab	282a	264ab	296a	0
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	26.9	35.2	31.5	34.1	19.3	
C.V%	3.8	4.5	4.4	4.0	4.1	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.4.3 Effect of integrating seed dressing, foliar sprays and intercropping on nodulation

Integration of seed dressing, foliar sprays and intercropping with maize did not have any significant effect (P > 0.05) on nodulation in snap beans in Mwea and Embu (Table 4.9). The two seasons did not result in any significant (P > 0.05) difference in nodulation in the treated plots and the untreated control. Seed dressing did not cause any significant effect (P > 0.05) on nodulation. The non-dressed plots and seed dressed plots were not significantly (P > 0.05) in nodulation (Table 4.9).

Table 4.9: Mean number of nodules per plant for each treatment in snap beans in Mwea and Embu for 1st planting July 2013- Oct 2013 and 2nd planting Oct 2013 – Jan 2014

Treatment	Mwea 1st planting	Mwea 2nd planting	Embu 1st planting	Embu 2nd planting
Seed dressing only (Moncerene)	12.7a	15.1a	37.7a	12a
Farmer practice (Thunder + Karate)	14.0a	14.3a	28.9a	13a
Seed dressing + 3 Neem	16.8a	17.0a	29.8a	17a
Seed dressing + 2 Pesthrin + 1 Neem	12.7a	17.6a	32.1a	16a
Seed dressing + Intercrop + 3 Pesthrin	19.0a	14.3a	30.3a	13a
Seed dressing+ 2 Pesthrin + 1 Biocatch	14.0a	15.4a	26.0a	17a
Seed dressing + 2 Neem + 1 Biocatch	13.5a	16.0a	30.0a	17a
2 Pesthrin+ 1 Neem	12.7a	15.1a	33.2a	19a
Control (Water only)	-	18.2a	-	15a
P-value	0.681	0.513	0.581	0.394
LSD ($_{p\leq0.05}$)	8.2	4.9	7.3	6.5
C.V%	14.2	6.2	5.3	9.0

No significant differences at 5% probability

- =Treatment missing in planting one

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.4.4 Effect of integrating seed dressing, foliar sprays and intercropping with maize on Whitefly population

Integration of seed dressing, foliar sprays and intercropping with maize significantly ($P < 0.001$) reduced the whitefly population. All the treated plots showed reduction in the whitefly population (Tables 4.10, 4.11, 4.12 and 4.13). The integration of seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding caused the highest reduction (48% reduction) in the adult whitefly population compared to the control (Table 4.10). Use of a pyrethroid at the vegetative stage and at early flowering plus a botanical at early podding reduced the whitefly nymphs by 57% in the first season in Mwea (Table 4.11). Similar results were observed in the plots with integration of seed dressing, a pyrethroid and intercropping with maize and in plots with a Pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding.

In the second season, integration of seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding and intercropping with maize had a significantly ($P<0.001$) reduced the whitefly population. Integration of seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding and intercropping with maize reduced the adult whitefly population by 54% compared to the control (Table 4.12). Integration of seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding and intercropping with maize reduced the white fly nymphs by 53% (Table 4.13).

Similar results were observed in plots with integration of seed dressing, a pyrethroid spray at the vegetative stage and early flowering plus a botanical at early podding and in plots without seed dressing, a pyrethroid and a botanical. In all the treated plots there was a lower whitefly population than in the control in planting one and two (Tables 4.10, 4.11, 4.12 and 4.13).

Table 4.10: Mean number of adult whiteflies per sticky card for different integrated treatments per sampling in snap beans for 1st planting July – Oct 2013 in Mwea

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	73.5a	124.8cd	142.0d	113.4d	0
Farmer practice (Thunder + Karate)	80.5a	85.8bc	101.2c	89.2bc	27
Seed dressing + 3 Neem	62.0a	72.8ab	89.5bc	74.8ab	34
Seed dressing + 2 Pesthrin + 1 Neem	57.2a	59.8a	61.5a	59.5a	48
Seed dressing + Intercrop + 3 Pesthrin	61.0a	66.5a	65.5ab	64.3a	43
Seed dressing+ 2 Pesthrin + 1 Biocatch	76.2a	67.0ab	80.2ab	74.5ab	34
Seed dressing + 2 Neem + 1 Biocatch	83.0a	97.8bc	94.5bc	91.1bc	20
2 Pesthrin+ 1 Neem	78.8a	49.2a	62.8a	63.6a	44
P-value	0.608	0.006	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	31.1	34.9	18.7	18.3	
C.V%	8.7	9.6	8.0	5.6	

Treatments with different letters in the same column are significantly different at 5% probability

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.11: Mean number of adult whiteflies per sticky card for different integrated treatments per sampling in snap beans for 2nd planting Oct 2013- Jan 2014 in Mwea

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	55.4a	77.8c	80.7bc	71.2c	0
Farmer practice (Thunder + Karate)	52.5a	41.0a	46.0ab	46.5ab	41
Seed dressing + 3 Neem	69.1a	58.3b	55.5b	61.0bc	22
Seed dressing + 2 Pesthrin + 1 Neem	60.0a	28.2a	22.6a	37.0a	53
Seed dressing + Intercrop + 3 Pesthrin	52.3a	30.5a	26.3ab	36.4a	54
Seed dressing+ 2 Pesthrin + 1 Biocatch	60.7a	58.0b	55.1b	57.9bc	26
Seed dressing + 2 Neem + 1 Biocatch	65.7a	40.4a	39.2ab	48.4ab	39
2 Pesthrin+ 1 Neem	67.9a	36.9a	18.8a	41.2ab	48
Control (Water only)	49.9a	86.1c	100.0cd	78.7cd	0
P-value	0.373	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	19.4	14.7	30.0	16.0	
C.V%	7.8	9.3	8.8	5.2	

Treatments with different letters in the same column are significantly different at 5% probability

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.12: Mean number of whitefly nymphs per leaf for different integrated treatments per sampling in snap beans for 1st planting July – Oct 2013 in Mwea

