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Effect of intercropping selected pesticidal plants with common bean on aphids infestation and natural enemies abundance in Arusha, Tanzania

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NM-AIST

EFFECT OF INTERCROPPING SELECTED PESTICIDAL PLANTS WITH COMMON BEAN ON APHIDS INFESTATION AND NATURAL ENEMIES ABUNDANCE IN ARUSHA, TANZANIA

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ABSTRACT

A Randomized Complete Block Design experiment was laid out in four replications to evaluate abundance of natural enemies (NEs) and aphid infestation on common bean (*Phaseolus vulgaris* L) when intercropped with pesticidal plants (PPs) namely *Tagetes minuta, Bidens pilosa, Ageratum conyzoides, Ocimum suave and Hyptis suaveolens*. The results showed that PPs attracted NEs and pollinators and reduced aphid infestation with no or little negative effect on bean actual yield. Increased NEs and pollinators was probably attributed to plant diversity created by intercropping system, which provide a greater number of opportunities for NEs and pollinators to survive in agricultural systems. However, the degree of abundance of NEs and pollinators differed among treatments. *H. suaveolens* and *O. suave* attracted high proportion of pollinators compared with other treatments, while *B. pilosa*, *T. minuta* and *A. conyzoides* attracted high proportion of NEs compared with *H. suaveolens* and *O. suave*. Likewise, abundance, incidence and severity of aphids was lower in the intercropped plots implying positive effects of the PPs-bean intercrop in reducing number of aphids. On repelling effects, all PPs repelled aphids in comparison with the control (un-intercropped common bean). Further work is required to determine the exact cause of the yield variability in common bean intercropped with *H. suaveolens* and *O. suave* compared with the yield of the same common bean when intercropped with other treatments in the same study.

DECLARATION

I, **Ancila Karani** do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

…………………………… ……………………….

Ancila Karani **Date**

Name and signature of candidate

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CERTIFICATION

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality, as a dissertation for the degree examination.

…………………………..   ……………………………

Prof. Patrick A. Ndakidemi   **Date**

Name and signature of Principal supervisor

…………………………..   ……………………………

Dr. Ernest R. Mbega   **Date**

Name and signature of Co-supervisor

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DEDICATION

This dissertation is dedicated to my daughter; Dorcas Antony and my entire family for their great love, understanding and support.

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LIST OF ABBREVIATION AND SYMBOLS

ANOVA	Analysis of variance
BFB	Bean Foliage Beetle
BSM	Bean Stem Maggot
NEs	Natural enemies
NM-AIST	Nelson Mandela African Institution of Science and Technology
PPs	Pesticidal plants
RCBD	Randomized Complete Block Design
SARI	Selian Agricultural Research Institute
TPRI	Tropical Pesticides Research Institute

CHAPTER ONE

INTRODUCTION

1.1 Background

Common bean (*Phaseolus vulgaris* L.) is an annual leguminous plant that belongs to the family Leguminoaceae, with pinnately compound trifoliate large leaves (Wortmann, 1998). It has high protein content and is a good source of energy and provides folic acid, dietary fiber and complex carbohydrates (Filella *et al.,* 1994). Common bean provide 15 % protein and 30 % energy to the world population (Kalavacharla *et al.,* 2011). About half of the grain legumes consumed worldwide is common beans (Broughton *et al.,* 2003). It is recognized as the second most significant source of human dietary protein and the third most important source of calories in Eastern and Southern Africa (Pachico, 1993; Akibode and Maredia, 2011). They are major source of iron and calcium (Shellie-Dessert and Bliss, 1991). Beans consumption in Eastern and Southern Africa exceeds 50 kg person^{-1} year^{-1} (Jaetzold and Schmidt, 1983). In Tanzania, beans are the main grain legume crop often intercropped with maize. Most of the beans production in Tanzania is carried out by smallholder farmers for their own consumption, with around 20 % surplus being marketed. The country ranks the fifth in the world and the first in Africa in bean production (Akibode and Maredia, 2011; FAOSTAT, 2013).

Common bean production is constrained by numerous factors such as social - economic and agronomic factors such as producer and consumer likings, climatic and edaphic stresses, diseases and insect pests (Hillocks *et al.,* 2006). Insect pests is considered to be a key factor, which limits bean production as it attacks all parts of the bean plant from the roots, lower stem, the pods and seeds; and if left unmanageable, pests can cause severe damage (Karel *et al.,* 1981; Hillocks *et al.,* 2006). Of these insect pests, aphids are considered a major insect pest of common bean in the tropics. It forms colonies around the stem, leaves and growing points; suck sap from plants; and cause seedlings to wilt and die. All parts of the plant may be damaged and older plants may be stunted as a result of aphid attack.

The phloem sap from the host plant is sucked by the aphids through narrow pierce-sucking mouthparts called stylets (Iwona *et al.,* 2011). This stylets form mechanical damage that may influence plant responses to infestation during probing (Tjallingii and Hogen, 1993).

The secondary metabolites have straight fatal effects on a variety of insect pests while other plant defense has secondary effect upon pest e.g. appealing predators and hindering insect oviposition (Shereen, 2007). Others have antixenotic or antibiotic properties and plant volatile that repel phloem feeding insects or attract their natural enemies (NEs) (Wagner *et al.,* 2004).

For hundreds of years since 1800s, farmers have been using botanical pesticides [henceforth called pesticidal plants (PPs) in this work] like *Azadirachta indica*, *Chrysanthemum cinerariifolium, Pongamia glabra* (Pavela, 2009), *Tephrosia vogelii, Venonia amygdalina, Tithonia diversifolia* and *Lantana camara* (Mkenda *et al.,* 2015; Mwanauta *et al.,* 2015) to provide means for crop protection in different parts of the world before the development of synthetic insecticide (Rosenthal and Berenbaum, 1991; Weinzierl, 2000; Guzmán *et al.,* 2009). In the early 1940s to the 1950s, PPs were abandoned in the industrialized countries' agriculture due to development of synthetic insecticides (Grdiša and Gršić, 2013). Later on in the 1990s, the use of PPs aroused due to numerous negative side effects of synthetic pesticides which were noticed including; the development of pest resistance, resurgence, pesticide food contamination, environmental pollution problems, the disruption of natural balance, toxicity to non-target organisms, and the most important, negative impact on human health (Weinzierl, 2000; Scott *et al.,* 2003; Scott *et al.,* 2009). These effects pushed researchers and the community to explore the PPs throughout the world.

In Tanzania, several researches have been conducted on the use PPs in control of bean insect pests. In a study by Kamatenesi *et al*. (2008), a number of plants such as *Capsicum frutescens, Tagetes spp, Nicotiana tabacum, Cyperus spp., Tephrosia vogelii, Azadirachta indica, Musa spp, Eucalyptus spp and Carica papaya* have been identified to have strong anti-insect properties and thus they are being used for insect pest management by the subsistence farmers in countries around Lake Victoria. Recent studies by Mkindi *et al*. (2015), Mwanauta *et al*. (2015) and Mpumi *et al*. (2016) reported toxicity and effectiveness of PPs particularly *Tephrosia vogelii, Venonia amygdalina, Tithonia diversifolia* and *Lantana camara* in managing both field and storage insect pests of major economic importance of common bean (aphids, bean stem maggot, *Ootheca* and bruchid) in beans production.

The effectiveness is due to chemical compounds which have toxic, deterrent or repellant properties to insect pests or attractant to NEs.

Thus this study aimed at evaluating the effect of intercropping selected PPs and common bean on aphids' infestation, abundance of natural enemies (NEs) and growth of bean so as to identify potential annual PPs to be intercropped with common bean to control damage caused by aphids and other insect pests in the bean growing areas in Tanzania.

1.2 Problem statement and justification

Insect pests particularly aphids are a big threat to common bean production worldwide. Infestations by these pests lead to reduction in quality and quantity of the crop. Yield losses of about 30 % to 90 % due to aphids' pest have been reported in Eastern Africa (Swaine, 1969; Nyiira, 1973; Autrique, 1989; Munyasa, 2013). Infestation by aphids has been reported to raise production cost by up to 30 % to smaller holder farmers (Grzywacs *et al.,* 2010). In addition, only 0.1 % of the agrochemical used for crop protection grasps the targeted pest leaving the remaining 99.9 % to enter the environment; causing hazards to non - target organisms including human (Piementel and Levitan, 1986; Ardley, 1999; Blackman and Eastop, 1999). Synthetic pesticides are also unaffordable, occasionally available, poorly labelled and packed, adulterated and/or sold beyond their expiry date (Stevenson *et al.,* 2012a). Several studies have been done in Tanzania on the use of PPs to control insect pests of bean including aphids. Mkenda *et al*. (2015), Mwanauta *et al*. (2015) and Mkindi *et al*. (2015) reported on importance of using PPs extracts from *Vernonia amygdalina, Lippia javanica, Dysphania ambrosioides, Tithonia diversifolia, Lantana camara* and *Tephrosia vogelii* to control various insect pests of beans.