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	41.4c	44.1b	56.9c	47.5c	0
Farmer practice (Thunder + Karate)	42.5c	38.6b	37.6b	39.0b	18
Seed dressing + 3 Neem	36.2c	36.3b	38.9b	37.1b	22
Seed dressing + 2 Pesthrin + 1 Neem	20.7ab	18.5a	26.1a	21.8a	54
Seed dressing + Intercrop + 3 Pesthrin	26.1b	19.1a	21.5a	22.2a	53
Seed dressing+ 2 Pesthrin + 1 Biocatch	40.1c	36.7b	40.5b	39.1b	18
Seed dressing + 2 Neem + 1 Biocatch	38.3c	39.6b	44.5b	40.8b	14
2 Pesthrin+ 1 Neem	17.9a	22.4a	21.3a	20.5a	57
P-value	<0.001	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	7.5	9.8	9.7	5.1	
C.V%	7.5	5.0	6.2	6.1	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.13: Mean number of whitefly nymphs per leaf for different integrated treatments per sampling in snap beans for 2nd planting Oct 2013 – Jan 2014 in Mwea

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	27.6a	35.2c	55.2d	39.3bc	0
Farmer practice (Thunder + Karate)	38.5a	21.3ab	22.4ab	27.4ab	40
Seed dressing + 3 Neem	42.5a	31.9bc	21.0ab	31.8bc	31
Seed dressing + 2 Pesthrin + 1 Neem	35.3a	18.1ab	13.3a	22.2ab	52
Seed dressing + Intercrop + 3 Pesthrin	30.0a	20.4ab	13.1a	21.2a	54
Seed dressing+ 2 Pesthrin + 1 Biocatch	36.9a	21.4ab	24.5ab	27.6ab	40
Seed dressing + 2 Neem + 1 Biocatch	40.8a	30.1bc	27.6bc	32.8bc	29
2 Pesthrin+ 1 Neem	35.1a	13.8a	18.1ab	22.3ab	52
Control (Water only)	32.4a	47.5d	57.8d	45.9cd	0
P-value	0.405	<0.001	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	13.4	9.2	13.8	9.6	
C.V%	9.2	10.8	12.3	9.3	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.4.5 Effect of integrating seed dressing, foliar sprays and intercropping with maize on thrips population

Integration of seed dressing, foliar sprays and intercropping with maize had significant ($P < 0.001$) effect thrips population. There was reduction in the thrips population in the treated plots (Tables 4.14, 4.15, 4.16 and 4.17). The integration of seed dressing, intercropping with maize and a pyrethroid and seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding caused the highest reduction (60% reduction) in the thrips population in planting one in Mwea (Table 4.14). In the second season, the integration of seed dressing, intercropping with maize and a pyrethroid caused the highest reduction (59% reduction) in the population of thrips (Table 4.15). Seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding also caused a high reduction in the thrips population (55% reduction) compared to the control (Table 4.15).

In Embu, the integration of seed dressing, foliar sprays and intercropping with maize had a significant ($P < 0.05$) effect on thrips population. The integration of seed dressing, intercropping with maize and a pyrethroid caused the highest reduction (59% reduction) in the thrips population (Table 4.16). Seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding and plots without seed dressing, a pyrethroid and a botanical also caused a high reduction in the thrips population (51 % reduction and 53% reduction respectively) (Table 4.16). In the second, the integration of seed dressing, intercropping with maize and a pyrethroid caused the highest reduction (51% reduction) in the thrips population (Table 4.17). Seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding and plots without seed dressing, a pyrethroid and a botanical also caused a high reduction in the thrips population (49 % reduction) compared to the control (Table 4.17).

Table 4.14: Mean number of thrips per flower for different integrated treatments per sampling in snap beans for for 1st planting July – Oct 2013 in Mwea

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	2.5bc	2.9bc	3.6c	3.0d	0
Farmer practice (Thunder + Karate)	2.3ab	2.7bc	2.2b	2.4c	30
Seed dressing + 3 Neem	2.1ab	2.2ab	1.7ab	2.0bc	33
Seed dressing + 2 Pesthrin + 1 Neem	1.3a	1.3a	1.0a	1.2a	60
Seed dressing + Intercrop + 3 Pesthrin	1.3a	1.2a	1.1a	1.2a	60
Seed dressing+ 2 Pesthrin + 1 Biocatch	2.7bc	2.0ab	2.0b	1.2a	60
Seed dressing + 2 Neem + 1 Biocatch	2.6bc	2.4ab	1.7ab	2.2c	27
2 Pesthrin+ 1 Neem	1.6ab	1.6ab	1.4ab	1.5ab	50
P-value	0.042	0.029	<0.001	<0.001	
LSD ($p \leq 0.05$)	1.1	1.1	0.8	0.5	
C.V%	11.3	19.9	8.7	12.8	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.15: Mean number of thrips per flower for different integrated treatments per sampling in snap beans for for 2nd planting Oct 2013 – Jan 2014 in Mwea

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	3.2a	4.3d	3.8b	3.7d	16
Farmer practice (Thunder + Karate)	3.3a	2.7bc	2.0a	2.6bc	41
Seed dressing + 3 Neem	2.9a	2.0ab	1.8a	2.3ab	48
Seed dressing + 2 Pesthrin + 1 Neem	2.7a	1.9ab	1.5a	2.0ab	55
Seed dressing + Intercrop + 3 Pesthrin	2.4a	1.8a	1.2a	1.8a	59
Seed dressing+ 2 Pesthrin + 1 Biocatch	3.2a	2.4ab	1.6a	2.4ab	45
Seed dressing + 2 Neem + 1 Biocatch	3.0a	2.5bc	1.6a	2.4ab	45
2 Pesthrin+ 1 Neem	2.8a	1.7a	1.8a	2.1ab	52
Control (Water only)	3.8a	4.5d	4.9c	4.4d	0
P-value	0.557	<0.001	<0.001	<0.001	
LSD ($_{p \leq 0.05}$)	NS	0.6	1.0	0.7	
C.V%	3.8	4.5	6.6	2.4	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.16: Mean number of thrips per flower for different integrated treatments per sampling in snap beans for 1st planting July – Oct 2013 in Embu