This seems to be an area of interest in pest management; more detailed studies involving intercropping have been reported to offer best returns to crops due to increased levels of beneficial insects. For instance, Abate and Ampofo (1996) reported abundance of natural enemies being enhanced by planting two or more crops in same field. Farrell (1976) reported reduction in the spread of peanut rosette virus by intercropping common bean with peanut in Malawi.

If intercropping non-medicinal plants with common bean seemed to reduce aphids infestation in the field, this study hypothesized that including PPs as intercrop would have a higher ability to control aphids than intercropping with non-pesticidal plants due to their ability to repel pests (Mkindi *et al*. (2015). Thus, this study was designed to develop a low cost, ecofriendly aphids' management strategy through PPs - bean intercrop in Arusha Tanzania.

1.3 Research objectives

1.3.1 Overall objective

To evaluate the effect of intercropping annual PPs with common bean on aphids infestation, diversity and abundance of NEs and to determine the damage caused by aphids so as to identify potential PPs species to be intercropped with common bean.

1.3.2 Specific objectives

(i) To determine the effect of intercropping common bean with annual pesticidal plants on diversity and abundance of natural enemies.

(ii) To determine the effect of intercropping common bean with annual pesticidal plants on aphids abundance and infestation.

(iii) To assess the effect of intercropping common bean and annual pesticidal plants on yield and yield components of common bean.

(iv) To assess the magnitude of the yield loss caused by aphids.

(v) To evaluate repellency effect of pesticidal plants on aphids.

1.3.3 Research Hypothesis

H0: Annual pesticidal plants will repel insect pests including aphids and enhance abundance of NEs.

H1: Annual pesticidal plants will not repel insect pests including aphids and enhance abundance of NEs.

1.3.4 Significance of the study

Annual pesticidal plants that can be intercropped with common bean for pest management without affecting main crops' yield being identified. This is important for biological control measure that is cost – effective and environmentally sound in recognizing potential yield of common bean.

CHAPTER TWO

LITERATURE REVIEW

2.1 Potential of intercropping pesticidal plants with common bean in promoting natural enemies for pest management in agro-ecosystems[1].

2.1.1 Introduction

Common bean (*Phaseolus vulgaris* L.) is an essential sustenance grain legume in the world, which provides 15 % and 30 % of the protein and calories respectively to the world's population (McConnell *et al.,* 2010; Kalavacharla *et al.,* 2011). The common bean forms 50 % of the most common grain legume consumed by a global population and it is nearly twice the production of chickpea, which is the global second most important grain legume (Broughton *et al.,* 2003). It covers 46 % of the global legume production followed by chickpea which occupies 22 % and the rest cover less than 10 % (Akibode and Maredia, 2011). Legume seeds with no exception to common bean are rich in lysine amino acid, complementing the nutritional profiles of cereals, roots and tubers (Phillips, 1993; Broughton *et al.,* 2003; Hillock *et al.,* 2006; Catherine, *et al.,* 2015). Regularly, they represent essential supplement to other protein sources (Duranti and Gius, 1997; Duranti, 2006; Graham and Vance, 2003).

Common bean occupies an important place in improving the nutritional status of most low earning populations in Eastern Africa (Doughty and Walker, 1982; Shimelis and Rakshit, 2005; Shimelis *et al.,* 2006). It also maintains animal health especially in developing countries where meat and dairy production is almost solely dependent upon forage legumes and grasses (Russelle, 2001; Wattiaux and Howard, 2001; Dorry, 2008; Graham and Vance, 2003).

The average global yield of common bean is 3.5 t ha^{-1} ranging from 1.3 t ha^{-1} in Africa to 6 t ha^{-1} in North America (FAO STAT, 2013). Globally Tanzania ranks fifth in terms of beans production (Akibode and Maredia, 2011). Despite Tanzania being the largest producer of common bean, the yields are still low with an average of 741 kg ha^{-1} under farmers' management condition (Bucheyeki and Mmbaga, 2013). Factors associated with this low yield include biotic, abiotic and socio-economic conditions (Kambewa, 1997; Hillocks *et al.,* 2006). In this study, biotic factor, mainly insect pests such as aphids and other few insect

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pests of economic importance in common bean and common method of control have been discussed.

2.1.2 Importance Common bean in Africa

Common bean (*Phaseolus vulgaris* L.) forms an important food and cash crop in Africa particularly in the Eastern and Southern Regions of the continent (Abate and Ampofo, 1996). While common bean are grown largely for subsistence and mainly by women farmers, around 40 % of the total production from Africa is marketed, at an average annual income of USD 452 million (Wortmann *et al.,* 1998; Hillocks, 2006) .

In Tanzania, common bean is highly cultivated in the mid to high altitude areas which experience more reliable rainfall and cooler temperature. Areas of Northern zone particularly Arusha, the Great Lakes Region in the West and in the Southern Highlands (Karel *et al.,* 1981; NBS, 2012). Its middling production is around 500 kg ha^{-1} although the potential yield is 1,500 – 3,000 kg ha^{-1} under optimal conditions. The reason for the low yield is a wide range of pests attack with insect pests being a major reason (Hillocks *et al.,* 2006). Henceforth management of insect pests is an integral and crucial component of bean production in Tanzania (Paul, 2007). Some insect pests of common bean are mentioned in 2.2.

2.1.3 Selected insect pests of economic importance in common bean

Insect pests endure a foremost constraint in agricultural production systems. They cause both direct damage to crops through feeding, indirectly damage through transmission of viruses and contamination, causing the low quality of the produce and low productivity (Degri, 2013). Several insect pests have been reported negatively affecting common bean production, including aphids (*Aphis fabae*); pod borers (*Helicoverpa spp*. and *Maruca testulalis*); bean stem maggot (*Ophiomyia spp.*); foliage beetles (*Ootheca spp*.) and thrips (*Megalurothrips sjostedti*) (Allen *et al.,* 1996). Insect pests being one of the biotic factors are considered as a key factor which limits bean production as they attacks all parts of the bean plant from the roots, stem, leaves, flowers, pods, and seeds. If left unmanageable, they can cause severe damage (Karel *et al.,* 1981; Hillocks *et al.,* 2006). Of the mentioned pests, aphid is considered a major insect pest of bean in the world (Stechmann, 1998; Shannag and Ababneh, 2007; Esmaeili-Vardanjani *et al.,* 2013) accounting for yield losses ranging from 37 to 90 % (Wosula, 2016).

Therefore, eco-friendly method of managing this insect pest is an integral and crucial component in common bean production. Detailed descriptions of some important insect pests of common bean are described below:

(i) Black bean aphid - *Aphis fabae* Scopoli (Hemiptera: Aphididae), (henceforth Aphid)

Aphid is one of the most significant pests of numerous cultivated crops throughout the world (Volkl and Stechmann, 1998). It is the principal insect pest directly damaging common bean in Africa (Remaudire *et al.,* 1985). It has been reported that large colonies may be very damaging, cause direct damage by phloem feeding, resulting in significant impairment of plant growth and grain yield (Parker and Biddle, 1998; Shannag and Ababneh, 2007b). The colonies around the stem, leaves and growing points; suck sap from plants through narrow piercing-sucking mouthparts called stylets and cause seedlings to wilt and die (Karel and Autrique, 1989; Iwona *et al.,* 2011; IPM legume manual, 2016). Fischer *et al*. (2005) and Bahar *et al*. (2007) reported the secretion of honeydew from the affected plants which enhances the growth of sooty moulds and hence interferes with the photosynthetic ability of plants. According to the study by Abate *et al*. (2000) and Basedow *et al*. (2006) the relationship between injuries caused by aphid and crop yield depends on the growth stage of the host at the time of invasion.

Further study by Wosula (2016) showed that in common bean production, a yield loss ranging from 37 to 90 % is caused by aphids. Due to the complexity in the life cycle and high reproduction rate of this insect (Rusin *et al.,* 2017), it has become difficult to control using synthetic pesticides. Therefore, there is a need of developing other strategies such as the use of agronomic, cultural, biological and pesticidal plants (PPs) as control methods which target the insect during the specific time of damage. Some of the PPs which have been reported to control this insect include *Azadirachta indica*, *Eucalyptus globules*, *Bidens pilosa*, *Tagetes minuta*, *Ageratum conyzoides* and *Ocimum basilicum* which were reported to have maximum repellency against aphids (Singh *et al.,* 2012; Anjarwalla *et al.,* 2016; Verma *et al.,* 2016; Rioba and Stevenson, 2017). Thus the use of live PPs can be manipulated in the cropping system (intercropping/mixed/strip cropping) to repel insect pests and attract the natural enemies which feed on aphids and other pests. This is an eco - friendly and low - cost method of controlling this insect pest and eventually improved common bean production. It is therefore necessary to carry out further studies on intercropping PPs with common bean to acquire information that can be used as the basis for potential plants that repels this insect pest and enhance abundance of NEs that prey on them.

(ii) Bean Stem Maggots (BSM) or Bean Fly (*Ophiomyia spp*.)