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	0.28a	0.55a	0.65a	0.49bc	0
Farmer practice (Thunder + Karate)	0.23a	0.28a	0.53a	0.34ab	31
Seed dressing + 3 Neem	0.28a	0.43a	0.68a	0.46bc	6
Seed dressing + 2 Pesthrin + 1 Neem	0.28a	0.23a	0.23a	0.24ab	51
Seed dressing + Intercrop + 3 Pesthrin	0.25a	0.25a	0.20a	0.20a	59
Seed dressing+ 2 Pesthrin + 1 Biocatch	0.35a	0.32a	0.48a	0.38bc	22
Seed dressing + 2 Neem + 1 Biocatch	0.30a	0.50a	0.60a	0.47bc	4
2 Pesthrin+ 1 Neem	0.23a	0.18a	0.30a	0.23a	12
P-value	0.551	0.197	0.069	0.002	
LSD ($_{p\leq0.05}$)	0.19	0.32	0.37	0.17	
C.V%	26.2	13.2	16.4	14.5	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.17: Mean number of thrips per flower for different integrated treatments per sampling in snap beans for 2nd planting Oct 2013 – Jan 2014 in Embu

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	2.6a	2.7b	3.8bc	3.0bc	14
Farmer practice (Thunder + Karate)	2.2a	1.7ab	1.8ab	1.9ab	46
Seed dressing + 3 Neem	2.8a	1.9ab	2.7ab	2.5bc	29
Seed dressing + 2 Pesthrin + 1 Neem	2.0a	1.5a	2.1ab	1.8a	49
Seed dressing + Intercrop + 3 Pesthrin	2.3a	1.5a	1.3a	1.7a	51
Seed dressing+ 2 Pesthrin + 1 Biocatch	3.2a	1.9b	1.5a	2.2ab	37
Seed dressing + 2 Neem + 1 Biocatch	2.1a	2.2ab	1.9ab	2.0ab	43
2 Pesthrin+ 1 Neem	2.3a	1.9ab	1.2a	1.8a	49
Control (Water only)	2.5a	3.7bc	4.2c	3.5cd	0
P-value	0.666	0.002	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	1.29	1.0	1.1	0.7	
C.V%	15.2	9.5	8.0	8.6	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.4.6 Effect of integrating seed dressing, foliar sprays and intercropping with maize on bean stem maggots

Integrating seed dressing, foliar sprays and intercropping with maize had significant (P <0.05) effect on the bean stem maggots population compared to the control and treatments without seed dressing in Mwea (Tables 4.18 and 4.19). Seed dressing significantly (P<0.05) reduced he bean stem maggots population by 4 to 61% in planting one (Table 4.18). However, the bean stem maggot population was generally less than one bean stem maggot per plant in all the plots. In the second season, seed dressing caused a high reduction in the bean stem maggot population of upto 59% reduction compared to the control (Table 4.19).

In Embu, seed dressing had no significant (P >0.05) effect on reduction of bean stem maggots population compared to the control and treatments without seed dressing in planting one (Table 4.20). However, during the second season, Seed dressing had significant (P <0.05) effect on reduction of bean stem maggots population compared to the control and treatments without seed dressing. Seed dressing caused a 57% reduction in the population of bean stem maggots (Table 4.21) compared to the control. The bean stem maggot population was less than one bean stem maggot per plant in all the plots (Table 4.20 and 4.21).

Table 4.18: Mean number of bean stem maggots per plant for different integrated treatments per sampling in snap beans for 1st planting July 2013- Oct 2013 in Mwea

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	0.45bc	0.48bc	0.68bc	0.53bc	16
Farmer practice (Thunder + Karate)	0.28a	0.45bc	0.75cd	0.49b	22
Seed dressing + 3 Neem	0.25a	0.38bc	0.40ab	0.34a	46
Seed dressing + 2 Pesthrin + 1 Neem	0.35ab	0.23ab	0.25a	0.28a	56
Seed dressing + Intercrop + 3 Pesthrin	0.23a	0.18ab	0.35ab	0.25a	60
Seed dressing+ 2 Pesthrin + 1 Biocatch	0.30ab	0.15a	0.28ab	0.24a	62
Seed dressing + 2 Neem + 1 Biocatch	0.26a	0.25ab	0.48bc	0.32a	49
2 Pesthrin+ 1 Neem	0.56bc	0.60cd	0.75cd	0.63c	0
P-value	0.001	0.002	<0.001	<0.001	
LSD ($_{p\leq0.05}$)	0.15	0.21	0.21	0.13	
C.V%	10.5	9.1	4.4	4.4	

Treatments with different letters in the same column are significantly different at 5% probability

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.19: Mean number of bean stem maggots per plant for different integrated treatments per sampling in snap beans for 2nd planting Oct 2013 – Jan 2014 in Mwea

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	0.35ab	0.25ab	0.50a	0.37ab	40
Farmer practice (Thunder + Karate)	0.45bc	0.48bc	0.33a	0.42bc	32
Seed dressing + 3 Neem	0.25a	0.18a	0.35a	0.26a	58
Seed dressing + 2 Pesthrin + 1 Neem	0.35ab	0.15a	0.33a	0.28ab	54
Seed dressing + Intercrop + 3 Pesthrin	0.28ab	0.23ab	0.38a	0.29ab	53
Seed dressing+ 2 Pesthrin + 1 Biocatch	0.35ab	0.33ab	0.43a	0.37ab	40
Seed dressing + 2 Neem + 1 Biocatch	0.40bc	0.43ab	0.60a	0.48bc	23
2 Pesthrin+ 1 Neem	0.63d	0.58bc	0.68a	0.63d	0
Control (Water only)	0.78e	0.55bc	0.56a	0.62d	0
P-value	0.006	0.03	0.082	<0.001	
LSD ($_{p\leq0.05}$)	0.13	0.29	0.26	0.15	
C.V%	10.3	23.3	16.2	11.3	

Treatments with different letters in the same column are significantly different at 5% probability

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.20: Mean number of bean stem maggots per plant for different treatments per sampling in snap beans for 1st planting July – Oct 2013 in Embu

Treatment	First sampling	Second sampling	Third Sampling	Mean
Seed dressing only (Moncerene)	0.45a	0.53a	0.35a	0.44a
Farmer practice (Thunder + Karate)	0.23a	0.45a	0.38a	0.32a
Seed dressing + 3 Neem	0.40a	0.38a	0.38a	0.38a
Seed dressing + 2 Pesthrin + 1 Neem	0.25a	0.33a	0.38a	0.28a
Seed dressing + Intercrop + 3 Pesthrin	0.40a	0.63a	0.35a	0.46a
Seed dressing+ 2 Pesthrin + 1 Biocatch	0.28a	0.30a	0.34a	0.27a
Seed dressing + 2 Neem + 1 Biocatch	0.28a	0.33a	0.38a	0.33a
2 Pesthrin+ 1 Neem	0.33a	0.53a	0.33a	0.39a
P-value	0.737	0.372	0.693	0.116
LSD ($_{p\leq 0.05}$)	0.31	0.33	0.20	0.15
C.V%	9.9	19.3	11.3	5.5

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.21: Mean number of bean stem maggots per plant for different treatments per sampling in snap beans for 2nd planting Oct 2013- Jan 2014 in Embu

Treatment	First sampling	Second sampling	Third Sampling	Mean	% Reduction
Seed dressing only (Moncerene)	0.33a	0.18a	0.30a	0.27ab	50
Farmer practice (Thunder + Karate)	0.30a	0.23ab	0.30a	0.28ab	48
Seed dressing + 3 Neem	0.33a	0.18a	0.33a	0.28ab	48
Seed dressing + 2 Pesthrin + 1 Neem	0.28a	0.18a	0.23a	0.23a	57
Seed dressing + Intercrop + 3 Pesthrin	0.28a	0.33ab	0.38a	0.33ab	39
Seed dressing+ 2 Pesthrin + 1 Biocatch	0.35a	0.20ab	0.28a	0.28ab	48
Seed dressing + 2 Neem + 1 Biocatch	0.33a	0.43bc	0.40a	0.38bc	30
2 Pesthrin+ 1 Neem	0.55b	0.55bc	0.60a	0.57c	0
Control (Water only)	0.63b	0.55bc	0.45a	0.54c	0
P-value	0.007	<0.001	0.12	<0.001	
LSD ($_{p\leq 0.05}$)	0.19	0.15	0.24	0.11	
C.V%	21.0%	10.1%	28.0%	14.9%	

Treatments with different letters in the same column are significantly different at 5% probability
Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.4.7 Effect of integrating seed dressing, foliar sprays and intercropping with maize on yield of snap beans

Integration of seed dressing, foliar sprays and intercropping with maize had significant ($P < 0.05$) positive effect on the snap bean yield. Generally treated plots had higher extra-fine and fine snap bean yield in Mwea in planting one and two (Table 4.22). The integration of seed dressing, intercropping with maize and a pyrethroid and seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding caused the highest increase in the extra-fine yield (158%- 163% increase respectively) compared to the seed dressing only in planting one (Table 4.22). The integration a pyrethroid and botanical and the integration of seed dressing and a botanical caused the highest increase in the fine yield (133% and 146% increase respectively) compared to seed dressing only in planting one (Table 4.22).

During the second season, the integration of seed dressing, intercropping with maize and a pyrethroid and seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding caused the highest increase in the extra-fine yield (105% and 75% increase respectively) compared to the control (Table 4.22). The integration of seed dressing, intercropping with maize and a pyrethroid and seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding caused the highest increase in the fine yield (80% and 59% increase respectively) compared to the control (Table 4.22). The first and second pickings had the highest yield for fine and extra-fine yields in planting one and two in Mwea.

In Embu, integration of seed dressing, foliar sprays and intercropping with maize had no significant ($P > 0.05$) effect on the extra-fine and fine yield of snap beans in planting one (Table 4.23). However, in the second season, integration of seed dressing, foliar sprays and intercropping with maize had significant ($P < 0.05$) positive effect on the extra-fine of snap beans (Table 4.23). The integration of seed dressing, intercropping with maize and a pyrethroid and seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding had the highest yield increase (139% and 149% increase respectively) of the extra-fine compared to the control (Table 4.23). Integration of seed dressing, foliar sprays and intercropping with maize had no significant (P >0.05) increase on the fine yield (Table 4.23). The yields of snap beans in Mwea were generally higher than in Embu both in planting one and planting two (Table 4.23).

Table 4.22: Total yield (kg/ ha) of marketable snap bean pods for different integrated treatments per season in Mwea in 2013

	1st planting				2nd planting			
Treatment	Ex-fine	%Inc	Fine	% inc	Ex-fine	% inc	Fine	% inc
Seed dressing only (Moncerene)	1851a	0	2392a	0	4511ab	37	2106ab	29
Farmer practice (Thunder + Karate)	4029bc	117	5551bc	132	4344ab	32	1877ab	15
Seed dressing + 3 Neem	3885bc	109	5949bc	148	4523ab	38	2059ab	26
Seed dressing + 2 Pesthrin + 1 Neem	4770c	157	5574bc	133	6731bc	105	2925bc	84
Seed dressing + Intercrop + 3 Pesthrin	4866c	162	5879bc	145	5758bc	75	2595bc	59
Seed dressing+ 2 Pesthrin + 1 Biocatch	2340ab	26	3543ab	48	5220b	59	1777ab	9
Seed dressing + 2 Neem + 1 Biocatch	2818ab	52	5687bc	137	3627a	11	2412b	48
2 Pesthrin+ 1 Neem	4178bc	125	6161cd	157	5319b	62	2585bc	59
Control (Water only)	-		-		3282a	0	1629a	0
P-value	0.002		0.043		0.004		0.008	
LSD ($_{p\leq0.05}$)	1461		2491.0		1552.7		678.9	
C.V%	20.0		27.7		21.9		6.2	

Treatments with different letters in the same column are significantly different at 5% probability

- =Treatment missing in planting one; % inc=percentage increase

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.23: Total yield (kg/ Ha) of marketable snap bean pods for different integrated treatments per season in Embu in 2013