This is an insect pest which attacks common bean and other leguminous plants mainly at seedling stage. It is distributed throughout Africa (Buruchara *et al.,* 2010). Its presence is indicated by small shiny black flies with clear wings that reflect a metallic blue color in sunlight (Abate and Ampofo, 1996; Ambachew *et al.,* 2015). The seedling wilt and dry in case of severe damage and this is due to disruption of nutrient transportation which cause tap root to die (Ampofo and Massomo, 1998; CIAT, 2010). The young seedlings under stress wilt and die within a short time while older and more vigorous plants may tolerate the damage though they become stunted and have reduced yield (CIAT, 2010). Some studies demonstrated bean fly incidence and severity to be more pronounced following the peak of the rain season (Greathead, 1968; Karel, 1985). A yield losses ranging from 8 to 100 % has been reported (Greathead, 1968; Abate, *et al.,* 2000; Okoko, *et al.,* 2005; Ojwang' *et al.,* 2010). The loss calls for affordable and safe method to control this insect pest. Among the method used in control this insect pest is the use of crop diversity which has been reported as a primary method for small - scale farmers in sub - Saharan Africa (Abate and Ampofo, 1996). However, studies on the manipulation of live PPs to control this insect pest are limited. Therefore, further studies to come up with potential PPs to be manipulated in common bean cropping system is essential so as to suppress this insect pest at minimal cost.

(iii) Bean Foliage Beetle – BFB (*Ootheca spp)*

Ootheca species are seedling pest which is widely distributed in Africa (Allen *et al.,* 1996). The presence of young bean seedlings has been reported to be a favorable condition to stimulate adult emergence of the BFB from hibernation in the soil (Buruchara *et al.,* 2010). The larva of this insect cause below ground damage and above ground damage is caused by the adult (Ampofo *et al*., 2002). However, both damages disrupt nutrients transport and potential for nitrogen fixation (Minja, 2005). Karel and Rweyemamu (1984) reported an adult *Ootheca* to cause 18 – 30 % yield loss.

Studies by Ampofo and Massomo (1998) revealed that heavy infestation of *Ootheca* is the result of crop intensification i.e. continuous cultivation of the same crop in the same piece of land without rotation or fallowing. Since common bean production in Africa is carried out by small-scale farmers with farms not exceeding one hectare, then fallowing or crop rotation is not practicable. Therefore, alternative method(s) to deal with this insect pest is inevitable. It has been reported that applying combinations of strategies including different forms of PPs such as neem seed extracts deter infestation and reduces the damage (Buruchara *et al.,* 2010). It's likely that if live PPs are intercropped/mixed with common bean can work in control of the foliage beetle problem at no or lower cost. Little is known on potential of some plant species in controlling of this pest. Thus, there is a need of exploring more plants particularly live PPs for bean protection.

(iv) Whitefly (*Bemisia tabaci*)

B. tabaci is the most economically important whitefly species which pose a challenge to beans production worldwide (Gerling, 1990). It has been reported to cause severe economic damage in over 60 crop plants (including common bean) as a phloem sap - sucking pest or as a vector of viral diseases (Navas - Castillo *et al.,* 2011; Naveen *et al.,* 2017). In Africa, the pest occurs almost in all bean growing ecologies (Buruchara *et al.,* 2010) and a yield loss of 14 – 86 % has been reported by in Sudan (Salifu, 1986).

The larvae of this insect pest need a lot of protein for growth thus consume a large quantity of plant sap and the excess is excreted as honey dew (Malais *et al.,* 2003) and this makes it to be a serious pest of common bean. The honey dew on the surface of leaves encourages growth of fungal moulds whereas heavy growth of sooty moulds reduces photosynthesis affecting plant growth (Henneberry *et al.,* 1996)**.** Both nymphs and adults suck sap from leaves, causing them to become mottled, with light yellowish spots on the upper surface. Whitefly populations may build up in large colonies on the underside of leaves. The adults may transmit the cowpea mild mottle virus in beans.

Whiteflies tend to breed all year, moving from one host to another as plants are harvested or dry up (Flint, 2007). Low levels of whiteflies do not cause much damage hence do not warrant control interventions (Abate and Ampofo, 1996). However, management of whitefly is very difficult in case of heavy infestations. This is because whiteflies are not well controlled with any available insecticides. Studies by Gorman *et al*. (2007), Nderitu *et al*. (2010), Cardona (2012) and Naveen *et al*. (2017) reported resistance by whitefly species to synthetic insecticides which make it difficult to manage the pest. Therefore, alternative affordable and safe methods to deal with the insect are crucial. PPs such as neem oil have been reported to reduce but not eliminate whitefly populations. Thus, studies can be conducted on the same concept as of neem to evaluate how different live PPs would work in control whiteflies when manipulated in common bean farming.

Generally, food crops such as beans are grown by small - scale farmers, whose farm sizes often do not exceed one hectare and as such crop rotation and fallowing as a means of reducing insect pest infestation is not practicable. Therefore, there is a continuous need of easy, affordable, safe and sustainable approaches for the management of the mentioned insect pests for small scale farmers. Such approach includes biological agent, PPs and cultural practices. However, further studies are required to compliment the available information.

2.1.4 Common control measures for insect pests in common bean

Farmers have been using different methods to control insect pests of common beans; among them are the uses of synthetic pesticides, PPs, cultural practices and biological method, as described below:-

(i) Use of Synthetic pesticides

It is estimated that about 1.8 billion people in the globe engage in agriculture and most of them use pesticides to protect food and commercial products they produce (Williamson *et al.,* 2008). Synthetic pesticides are reported to be fast acting and can kill a wide range of insect pests but have a number of limitations attributed to killing of both beneficial and non-beneficial insects. They are also limited in rural areas, are too expensive or unavailable and are often adulterated or applied at inappropriate application rate due to lack of knowledge, and are often poorly labeled or even used after expiry date. All these lead to the evolution of pesticide resistance and resurgence (Stuart, 2003). Producers and consumers health and safety are highly threatened by the use of synthetic pesticides with no mechanism in place to ensure safeness of the produce and concern for the prolonged effects of exposure (Hart and Pimentel, 2002; Pimentel, 2005).

Agrow (2006) and Sola *et al*. (2014) reported that a very low quantity (2 – 3 %) of the global pesticide market is used in Africa. Still, the continent bears the highest human mortality risks related to misapplication of pesticides. Stoddard *et al*. (2010) reported the reduction of leaf miner, *Liriomyza huidobrensis* by using imidacloprid pesticide which at the same time suppressed its parasitoid. From these descriptions, synthetic pesticides kill a wide range of organisms in place including beneficial ones. Therefore, adoption of alternative low - cost control measure that is less harmful to natural enemies and pollinators and with health benefits to the applicators, producers and consumers are inevitable. In that case, pests' management through manipulation of live PPs in common bean cropping system can be critical.

(ii) Botanical pesticides (hereinafter pesticidal plants)

Pesticidal plants (PPs) are naturally occurring chemical compounds extracted or derived from plants to manage pests in the field and pests damaging stored produces (Sola *et al.,* 2014). Rosenthal and Berenbaum (1991) and Weinzierl (2000) reported the use empirical knowledge on the use of PPs for managing pest in different parts of the world before the development of synthetic insecticide.

Some examples of PPs used to control different insect pests are; rotenone compounds from several plant species in East Asia and South America (Kennedy, 2011), neem (*Azadirachta indica*) in India (Hedge, 1995; Singh and Raheja, 1996; Anonymous, 2006), sabadilla (*Schoenocaulon officinale*) in Central and South America (Isman, 2006; Guzman-Pantoja, 2009; Singh and Saratchandra, 2005) and pyrethrin from Pyrethrum (*Chrysanthemum cineraniifolium*) in Persia (Iran) (Parr, 1975; Weinzierl, 2000). Studies have shown that plants are very good source of crop protectants against pests (Isman, 2008). They can easily degrade in the environment, and they are easily available, less toxic to human and non - targeted organisms and are compatible with different human cultures (Weinzierl, 2000; Oruonye and Okrikata, 2010; Mpumi *et al.,* 2016).

In countries such as Benin and Uganda, PPs such as pyrethrins and neem and African marigold extracts are used to control cotton bollworm and storage pest of cowpeas respectively (Kawuki *et al.,* 2005). In other parts of Africa, PPs such as bushmints (*Hyptis suaveolens*) have been used for the control of pink stalk borer (*Sesamia calamistis*) on maize (Adda *et al.,* 2011). Ogunsina *et al*. (2011) reported *Lantana camara*, (Verbenaceae), African nutmeg and *Euphorbia lateriflora*, Schum and Thonner to be effective against bean weevil and maize weevil. Recently, Stevenson *et al*. (2017) have reported selected pesticidal plants being used by small scale farmers in Africa to manage different field and storage pests. This includes *Ageratum conyzoides, Biden pilosa*, *Dysphania ambrosioides*, *Tagetes minuta*, *Tephrosia vogelii*, *Tithonia diversifolia* and *Vernonia amygdalina* among others. With these few examples, it is undeniable that the PPs are used intensively in a number of crop systems, particularly in Africa. Most studies described the use of PPs in different form e.g. powder, crude oil, aqueous extract, ethanol extract (Asogwa *et al.,* 2010; Amoabeng *et al.,* 2013; Karani *et al.,* 2017).

In East Africa, a number of PPs have been reported to have pesticidal effects and are used by small-scale farmers for pest management in the field and stored produces. Examples of those PPs are *Capsicum frutescens*, *Tagetes spp, Nicotiana tabacum*, *Cyperus spp., Tephrosia vogelii*, *Azadirachta indica*, *Musa spp*, *Eucalyptus spp* and *Carica papaya* have been identified to have strong anti-insect properties (Mugisha-Kamatenesi *et al*., 2008).

In Tanzania, several studies have shown that the PPs are effective in controlling field and storage insect pest of common bean. For instance, Paul (2007) reported insecticidal properties of neem (*Azadirachta Indica* L.), worm seed (*Chenopodium ambrosioides* L.), cypress (*Cupressus lucitanica*) and marigold (*Tagetes minuta* L.) in management of important field insect pest of beans. Studies by Mkenda and Ndakidemi (2014), Mkindi *et al*. (2015), Mwanauta *et al*. (2015) and Mpumi *et al*. (2016) reported effectiveness and toxicity of PPs particularly *Tephrosia vogelii*, *Venonia amygdalina*, *Tithonia diversifolia* and *Lantana camara* in managing field insect pests of major economic importance (Aphids, Bean stem maggot and *Ootheca)* in common bean production. Other PPs reported having a strong ant-insecticidal properties include *Tagetes minuta, Grewia similis* K. Schum and Echnops, *Hispidus fresen* (Machocho, 2012). All these studies described the use of PPs in other forms (such as powder, oil, aqueous and commercial) to control insect pest of common bean.

Very few studies have explored the influence of live plants (pesticidal ones) on the abundance of natural enemies and pests in bean fields when intercropped with common bean. It is therefore of great importance to investigate the role played by pesticidal plants in common bean crop production without affecting the yield of the main crop. Table 1 shows some of the PPs which can be intercropped with several crops to enhance abundance of natural enemies and suppress pests.

Table 1: Important pesticidal plants used as intercrop to promote natural enemies and control insect pests in different crops.

Intercropping type	Target pest	Natural enemies/parasitoids promoted	Reference
Hyptis suaveolens + maize	Pink stalk borer (*Sesamia calamistis*)	*C. flavipes* *C. sesamiae*	(Adda *et al.,* 2011 Overholt *et al.,* 1994c; Midega *et al*., 2006)
Maize + *Desmodium uncinatum*(repellant) + *Napia grass* (trap) + *Melinis minutiflora* (border)	Pink stalk borer (*Sesamia calamistis*)	Generalist predators Parasitic wasp *Cortesia Sesamia* – larva, *Descampsina sesamiae*- larvae & pupa, *Sturmiopsis parasitic* – larva &pupa	(Polaszek, 1998; Kfir *et al.,* 2002; Mbuya and Fujian, 2016; Chinwada and Overholt, 2001; Chinwada *et al.,* 2003; Chinwada *et al.,* 2004)
Tagetes spp + cash crop	Root-knot nematodes		(Hooks *et al.,* 2010)
Rocket salad, *Erica sativa* + mustard	Mustard aphids	Coccinellid beetle, *Chrysoperla carnea*, Wasp, Spider	(El-Hamawi *et al.,* 2004; Reddy *et al.,* 1990; Malik *et al.,* 2012; Rana *et al.,* 1995; Singh *et al.,* 2002)
Canola *Brassica napus* as an intercrop	Aphids	Lacewings, spider, syrphid fly, ladbird beetles, *Aphidius*	(Prakash, Rao and Nandagopal, 2008; Sarwar, 2013)
Pear orchard + aromatic plants	Major insects of pear e.g. *Cacopsylla pyricola*	*Anthocoris nemoralis*, Coccinellids,Chrysopids, Parasitoids-(*Trechnites psyllae, Syrphophagus mamitus*)	(Beizhou *et al.,*2011; Onder, 1982; Erler, 2004)
Ocimum basilicum L + *Vicia faba* L, *Satureja hortensis* L + *Vicia faba* L	Aphid (specifically *Aphis fabae*)	Aphid predators (Syrphidae and Coccinellids)	(Basedow *et al.,* 2006; Gospodarek *et al.,* 2016)
Aromatic plants intercropped with apple orchard [Ageratum (*Agerarum houstonianum* Mill.), *French marigold (Tagetes patula* L.) and basil (*Ocimum basilicum* L.)]	Spirea aphids (*Aphis citrocola*)	*Chrysopa sinica* Tjeder, *Crysopa foemosa* Brauer, *Episyrphus balteata* De Geer, *Coccinella septempunctata* L., *Leis axyridis* Pallas, *Propylaea japonica* (Thun berg), *Orius tantillus* Motschulsky	(Song *et al.,* 2013)

(iii) Biological control

This can be defined as the use of an organism to reduce the population density of another organism (Bale *et al.,* 2008). When we focus on the biological control of insect pest, it can be defined as the study and uses of predators, parasites and pathogens for regulation of pest densities (DeBach, 1964). Biological control is divided into three techniques which are: classical (sometimes termed as inoculative biological control), augmentative (where a distinction can be made between ‘inundation’ and ‘seasonal inoculation’) and conservation control (van Lenteren 1993a, 2006b).

Classical control is used mainly when exotic pests have become established in new countries or regions of the world where small numbers (usually less than 1000) of a certain species of natural enemy are collected from the country or region of origin of the pest, then inoculated into the new environment, and allowed to build up the level of control and this can be maintained over very long periods of time (Bale *et al.,* 2008).

Augmentation control states all forms of biological control in which natural enemies are periodically introduced, and usually requires the commercial production of the released agents (van Lenteren, 2006b). van Lenteren and Bueno (2003) described inundation as the mass production and release of large numbers of the control agent, such as the *Trichogramma* egg parasitoids of various lepidopteran pests including the cotton bollworm, *Heliothis virescens*. Seasonal inoculative control is a form of augmentation where natural enemies are similarly mass reared in the laboratory and periodically released into short-term crops where many pest generations can occur in each growing season (van Lenteren and Woets, 1988). As with augmentative control, relatively large numbers of natural enemies are released to obtain immediate control, but in addition, a build-up of the natural enemy population occurs through successive generations during the same growing season.

Conservation control refers to the usage of native predators and parasitoids against native pests. Various measures are implemented to enhance the abundance and activity of the natural enemies, including manipulation of the crop microclimate, increasing the availability of prey, and providing essential food resources such as nectar and pollen for adult parasitoids and aphidophagous hoverflies (Gurr *et al*., 2000; Wackers, 2003; Winkler *et al*., 2005).

Biological control is more advantageous in comparison with synthetic pesticides and therefore its practicability is highly encouraged to lower cost of production, ensure environmental safety and health of the consumers and farmers.

Most pests have natural enemies that control or suppress them effectively in some situations. These include predators and parasitoids which help to protect plants from damage caused by insect pests (Rodriguez-Saona *et al.,* 2012). Greathead (1968), Autrique (1989), Abate (1990) and Abate and Ampofo (1996) reported numerous parasitoids attacking bean stem maggot (BSM) and causing significant mortality, therefore providing good natural biological control for the mentioned pest. *Opius phaseoli* (Hymenotera: Braconidae) and *Eucolidae spp* (Hymenoptera: cynipidae) are the major reported parasitoids against BSM. Letourneau and Altieri (1983) and Salih *et al.* (1990) reported *Orius spp* as a predator which prey bean flower thrips. Also Aphid has been reported to be parasitized by various beneficial insects of the order Hymenoptera, family Aphididae. Examples are *Aphidius colemani*, *Lysiphlebus fabarum*, *Lysiphlebus confuses*, *Lysiphlebus cardui*, *Trioxy angelicae* and *Epherdus plaitor* which have been reported to have promising effect on aphid control in Burundi (Autrique *et al.,* 1989). Ogenga-Latigo *et al*. (1993) unveiled Coccinellids as a good predator of aphids i.e. aphidophagous coccinellids. Both larvae and adult of coccinellids prey on aphids and other insect pests thus a good predator (Michaud, 2012). Heinz *et al.* (1999) showed effectiveness of *Delphastus catalinae* in suppression of *Bemisia tabaci* in cotton. Powell and Pell (2007) listed augmentation trials of ladybirds against aphids reporting the target species, crop, life stages released, and degree of success obtained. From those examples, the uses of biological agents is one of the control measures in pest management programs that seems less laborious, more environment-friendly and more effective without harmful effects on non-target organisms and coccinellid beetles have an incredible potential in this regard. More studies are needed to investigate the dynamics of natural enemies and pests and their association with several PPs in bean fields for increasing productivity and hence improve people livelihoods.

(iv) Cultural control

This method aims at altering hosts' environment or behavior of the pests and the host makes the pests less likely to survive, grow or reproduce. It involves the use of crop rotation, planting and harvesting time, irrigation management; trap crops, intercropping (Herzfeld *et al.,* 2011).