	1st planting				2nd planting			
Treatment	Ex-fine	%Inc	Fine	% inc	Ex-fine	%Inc	Fine	% inc
Seed dressing only (Moncerene)	3378a	0	3853a	0	3060c	95	2455a	99
Farmer practice (Thunder + Karate)	2905a	0	4665a	21	2250b	43	2019a	63
Seed dressing + 3 Neem	3200a	0	5415a	40	2884bc	84	2032a	64
Seed dressing + 2 Pesthrin + 1 Neem	3654a	8	4429a	15	3905de	149	2498a	102
Seed dressing + Intercrop + 3 Pesthrin	3581a	6	4994a	30	3746cd	139	2141a	73
Seed dressing+ 2 Pesthrin + 1 Biocatch	3787a	12	5880a	53	2258b	44	2392a	93
Seed dressing + 2 Neem + 1 Biocatch	2782a	0	4438a	15	3113c	99	1866a	50
2 Pesthrin+ 1 Neem	2141a	0	3789a	0	3198c	103	3251a	163
Control (Water only)	-		-		1568a	0	1236a	0
P-value	0.739		0.576		<0.001		0.068	
LSD (5% significance level)	1353		2032		652		1086	
C.V%	11.3		18.9		9.2		12.0	

Treatments with different letters in the same column are significantly different at 5% probability

- =Treatment missing in planting one; % inc=percentage increase

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.4.9 Effect of integrating seed dressing, foliar sprays and intercropping with maize on pest damaged pods

Integration of seed dressing, foliar sprays and intercropping with maize had a significant (P <0.05) effect on the pest damage of fine and extra-fine grade pods. All treated plots showed a reduction in the weight of pest damaged pods compared to the control. The integration of seed dressing, foliar sprays and intercropping with maize had significant (P <0.05) reduction on the pest damage of extra-fine yield of snap beans in Mwea in planting one (Table 4.24). The integration of seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding and seed dressing, intercropping with maize plus a pyrethroid had the highest reduction (70% and 73% reduction respectively) of pest damaged extra-fine pods compared to seed dressing only in planting one in Mwea (Table 4.24). During the second season, the integration of seed dressing, a pyrethroid at the vegetative stage, a botanical spray at early flowering plus a biological at early podding and seed dressing, intercropping with maize plus a pyrethroid had the highest reduction (86% and 92% reduction respectively) of pest damaged extra-fine pods compared to the control (Table 4.24).

The Integration of seed dressing, foliar sprays and intercropping with maize had no significant (P >0.05) effect on the pest damage of fine yield of snap beans in Mwea in planting one (Table 4.24). However, in the second season, integration of seed dressing, foliar sprays and intercropping with maize had significant (P <0.05) effect on the pest damage of fine yield of snap beans (Table 4.24). The integration of seed dressing, a pyrethroid at the vegetative stage, a botanical at early flowering plus a biological spray at early podding and seed dressing, intercropping with maize plus a pyrethroid had the highest reduction (64% and 63% reduction respectively) of pest damage compared to control (Table 4.24).

In Embu, integration of seed dressing, foliar sprays and intercropping with maize had a significant (P <0.05) reduction on the pest damage of extra-fine and fine yield of snap beans in planting one. Integration of seed dressing, a pyrethroid at the vegetative stage, a botanical at early flowering plus a biological spray at early podding and seed dressing, intercropping with maize plus a pyrethroid had the highest reduction (86% and 95% reduction respectively) of pest damaged extra-fine pods compared to seed dressing only (Table 4.25). In the second season, alternate application of Thunder (Imidacloprid 100g/L + Betacyfluthrin 45g/L) and Karate (Lambda Cyhalothrin 25g/Kg) on pest detection and integration of seed dressing, intercropping with maize plus a pyrethroid had the highest reduction (70 and 65% reduction respectively) of pest damaged extra-fine pods compared to the control. The Integration of seed dressing, foliar sprays and intercropping with maize had a significant (P <0.05) reduction on the pest damage of fine yield of snap beans (Table 4.25).

The integration of seed dressing, a pyrethroid at the vegetative stage, a botanical at early flowering plus a biological spray at early podding and seed dressing, a pyrethroid at vegetative and early flowering plus a botanical at early podding had the highest reduction (65% and 63% reduction respectively) of pest damage compared to the control (Table 4.25). In the second season, integration of seed dressing, a pyrethroid at the vegetative stage and at early flowering plus a botanical spray at early podding and seed dressing, intercropping with maize plus a pyrethroid had the highest reduction (57% and 63% reduction respectively) of pest damage compared to the control (Table 4.25).

Table 4.24: Total yield (kg/ ha) of pest damaged snap bean pods in each grade for different integrated treatments per season in Mwea in 2013

	1st Planting				2nd Planting			
Treatment	Ex-fine	%dec	Fine	% dec	Ex-fine	% dec	Fine	% dec
Seed dressing only (Moncerene)	121c	0	153a	0	160b	22	393d	1
Farmer practice (Thunder + Karate)	110c	9	158a	0	148b	27	289c	26
Seed dressing + 3 Neem	83bc	31	137a	10	48a	76	191ab	51
Seed dressing + 2 Pesthrin + 1 Neem	33a	73	89a	41	46a	77	187ab	52
Seed dressing + Intercrop + 3 Pesthrin	36a	70	91a	40	17a	92	143a	63
Seed dressing+ 2 Pesthrin + 1 Biocatch	55ab	54	98a	36	34a	83	138a	65
Seed dressing + 2 Neem + 1 Biocatch	88bc	27	76a	50	29a	86	178ab	54
2 Pesthrin+ 1 Neem	93bc	23	162a	6	64a	69	231bc	41
Control (Water only)	-		-		204b	0	389d	0
P-value	<0.001		0.067		<0.001		<0.001	
LSD ($_{p\leq0.05}$)	38.8		69.1		60.0		72.1	
C.V%	19.8		11.3		20.5		17.6	

Treatments with different letters in the same column are significantly different at 5% probability

- =Treatment missing in planting one; % dec= Percentage decrease

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

Table 4.25: Total yield (kg/ ha) of pest damaged snap bean pods in each grade for different integrated treatments per season in Mwea in 2013