Intercrops as a cultural control of insect pest

Intercropping is the practice of rising different crops in the same field at the same season. It can reduce the insect pest populations, increasing beneficial insects (natural enemies, and pollinators), and weed suppression (Gurr *et al.,* 2004; Gianol *et al.,* 2006; Smith and Liburd, 2012; Bellon and Penvern, 2014). In addition, non-crop plants such as pesticidal plants (PPs) can be intercropped with crop plants to influence numbers of pest and beneficial arthropods (Frank and Liburd, 2005; Smith and Liburd, 2012). Gurr *et al*. (2016) reported improvement of natural enemies and detritivore abundance by different plants grown in the same field and at the same season.

Kasina *et al*. (2006) reported insect pests to be repelled by volatiles produced from intercropped crops and promote the population of natural enemies. There are limited studies on the role(s) played by important pesticidal plants in bean fields for crop protection. Therefore, more research is needed to investigate the role played by the plants particularly pesticidal ones for effective biological control.

2.1.5 Effect of synthetic pesticides use on natural enemies

Natural enemies (NEs) are adversely affected by and usually perish through synthetic pesticides. Synthetic pesticides kill natural enemies including those in resistant stages at the time of application and those which will migrate into the sprayed area (Bacci *et al.,* 2007). The same author reported that if natural enemies exposed to pesticides were not killed at the time of application, there is a possibility of the pesticides to accumulate to a lethal level. The mortality rate of 61 % of parasitoids *Encarsiasp* has been reported to be caused by cartap, imidacloprid, malathion, methamidophos, abamectin, acephate and acetamiprid insecticides (Thomson *et al.,* 2001). Martinous *et al*. (2014) reported 100 % mortality rate of *Macrolophus pygmaeus* nymphs predator caused by thiacloprid pesticides. Another insecticide cypermethrin has been reported to reduce the number of spiders (generalist predator) and increase the number of white-backed plant hoppers. An increase in this insect pest can be due to resurgence (Vorley, 1985; Caroline, 1996). Hassan *et al*. (1988) reported over 80 % mortality of the tested parasitoid and predators to be caused by the same synthetic pesticide.

The indirect effect of a synthetic pesticide includes weakening of the natural enemies; changing their behaviour and lengthening the development period of the immature stages which lead to reduced prey consumption and reproductive ability (Dent, 2000). Other indirect effects include reduced ability to capture prey. The doses of cypermethrin reduce predators' capability of finding and arresting the prey (Bacci *et al.,* 2007). It is further reported that parasitoids submitted to insecticides lambda-cyhalothrin and carbamates treatments reduced their capacity of guiding themselves to the host plants with aphids' attack (Shoeb, 2010). When treated with fenvalerate and methomyl, females of *Microplitis croceipes* (Braconidae) which is a parasitoid of *Heliothis* sp. (Lepidoptera: Noctuidae) reduced flying activity, 20 hours after the treatment (Cortesero *et al.,* 2000). Synthetic pesticides pose negative effect to NEs therefore alternative means of insect control is inevitable.

2.1.6 The effect of intercrops on natural enemies

Intercropping is a form of polyculture commonly used in tropical parts of the world and by indigenous peoples throughout the world (Altieri, 2000; Cai *et al.,* 2010). Elmore and Jackobs (1984), Altieri (1994), You and Xu (2000) and Blaser *et al.* (2007) described intercropping as a means of enhancing botanical diversity and abundance of natural enemies, (such as predators and parasitoids) which prey on insect pest thus increased crop yield and quality.

In view of this, many ecologists and entomologists advocate intercrops in cropping system for suppression of insect pests (Andow, 1991; Landis *et al.,* 2000). For example, it has been reported that increased botanical diversity generally enhances abundance of ground predators, such as carabids, staphylinidae and lycosid spiders (Hummel *et al.,* 2002). Andow (1991) and Altieri (1994) reported an increase of natural enemies specifically predators in cotton and maize and peanut and corn intercropping systems.

This is an important practice to be incorporated in the cropping system for pests' suppression, control of soil erosion, conservation of soil moisture, build-up of organic matter and more important the health of the growers and consumers as it is an alternative to synthetic pesticides which pose high health risk to producers and consumers. However, little information is known about intercropping some native live pesticidal plants in attracting the agents of biological control and repel pests. Thus, there is a need for further study to determine effects of intercropping the plants in bean fields.

2.1.7 The effect of intercropping pesticidal plants with other crops

Pesticidal plants (PPs), especially of weed species can be intercropped with crops for different purposes with insect pest suppression being the major one. In a study by Penagos *et al*. (2003), it was observed that, there was a decrease in insect pest and increase in natural enemies' numbers in a maize plot with weeds compared with maize plots under rigorous manual weed control. In the same study infestation of maize by fall armyworm larvae, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) was heavy in non-weedy plot compared with a weedy plot. Under the same condition, the number of aphid infestation was reported to be lower (Altieri, 1980; Penagos *et al.,* 2003).

It is possible some weedy species had volatile organic compounds which repelled insects including aphids and at the same time created diverse environment for NEs such as predator which feeds on aphids and parasitoid which parasitized *S. frugiperda*. Another study by Ngatimin *et al*. (2013) reported the effect of weed management level on the abundance of insect natural enemies in cabbage fields where the number of natural enemies in the field without herbicide application was reported to be higher compared with the field with herbicide application. The same has been reported in the study by Penagos *et al*. (2003). From those examples, it seems that weeds have something to do with insect pest suppression. Therefore, weeds with pesticidal effect can be mixed/intercropped in cropping system to attract NEs and repel some insect pests. Examples of weeds reported to have positive outcome in insect pest suppression in cabbage field are; *Nasturtium indicum* (Brassicaceae), *Galinsoga parviflora* (Asteraceae), *Ageratum conyzoides* (Asteraceae) and *Cleome rutidospema* (Capparidaceae).

It is further reported that weeds have been used to increase the vegetation diversity which in turn helps to enhance the natural enemy population (Altieri and Whitcomb, 1979). The hypothesis here would be greater diversity of habitat for NEs so provision of greater abundance and variety of prey and hosts of predators and parasitoids. With this description, weed population in a cropping system can be manipulated (e.g. intercropped, strip cropping, planting at the edge of the field) in such a way that non - crop vegetation can effectively function as a source of natural enemies but without causing adverse effects on the main crop production. For example, weeds are kept as strip plant between crop rows or allowed to grow on the boundaries of the field (Andow, 1991; Landis *et al*,. 2005; Ngatimin *et al.,* 2013).

Hyptis suaveolens is another weed with pesticidal properties which have been reported to have insecticidal properties under field conditions. In studies by Adda *et al*. (2011), maize stemborer, *Sesamia calamistis* was reported to be significantly reduced when *H. suaveolens* used as extracts and also when used as an intercrop of *H. suaveolens* and maize. The idea is that *H. suaveolens* may have driven away the adult *S. calamistis* from the maize plant by their smell or the plant probably played a disturbing role i.e. volatiles produced by *H. suaveolens* confused the pest hence failed to locate the host.

More studies have revealed the importance of PPs particularly weed species to control insect pests and attract natural enemies. Basedow *et al*. (2006) reported that intercropping of *Ocimum basilicum* L. and *Satureja hortensis* L. with *Vicia faba* L. to repel *Aphis fabae*.

The same author reported intercropping crops with plants which produce volatile oil, to have a negative effect on aphids. Reddy *et al*. (1990) and Prakash *et al*. (2008) reported the use of biologically active plant especially pesticidal ones, as an intercrop with tomato or brinjal or wheat to minimize incidences of root-knot nematode, *Meloidogyne incognita*. Also use *Ageratum conyzoides* to control aphids in common bean field has been reported (Rioba and Stevenson, 2017).

It is further reported that coccinellids predator demonstrate affinities for certain plants regardless of prey availability but, such preference has not been effectively exploited in biological control (Michaud, 2012). For example, in German, Schmid (1992) it was observed that coccinellids had consistent patterns of occurrence on particular non-crop plant species, mostly common weeds, and avoided others.

The reported affinities were independent of the presence of prey as fully as 40 % of the coccinellids were observed on plants without aphids, it seems that, non-crop plants can attract beneficial insects regardless of its prey availability.

Lixa *et al*. (2010) reported six species of coccinellidae to be attracted to aromatic species of Apiaceae (dill, coriander and sweet fennel) particularly in their blooming seasons. Silva *et al*. (2010) found the increased abundance of coccinellids and other beneficial insects in lemon orchards in response to ground cover vegetation. In Africa PPs like *Biden pilosa*, *Tagetes minuta* and *Ageratum conyzoides* have shown the same effect of attracting Coccinellids (unpublished data). However, with the described effect of live PPs on insect pests and natural enemies, information on the use of PPs as an intercrop with common bean is very limited.

This calls for diverse research of PPs especially of weed species to be intercropped with common bean to come up with findings on how they control insect pests without negatively affecting the main crop yield.

2.1.8 Conclusion

The potential of intercropping PPs with common bean needs to be pronounced as a means of enhancing botanical diversity for promotion of natural enemies and therefore the eco - friendly and low - cost strategy for pest management. Intercropping common bean with non - crop plants is a possible approach toward pest control since they are considered safe to the environment, growers, consumers and human health.