	1st Planting				2nd Planting			
Treatment	Ex-fine	%dec	Fine	% dec	Ex-fine	%dec	Fine	% dec
Seed dressing only (Moncerene)	234e	0	360d	0	532c	31	725ab	38
Farmer practice (Thunder + Karate)	172d	26	300cd	17	228a	70	503ab	57
Seed dressing + 3 Neem	93bc	60	176ab	51	352abc	54	613ab	47
Seed dressing + 2 Pesthrin + 1 Neem	57ab	75	154a	57	286a	63	505ab	57
Seed dressing + Intercrop + 3 Pesthrin	17a	93	162a	55	269a	65	434a	63
Seed dressing+ 2 Pesthrin + 1 Biocatch	45ab	81	147a	59	379abc	51	885c	24
Seed dressing + 2 Neem + 1 Biocatch	99bc	58	239bc	34	364abc	53	755bc	
2 Pesthrin+ 1 Neem	320f	0	424d	0	275a	64	650a	
Control (Water only)	-		-		768d	0	1164d	0
P-value	<0.001		<0.001		0.001		<0.001	
LSD ($_{p\leq 0.05}$)	58.8		64.6		223.6		298.8	
C.V%	14.5		10.6		16.4		9.2	

Treatments with different letters in the same column are significantly different at 5% probability

- =Treatment missing in planting one; % dec= Percentage decrease

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.4.10 Cost benefit analysis for different integrated treatments in snap beans in 2013

The cost benefit calculations showed that use of seed dressing, two pyrethroid sprays plus a botanical spray was the most profitable pest management option with a cost-benefit ratio of 4.3 compared to the other pest management options used in the study. The integration of seed dressing, intercropping and three pyrethroid sprays was the second most profitable pest management option with a cost-benefit ratio of 4.1 (Table 4.26). The application of Thunder (Imidacloprid 100g/L + Betacyfluthrin 45g/L) and Karate (Lambda Cyhalothrin 25g/Kg) on pest detection and the integration of seed dressing, two botanical sprays and a biological spray were the least cost effective pest management strategies compared to other pest management options with cost-benefit ratios of 2.1 and 2 respectively (Table 4.26). Seed dressing only had the lowest input in terms of chemical cost and labour costs compared to the pest management options tested in this study however, it was less profitable compared to integration of seed dressing, two pyrethroid sprays plus a botanical (Table 4.26). The labour costs were lowest in the seed dressing only and control treatment during the study.

Table 4.26: Cost benefit analysis for different integrated treatments in snap beans in 2013

Treatments	Total Marketable Kg/Ha	Price/ Kg (Ksh)	Gross Returns (Ksh)	Labour (Ksh)	Chemical (Ksh)	Net Returns (Ksh)	Cost benefit ratio
Seed dressing only (Moncerene)	5901.5	40	236060	110000	7200	118,860	1.0
Farmer practice (Thunder + Karate)	6910.0	40	276400	140,000	41200	95200	0.5
Seed dressing + 3 Neem	7486.8	40	299470	140,000	23670	135,800	0.8
Seed dressing + 2 Pesthrin + 1 Neem	8621.5	40	344860	140,000	16438	188,422	1.2
Seed dressing + Intercrop + 3 Pesthrin	8390.0	40	335600	142,500	12822	180,278	1.2
Seed dressing+ 2 Pesthrin + 1 Biocatch	6799.3	40	271970	140,000	32,548	99,422	0.6
Seed dressing + 2 Neem + 1 Biocatch	6685.8	40	267430	140,000	39,780	87,650	0.5
2 Pesthrin+ 1 Neem	7405.5	40	296220	140,000	9238	146,982	1.0
Control (Water only)	3857.5	40	154300	110,000	0	44,300	0.4

Moncerene= Imidacloprid 233g/L +Pencycuron 50g/L +Thiram 107g/L; Thunder= Imidacloprid 100g/L + Betacyfluthrin 45g/L; Karate= Lambda Cyhalothrin 25g/Kg; Pesthrin= Pyrethrins 6%; Biocatch= *Verticillium lecanii;* Neem = Azadirachtin 0.03%

4.5 Discussion

Seed dressing had a significant (P<0.05) increase of up to 25% increase on emergence of snap beans compared to the non-seed dressed plots. There was no significant (P>0.05) difference in emergence between the non-seed dressed plots and the control. These findings are consistent with findings by Mahajan et al., (2013) who reported higher emergence in the field due to seed dressing. The study results also agree with studies by Mastouri et al., (2010) and Okoth et al., (2011) who reported enhanced germination and emergence as a result of seed dressing. Srivastava et al., (1990) also reported improved germination and emergence in *Cicer arietinum* Linn due to seed dressing.

The higher emergence in the seed dressed treatments is as a result of the seeds being protected by the seed dressing chemical from soil pests and pathogens that affect germinating seeds. Several studies have reported use of seed dressing with insectides and fungicides to protect seeds from soil pests and soil borne diseases that affect germination leading to low emergence of seeds (Pons and Albajes, 2002; Muthomi, et al., 2007; Allah, 2010).

The integration of seed dressing, a pyrethroid spray at the vegetative and early flowering stage plus a botanical at the early podding stage and the integration of seed dressing, intercropping with maize plus pyrethroid sprays at the vegetative stage, early flowering stage and early podding stage significantly ($P < 0.05$) increased the plant stand by up to 40% of snap beans compared to the control. The findings in this study are consistent with findings by Malaker et al., (2009) where seed dressing and foliar sprays increased plant population in wheat. The study results also agree with studies by Srivastava et al., (1990); Mastouri et al.,)2010) and Okoth et al.,(2011) who reported enhanced germination and emergence as a result of seed dressing which leads to a higher plant stand. These results also agree with results by Hossain et al., (2013) in which foliar sprays and seed dressing led to reduced post emergence pest damage by insect pests that can lead to death of plants leading to a poor plant stand.

The higher plant stand could be as a result of reduced pest and pathogen damage as a result of seed dressing on germinating seeds leading to a higher emergence (Srivastava et al., 1990). Additionally foliar sprays and seed dressing could have led to reduced post emergence pest damage for example by the bean stem maggots that can lead to death of plants leading to a poor plant stand (Hossain et al., 2013).