Furthermore, farmers do not need time for extract/powder preparation, they will not bother with the knowledge on dosage and application frequency which are technical recommendations. After crop harvest, PPs can also be harvested for making different extract against field and storage pest. More research has to be done on the use of live plants particularly pesticidal ones on the effect of insect pests, diversity and abundance of natural enemies also beneficial insects like pollinators and their effects on common bean production.

The hypothesis behind can be one or combination of the following; 1) the volatile organic compound produced from the plants as a response to damage by herbivore insects are used as cues by the natural enemies (NEs) to aid in the location of their prey, 2) volatiles produced by intercropped plant can confuse the pests and make it difficult for them to locate the host, 3) crop mixture provide a greater diversity of NEs through provision of of greater abundance and variety of prey and host of predators and parasitoids , 4) when two or more plants are grown concurrently, food resources are scattered compared with monoculture therefore condition will not fully favor the pests, 5) non - crop shading can affect the pests e.g aphids are highly affected by shading, 7) non - crop plant can directly mask the crop plant and therefore protect it from pest, 8) botanical diversity provide food resources and shelter for NEs (make it possible to survive even in the absence of its host) and 9) volatiles from non - main crop can directly repel the pests (Fig. 1 is a model which describe the scenerios).

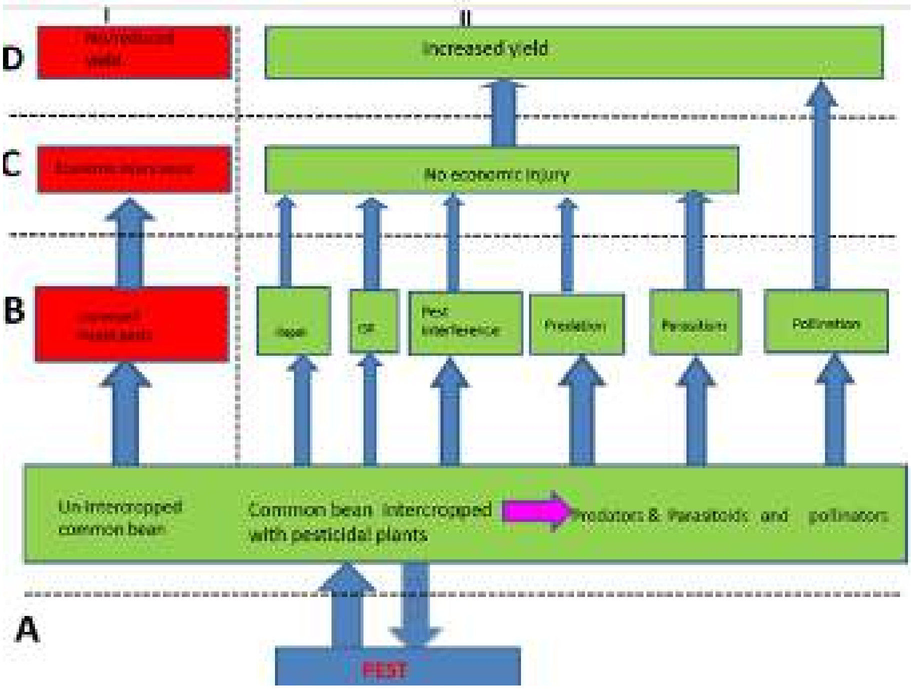

Figure 1: A modified model after Karani *et al.* (2017), describes how common bean, pesticidal plants (PPs) and natural enemies (NEs) interact with the pests in the field.

In stage A, the pest receives signals (essential oil/chemical communication) released by a host plant (common bean) and moves towards the host plant. In stage B (II), the pest reaches the surface of the host plant intercropped with PPs and there a combination or either of the following can happen, volatiles produced by PPs can repel the pest or elicit the plant to develop induced systemic resistance (ISR), the intercropped plants produce volatiles which can confuse the pest and therefore difficult for it to locate the host, when two or more plants are grown in the same field concurrently, food resources are scattered compared with monoculture therefore condition will not fully favor the pests. Furthermore, intercropped plants create vegetative diversity which is an essential condition for attracting beneficial insects i.e. NEs (predators and parasitoids) and pollinators.

NEs prey or parasitize the pests and if combination or either of these happens, the plant will not be colonized by the pest thus no economic injury (part II C) as a result bean quality and productivity will be enhanced D (II). In stage B (I), the pest will also reach the surface of un-intercropped host plant (monoculture) where population density of the pest is high (resource concentration hypothesis). If no control measure being applied here then the pests population will multiply and colonize the plant leading to reach stage C (I) and cause economic injury. As a result there will be no/low yield; Stage D-II (Karani *et al.,* 2017 with modification).

2.2 Botanical Pesticides in Management of Common Bean Pests: Importance and Possibilities for Adoption by Small-scale Farmers in Africa[2]

2.2.1 Introduction

Common bean (*Phaseolus vulgaris* L.) is the most important protein-source grain legume for direct consumption in the world (Broughton *et al.,* 2003). Worldwide production exceeds 23 million Metric tonnes (MT) of which 7 million MT are produced in Africa and Latin America. It is recognized as the second most important source of human dietary protein and the third most important source of calories and consumed by almost everyone both vegetarian and non-vegetarian in Africa. In the Eastern and Southern Africa the consumption exceeds 50 kg person^{-1} year^{-1} (Jaetzold and Schmidt, 1983; Shellie-Dessert and Bliss, 1991; Pachico, 1993; Akibode and Maredia, 2011). Despite this big consumption, common bean production in Africa is threatened by a number of constraints especially insect pests and diseases. Control of these constrains is currently considered difficult due to costs and risks on health and environment associated with synthetic pesticides in crop pest management in Africa. This review highlights an alternative option of using botanical pesticides (BPs) in managing common bean pests in Africa. BPs is naturally occurring chemical compounds extracted or derived from plants to manage field and storage crop pests (Sola *et al.,* 2014). For thousands of years, empirical knowledge of the use of BPs for pest control provided means for crop protection in different parts of the world before the development of synthetic insecticide (Rosenthal and Berenbaum, 1991; Weinzierl, 2000). Some examples of useful plant products used as source of BPs include rotenone (Kennedy, 2011), neem (Anonymous, 2006; Girish, 2008; Hedge, 1995; Singh and Raheja, 1996), sabadilla (Guzman-pantoja, 2009; Singh and Saratchandra, 2005) and pyrethrin (Parr, 1975; Weinzierl, 2000). In other areas such as Northern America and Europe, the use of BPs dates as early as 1800s (Guzman *et al.,* 2009). In these continents, the BPs were widely used to protect field crops and stored products until early 1940s to the 1950s when they were abandoned in the industrialized countries' agriculture due to development of synthetic insecticides (Grdisa and Grsic, 2013). Later on in the 1990s, use of BPs aroused due to numerous negative side effects of synthetic pesticides which were noticed, including the development of pest resistance, pesticide food contamination, environmental pollution problems, the disruption of natural balance, toxicity to non-target organisms and the most important negative impact on human health (Scott *et*

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al., 2003; Scot *et al.,* 2009; Weinzierl, 2000). These effects pushed researchers and the community to explore the BPs throughout the world. The BPs have been reported to have ability to protect field and stored commodities or to repel various pests from human habitations (Abatania *et al.*, 2012; Isman and Machial, 2006). Different studies have shown that the biological activity of botanical pesticides is significantly depending on the species of plants, plant parts used for the preparation of the extracts, the physiological state of the part used the extraction solvent and the insect species under study (Shaalan *et al.,* 2005).

The BPs can easily degrade in the environment, and they are easily available, less toxic to human and non-targeted organisms and are compatible with different human cultures (Mpumi *et al.,* 2016; Oruonye and Okrikata, 2010; Weinzierl, 2000). Studies have shown that, plants are very good source of crop protectants against pests (Isman, 2008). In countries like Benin, BPs such as pyrethrins and neem extracts are used to control cotton bollworm and in Uganda extracts from marigold (*Tagetes spp*) are used against bruchid beetles of cowpeas (Kawuki *et al.,* 2005). In other parts such as West Africa, some plant species such as bushmints (*Hyptis suaveolens*) have been used for the control of pink stalk borer (*Sesamia calamistis*) on maize. Lantana (*Lantana camara*, African nutmeg (*Monodora Myristica*) and Enu-opiri (*Euphorbia lateriflora*, Schum and Thonner) are also reported to be effective against common bean weevil and maize weevil (Ogunsina *et al.,* 2010, 2011). With these few described examples, it seems interestingly that, the BPs can be used intensively in a number of crop systems, particularly in Africa. In a study by Kamatenesi *et al*. (2008), a number of plants such as chill pepper (*Capsicum frutescens),* African marigold (*Tagetes spp,)* cultivated tobacco (*Nicotiana tabacum), Cypressus spp.,* fish bean *(Tephrosia vogelii),* neem *(Azadirachta indica),* banana (*Musa spp), Eucalyptus spp and Carica papaya* have been identified to have strong anti-insect properties and thus they are being used for pest management by the subsistence farmers in countries around Lake Victoria.

In Africa, several studies have shown that the BPs is effective in controlling field insect pest of common beans. For instance, Paul (2007) reported insecticidal properties of neem (*Azadirachta Indica L.*), worm seed (*Chenopodium ambrosioides L.*), cypress (*Cupressus lucitanica*) and marigold (*Tagetes minuta L.*) in management of important field and storage insect pest of common beans particularly, Ootheca (*Ootheca Bennigseni*) and common bean weevil (*Acanthoscilides Obtectus)*. Recent studies by Mkindi *et al*. (2015), Mwanauta *et al*. (2015) and Mpumi *et al*. (2016) reported toxicity, potentiality and effectiveness of BPs particularly *Tephrosia vogelii, Venonia amygdalina, Tithonia diversifolia* and *Lantana camara* in managing both field and storage insect pests of major economic importance i.e. Common bean stem maggot (*Ophiomyia phaseoli*), Ootheca (*Ootheca Bennigseni*) and Aphids (*Aphis fabae*) in common beans production in Tanzania. Other BPs reported to have a strong anti-insecticidal properties include *Grewia similis*, K. Schum and *Echnops hispidu*s, Fresen (Machocho, 2012). Several authors have described some BPs such as *Tagetes minuta (Mexican marigold*), *Boscia anguitifolia* (Agahini) to be effective against a number of pests of economic importance in common beans (Table 1).

Chemical composition of some BPs described in this review is as shown in Table 2. Although beneficial effects of the BPs have been reported (Mkindi *et al.,* 2015; Mwanauta *et al.,* 2015), limited information is available on the importance of BPs in the control of common bean pests in Africa. Understanding the role of this BPs will improve their application by common beans farmers and encourage more research in the areas of BPs, thus contributing positively to sustainable management of common bean pests in Africa.

Table 2: Some botanicals pesticides commonly used to control common beans pests in different countries

SN	Common bean disease/ Common bean insect pest	BPs used	Country	Reference
1	Aphids, bruchid beetle	*Targetes minuta*	Uganda	(Kawuki *et al.,* 2005)
2	Pink stalk borer	*Hyptis suaveolens, Lantana camara*	West Africa	(Ogunsina *et al.,* 2011)
3	Anthracnose, common bean leeaf spot	*Targetes minuta*	Kenya& Tanzania	(Machocho, 2012)
4	Common bean rust fungus	*Boscia angustifolia Zanthoxylum chalybeum*	Kenya	(Menge *et al.,* 2014; Fabry *et al.,* 1996)
5	Urdcommon bean Leaf Crickle Virus (ULCV)	*Mirabilis jalapa, Datura metel, Catharanthus*	India	(Ravinde, nd)
6	Common bean Common Mosaic Virus	*Nicotiana tabacum* L. *Azadirachta Indica, Allium sativum* L.	Bangladesh	(Bahar *et al.,* 2007)
7	Sclerotium root rot	*Azadirachta Indica*	Uganda	(Buruchura, 2010)
8	Cotton bollworm	Pyrethrin, *Azadirachta Indica*	Benin,India, United States	(Isman, 2006)
9	Grasshoppers, armyworms Aphids, cabbage loopers	Sabadila	South America	(Bloomquist, 1996 and 2003)
10	Potato aphids, onion thrips, corn earworm	*Ryania speciose*	India, united States	(Copping *et al.,* 2000)
11	Aphid, thrips, caterpillar	Nicotine	Mexico	(Casanova, 2002)

Table 3: Composition of selected commonly botanical pesticides in majority of African countries

SN	BPs	Chemical composition	Reference
1.	Fish bean, *Tephrosia vogelii*	complex mixture of rotenoid, sesquisterpene and lignin	(Gomez *et al.,* 1985)
		Potential compounds are rotenone, tephrosin and deguaelin	(Gaskins *et al.,* 1972)
2.	Neem, *Azadirachta indica*	Azadirachtin	(Khalil, 2013)
3.	Lantana, *Lantana camara* L	oxo-triterpenic acid e.g. Pomolic acid, lantanolic acid, lantoic acid, camarin, lantacin, camarinin, and ursolic acid	(Ntalli and Caboni, 2012; Srivastava *et al.,* 2006)
4.	Pyrethrum, *Chrysanthemum cinerariaefolium*	chrysanthemic acid and three esters of pyrethric acid	(El-Wakell, 2013; Casida and Quisda, 1995; Glyne-Jones, 2001)
5.	Mexican sunflower, *Tithonia diversifolia*	diter-penoids,flavonoids, sesquiterpene lactones	(Chagas-Paula *et al.,* 2011; Ambrosio *et al.,* 2008)
6.	Bitter leaf, *Vernonia amygdalina*	Vernodalin, Vernodalol and Epivernodalol	(Abdullahi *et al.,* 2015)
7.	Pignut, *Hyptis suaveolens*	Alkalloids, tannins, phenols, flavonoids, saponins	(Edeoga *et al.,* 2006)

2.2.2 Importance of BPs in environmental protection and biodiversity conservation in Africa

The BPs are believed to be very important for environmental and biodiversity conservation (Sola *et al.,* 2014). The active component in BPs are non-persistent with many being UV labile and others are broken down through oxidation or by micro-organisms hence presenting lower risks to human, and environments (Sola *et al.,* 2014; Delvin and Zettel; 1999). The BPs can maintain biological diversity of natural enemies, lower impact to beneficial insects such as pollinators, and this makes them alternative to synthetic pesticides in pests' control (Sola *et al.,* 2014). Contrary to the BPs, synthetic pesticides pose adverse effect of persistent organic pollutants (POPs) on the environment, human health and non-targeted microorganisms.

These POPs do not degrade easy, but remain intact in the environment for long period of time and they disperse easily across a wide geographic area, retain their toxicity and have a tendency to accumulate in the fatty tissue of different organisms comprising the biodiversity (Vapnek, 2007; Oruonye and Okrikata, 2010). Use of BPs will assist majority of common bean farmers who lack or who are unable to comply with safety information on use of the synthetic pesticides in pest control in Africa. The BPs are easily available, lower in cost compared to synthetic pesticides, accessible and can be renewed sustainably as botanicals can be grown, multiplied and easily shared within local communities.

2.2.3 Preparation and application method of BPs

Most BPs can be prepared in different forms such as powder, liquid formulation including water extract, crude oil extract, ethanol extract, aqueous extract or commercial formulation. In this section the most common methods of preparation have been discussed.

(i) Powder formulation and mode of application

To prepare powder formulation, plant materials are collected; either sun dried or oven dried and then pulverized into fine powder using pestle and mortar or electric mill. The materials are then sieved with a fine mesh (0.25 mm diameter sieve) (Asongwa *et al.,* 2010; Jackai and Oyedirani, 1991; Jackai *et al.,* 1992; Jackai *et al.,* 1993). For field application, the powder can be spread out by hand (broadcasting) over the field crops in a manner similar to fertilizer application or they can be applied at planting time along with the basal fertilizer application and work into the soil or applied around the growing plants by ring method or side banding.

One of commonly used BPs in this form is the neem leaves (Ahmed *et al.,* 1984).

The application rate of powder formulation ranges from 1-20 g kg^{-1} of the produce, but does not usually exceed 2 % of the weight of produce (Ivbijaro and Agbaje, 1986; Ogunwolu and Idowu, 1994; Yar'adua, 2007). For instance, BPs such as neem dust can be used as soil amendments at 100 - 2000 kg ha^{-1} for the management of soil borne pests (Yar'adua, 2007). For storage of product, the powder is applied directly over the produces and mixed thoroughly before storage (Asongwa *et al.,* 2010; Stoll, 1992; Yusuf *et al.,* 1998).

(ii) Oil formulation and mode of application

A crude extract of oil is extracted from seeds by pounding them lightly in a motor to obtain the kernels after removal of the outer cover (Asongwa *et al.,* 2010). The kernels are ground into a paste, transferred to a pot and briefly heated, then small amount of water is added followed by boiling (Jackai, 1993). The mixture is then allowed to cool. When the content has cooled down, the oil on top of the mixture is collected ready for application (Jackai and Oyediran, 1991).

To apply the oil for controlling insect or disease causing pathogens in the field, oil extract at 0.25 – 3 % (high volume spray) or about 3 L ha^{-1} (low volume spray) can be applied by using conventional knapsack, ULV or hand sprayers (Asongwa *et al.,* 2010; Passerini and Hill., 1993; Yaradua, 2007). Otherwise the broom sprinkling method can be used where a long broom or leaf branch is dipped into desired concentration of the extract and sprinkling it on the crops (Bottenberg and Singh, 1996). The application is usually repeated at 10 days intervals. To apply the oil extract in the storage of seeds the application rate of 2.5 – 5 ml kg^{-1} seeds is recommended (Asongwa *et al.,* 2010; Yar'adua, 2007).

(iii) Aqueous formulation and mode of application

Using neem plant materials as example, aqueous formulation can be extracted by using water as a solvent. The aqueous neem solution can be obtained by pressing out fresh juice and diluting it in water at 10 % - 50 % (v/v) concentrations or through maceration (that is immersing in water for prolonged periods). It can also be obtained by infusion (the immersion of plants in already boiled water for prolonged periods) (Jackai and Oyediran, 1991; Jackai *et al.,* 1992; Lale, 1995; Jackai, 1993). Immersion of the plant extracts in water for longer period improves the efficacy of the neem aqueous extracts (N'Guessan *et al.,* 2006). The mode of application is as described under the oil formulation and mode of application section (3.2).