The integration of seed dressing, a pyrethroid spray at the vegetative and early flowering stage plus a botanical at the early podding stage and the integration of seed dressing, intercropping with maize plus pyrethroid sprays at the vegetative stage, early flowering stage and early podding stage had no significant effect (P> 0.05) nodulation of snap beans in Mwea and Embu compared to the control. The results above agree with results by Vasileva and Ilieva (2007) who reported no effect on nodulation of Lucerne due to pre sowing seed treatment with insecticides. The present results disagree with results by Zilli et al., (2009) who reported reduction in nodulation of soybean as a result of seed treatment with a fungicide.

The integration of seed dressing, a pyrethroid spray at the vegetative and early flowering stage plus a botanical at the early podding stage and the integration of seed dressing, intercropping with maize plus pyrethroid sprays at the vegetative stage, early flowering stage and early podding stage significantly (P< 0.05) reduced the whitefly population by up to 57% in snap beans compared to the control. These findings concur with findings by Rao et al., (2012) who reported management of pests through intercropping. The results in this study are consistent with results by Hossain et al., (2013) on effect of seed dressing and foliar sprays in control of sucking pests in cotton. Zhang et al., (2011) also reported control of whitefly in cotton by seed treatment with Imidacloprid. Mandi et al., (2009) reported on management of pests through integration of botanical and microbial insecticides.

Similar results have been observed in other studies where seed dressing has been employed successfully for instance, in the management of sucking pests for example whitefly and thrips in cotton (Hossain et al., 2012), management of rice water weevil in rice (Mazzanti et al., 2011) and management of red spider mites and beanfly in beans (Allah, 2010). Intercropping systems have been shown to result in reduced pest incidences compared to monocropping systems (Rao et al., 2012). This results prove results reported in Kenya on the management of lepidopteran stem borers on maize and thrips in bulb onions through intecropping (Songa et al., 2007; Gachu et al., 2012).

The effect of seed dressing on whiteflies in this study was been through systemic and residual toxicity of the seed dressing insecticide (Hossain et al., 2012; Zhang et al., 2011). The seed dressing chemical is usually taken up by the plant at the root zone and translocated to other parts of the plant (Mazzanti et al., 2011). Application of foliar sprays had a direct kill on whiteflies and therefore reducing their population. Intercropping on the other had results in reduced pest populations due to increased biodiversity and build up of natural enemies which contribute to pest management (Rao et al., 2012).

The integration of seed dressing, a pyrethroid spray at the vegetative and early flowering stage plus a botanical at the early podding stage and the integration of seed dressing, intercropping with maize plus pyrethroid sprays at the vegetative stage, early flowering stage and early podding stage significantly ($P< 0.05$) reduced the thrips population in snap beans in by up to 60% compared to the control. The above results agree with results by Nyasani et al., (2012) and Nderitu et al., (2009) in which thrips population in intercropped snap beans was lower than in plots with snap beans alone. Similar results have been reported by Gachu et al., (2012) where vegetable intercrops were used in the management of thrips. The results in this study also confirms reports by Hossain et al., (2012) and Elbert et al., (2008) in which seed dressing with insecticides for example imidacloprid has been used for management of thrips. The findings in this study are also consistent with findings by Malarker et al., (2009) where the combination of seed dressing and foliar sprays suppressed pest populations. The results in this study proves that an IPM system is better than a system based on a single pest management approach.

The reduction in thrips population in this study was through systemic and residual toxicity of the seed dressing insecticide (Hossain et al., 2012; Zhang et al., 2011). The seed dressing chemical is usually taken up by the plant at the root zone and translocated to other parts of the plant (Mazzanti et al., 2011). Application of foliar sprays had a direct kill on thrips and thereby reducing their population. The reduction was also caused by intercropping with maize that increases divesirty and acts as a physical barrier for pests (Nyasani, et al., 2012; Theunissen, et al., 1996)

The integration of seed dressing, a pyrethroid spray at the vegetative and early flowering stage plus a botanical at the early podding stage and the integration of seed dressing, intercropping with maize plus pyrethroid sprays at the vegetative stage, early flowering stage and early podding stage significantly ($P < 0.05$) reduced the bean stem maggots population by up to 57% in snap beans compared to the control. The above results are agree with results by Ratnadass et al., (2012) and Mazzanti et al., (2011) who reported that seed dressing is effective in controlling various soil. Mishek et al., (2011) also reported on use of varoius neonicotinoid seed dressing formulations in th control of the bean stem maggots. The low pouplation of bean stem maggots in the treated area was as a result of chemical systemic and contact action from the seed dressing chemical and foliar sprays (Mishek et al 2011; Allah, 2010).

The integration of seed dressing, a pyrethroid spray at the vegetative and early flowering stage plus a botanical at the early podding stage and the integration of seed dressing, intercropping with maize plus pyrethroid sprays at the vegetative stage, early flowering stage and early podding stage significantly ($P < 0.05$) increased yield in snap beans by up to up to 163% compared to the control. The above results agree with results by Szwejkowska et al in 2008 who reported increase in yield elements in some pea cultivars as a result of seed dressing. These findings are also consistent with findings by Nderitu et al in 2009 in which there was higher yield in intercropped snap beans. Similarly the results concur with results by Delkhoshi et al (2012) and El-Mohamedy et al., (2008) who reported increase in yield in maize and peas as a result of seed treatment. The present results disagree with results by Zilli et al., (2009) who reported reduction in the yield of soybean as a result of seed treatment with a fungicide. The increase in yield in the treated plots was as a result of lower pest populations leading to lower pest damage to the crops which affects growth and eventually yield. The reduced number of chemical sprays in the integrated approach also reduced the stress on the plants leading to better growth as opposed to the case in the farmer practice where the chemical sprays were carried out on pest detection which stresses the crop and eventually causes lower yield.

The integration of seed dressing, a pyrethroid spray at the vegetative and early flowering stage plus a botanical at the early podding stage and the integration of seed dressing, intercropping with maize plus pyrethroid sprays at the vegetative stage, early flowering stage and early podding stage reduced significantly ($P< 0.05$) the pest damage in snap beans in Mwea and Embu by 57-95% compared to the control. The above results are agree with results by Radanass et al in 2012, who reported reduced damaged in upland rice as a result of seed dressing. The reduction in pest population for instance, thrips population also leads to less pest damage on snap bean pods (Nyasani et al., 2012; Nderitu et al., 2009). The effect of seed dressing on whiteflies in this study was been through systemic and residual toxicity of the seed dressing insecticide (Hossain et al., 2012; Zhang et al., 2011). The results in this study also are consistent with results by Mazzanti et al., (2011); Rao et al., (2012) who reported reduction pests due to seed dressing and intercropping.

The lower pest damage on snap bean pods was as a result of lower pest poulation in the treated plots as a result of seed dressing, foliar sprays and intercropping. The use of seed dressing in integrated pest management to reduce pest damage in greenhouses has been reported (Cárcamo et al., 2012). Seed dressing chemicals have a system action on the sucking pests which leads to reduction in their popluation (Pons and Albajes, 2002) while foliar sprays also lead to reduction in the pest population through contact and systemic action (Suganthy et al., 2012; Elbert et al.,2008). Intercropping also results in pest reduction through increase in biodiversity and the intercrop accting as a physical barrier or a trap crop for the pests (Nyasani, et al., 2012; Gachu et al., 2012; Theunissen, et al., 1996).

In conclusion seed dressing with moncerene plus two pesthrin sprays at the vegetative stage followed by one nimbecidine spray at early podding and seed dressing with maize intercrop plus three sprays with pesthrin at the vegetative, early flowering and early podding stage were the the most effective treatments resulting in high reduction in the number of bean stem maggots, thrips and whitefly. They also resulted in increased yields and less pod damage and as a result had the highest cost benefit ratio. The two integrated pest management options can be adopted by farmers in the management of bean stem maggots, thrips and whitefly.

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CHAPTER FIVE: GENERAL DISCUSSIONS , CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

Potassium salts of fatty acids at the rate of 1.5% concentration were effective in reducing the whitefly and thrips population. The yield was also high in plots treated with potassium salts of fatty acids in both the fine and extra-fine grades. The cost benefit analysis indicated that it was just as profitable to use potassium salts of fatty acids in the management of whitefly and thrips on snap beans as when using chemical pesticides. These findings are consistent with reports by Mohamad et al., (2013) and Dheeraj et al., (2013) who reported effect of potassium salts on aphids and whiteflies respectively. Similar results have been reported by Liu et al., (2000), Vavrina et al., (1995) and Ciancio et al., (2010). Hollingsworth, (2005) also reported control scales and mealybugs using potassium salts of fatty acids. Potassium salts of fatty acids are fast acting with a quick knock down effect on the pests and break down quickly after application leaving no residues (Dheeraj et al., 2013). Insecticidal soaps are also easy to handle because of their low toxicity to human beings and therefore are user friendly (Dheeraj et al., 2013). As a result potassium salts of fatty acids have no MRL or PHI requirements (Koppert, 2013).

Integration of seed dressing with moncerene plus two pesthrin sprays at the vegetative stage followed by one nimbecidine spray at early podding and seed dressing with maize intercrop plus three sprays with pesthrin at the vegetative, early flowering and early podding stage were the the most effective treatments resulting in high reduction in the number of bean stem maggots, thrips and whitefly. They also resulted in increased yields and less pod damage and as a result had the highest cost benefit ratio. Seed dressing is an important technology which is effective for management of sucking insect pests (Hossain et al., 2012; Pons and Albajes, 2002). The findings in this study are consistent with findings by Malaker et al., (2009) where seed dressing and foliar sprays increased plant population in wheat. Bio-pesticides which include botanical products like neem, are readily degradable and pose no risk of residues on produce are a suitable alternative to sythethic chemicals (Al-Samarrai et al., 2012). Biopesticides also pose little risk to non-target organisms and therefore play an important role in an IPM system (Gašić et al., 2013). Intercropping is a cultural practice that has been reported to contribute greatly in the management of various insect pests (Abd-Rabou et al., 2012; Theunissen et al., 1996; Rahnama et al., 2013). .

The integration of all this pest management options can offer a sustainable pest management solution in agricultural production systems. Potassium salts of fatty acids, seed dressing, use of natural pyrethroids, use of botanical products and intercropping in an IPM system can effectively provide a solution to snap bean farmers as shown in this study. As a result of the synergy resulting from an IPM approach, the number of chemical sprays required will be reduced. The reduced number of sprays results in less stress to the plant leading to better growth and eventual better yield. The same pest management options are cost effective and will lead to higher returns to snap bean farmers.

5.2 Conclusions

Based on the results of this study, potassium salts of fatty acids at the rate of 1.5% are effective in the management of thrips and whiteflies on snap beans. The use of potassium salts of fatty acids at the rate of 1.5% results in higher yields and low pest damage on snap bean pods. This pest management option is cost effective based on the cost- benefit analysis in this study and can be used by any farmer in the management of whitefly and thrips on snap beans. This pest management option will contribute to compliance by snap bean farmers to the stringent export regulations.

The integration of seed dressing, foliar sprays at the vegetative stage, early flowering stage and early podding plus intercropping is effective in the management of the bean stem maggots, thrips and whiteflies in snap beans compared to application of chemicals on pest detection. The pest management options also lead to higher yields and better returns as shown in this study. This pest management option will contribute to compliance by snap bean farmers to the stringent export regulations.

5.3 Recommendations

1. Further investigation should be carried out on the effect of potassium salts of fatty acids on the different species of whitefly and thrips

2. Potassium salts of fatty acids at the rate of 1.5% concentration as an alternative to chemical pesticides should be adopted by snap bean farmers for the management of thrips and whiteflies

3. The integration of seed dressing, foliar sprays with pesthrin and intercropping with maize should be adopted by snap bean farmers for management of bean stem maggots, thrips and whiteflies

4. A policy should be developed to encourage the registration and create awareness on alternative and biological control products to enhance and promote sustainable farming.

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