(iv) Commercial formulation

Schmutterer (2002) reported that, bioactive components in plants are usually extracted in 95 % ethanol, using chromatographic techniques, which include open column chromatography, flash chromatography, thin layer or vacuum liquid chromatography on silca gel and liquid chromatography. The extraction can be done in laboratories or in a small-scale industry using standard protocols (Padi *et al.,* 2000). The mode of application of commercial formulations is based on the manufacturer's recommendations.

2.2.4 Host-BPs-Pest interaction

There seems to exist some mechanisms that aid the pest to allocate its host. An illustration showing how the BPs interacts with host and pest is shown in Fig. 2. In this interaction, the pest receives signals (essential oil/chemical communication) released by a host plant and when it reaches the plant surface, it tries to start infesting. If the BPs is applied they can kill the pest, interfere with insect physiology and development, repel it from the surface or elicit the plant to develop induced systemic resistance (ISR) (Bhuvaneshwari *et al.,* 2015). If that happens, the plant will not be injured thus no negative economic effect. In the situation where application of BPs has no action on pest, colonisation of plant by the pest can occur, leading to economical injury of the plant.

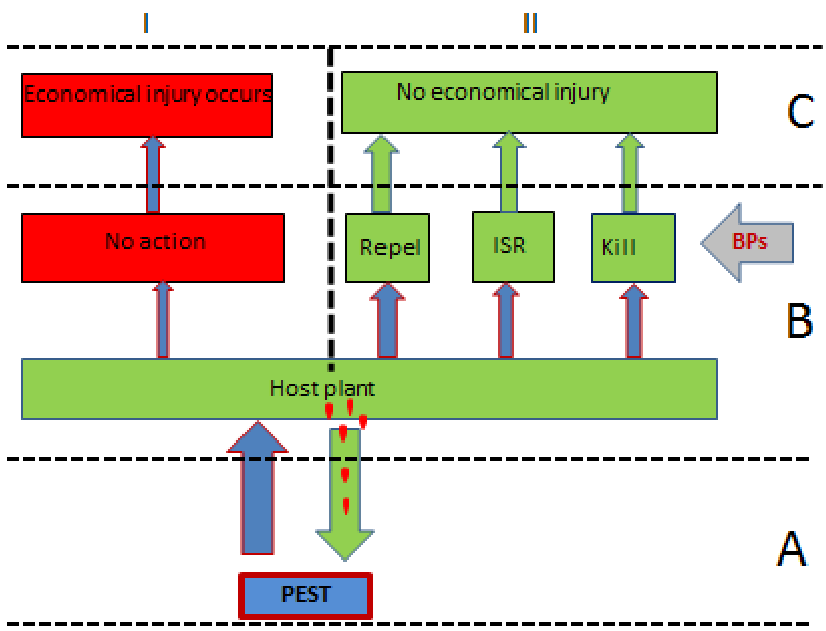

Figure 2: A model describes how botanical pesticides (BPs) interact with the host and pest.

In stage A, the pest receives signals (essential oil/chemical communication) released by a host plant and moves towards the host plant. In stage B, the pest reaches the plant surface and when BPs are applied at this stage, the BP can either kill the pest, elicit the plant to develop induced systemic resistance (ISR) or repel the pest. If that happens, the plant will not be colonised by the pest thus no economic injury (part II C). In the situation where application of BPs has no action on pest in stage B (I), the pest will colonise the plant leading to economical injury of the plant (part I C).

2.2.5 BPs Availability and adoption in Africa

BPs plants are widely distributed across many countries in Africa. Some most common PBs in Africa is as shown in Table 2. Between 1994 and 2012; about 59 plant species were reported to have pest control properties in six African countries namely Ghana, Kenya, Malawi, Tanzania, Zambia and Zimbabwe (Sola *et al.,* 2014). There exists evidence that, farmers feel that BPs is their heritage thus any technologies that can be developed from the BPs can easily be adopted. For instance, Minja *et al.* (1999) reported that over 80 % of the farmers in Malawi, Tanzania, and Uganda exclusively employ traditional methods that included BPs use in pest management.

In another study by Cobbinah *et al.* (1999) in Northern Ghana, 90 % of farmers regularly use BPs in pest control. In other countries outside Africa, report by Isman (2006), Thacker (2002) and Ware (1883) show that China, Egypt, Greece and India have been using the BPs for the past two millennia. With this evidence on use of BPs not only in Africa but also elsewhere globally, it is undoubtedly convincing that the BPs are indeed worthy for consideration, exploration and use for sustainable insect pest control in many crop systems including common bean. Thus, we hereby and doubtlessly declare the potentiality of BPs adoption by small-scale farmers in common bean pest management. In line with this recommendation, there is need to create awareness and avail BPs information so that communities, specifically common bean growers can maximize crop productivity resulting from BPs for sustainable pest control in Africa.

2.2.6 Conclusion

In this review, the potential of using the BPs for insect pest control in common bean has been described. We have shown that the BPs are a possible way forward in pest control since they are considered safe to the environment. Generally, authors have shown that majority of Africans, feel that BPs are their heritage, thus any technology derived from the BPs is likely to be highly adopted. Highlights on importance, preparation and different methods of applying the BPs have been described so that farmers and other users of this document can easily understand and use BPs as alternative to synthetic pesticides in combating common bean pests in Africa.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

This research was carried out in the experimental fields of Nelson Mandela African Institution of Science and Technology NM-AIST, Arusha, Tanzania. The site is located at Latitude -3°24'S and Longitude 36°47' East and at an altitude of 1168 m a m s l. The area has a mean rainfall of above 1000 mm year^{-1} distributed between short rains of October/November to January and long rains of February/March to May (Meru District Council, 2013).

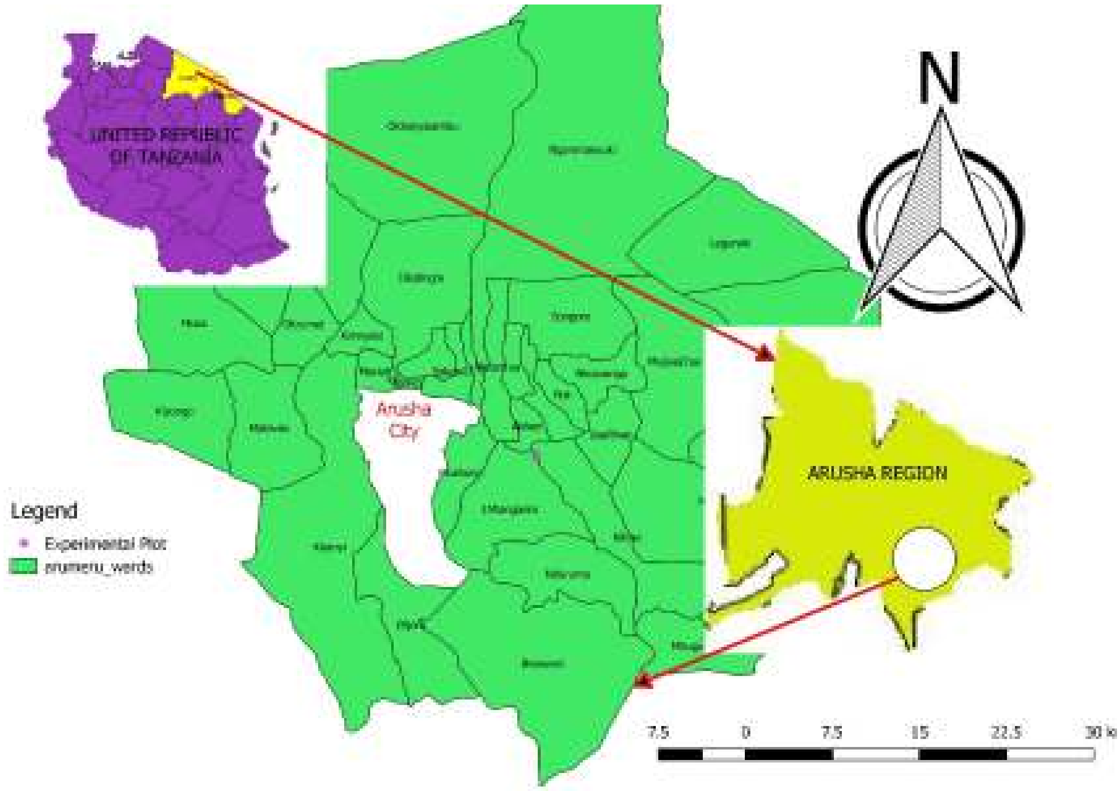

Figure 3: A map showing the study area: Source: Field survey, 2017

3.2 Land preparation and planting

The study was conducted between April and August growing season. Generally, the site had a soil classified as phaeozem (Raeymaekers and Stevens, 2015). The land was cleaned, stumps removed and ploughed. Raking activities were carried out on the ploughed land followed by the setting of the experiment.

The experiment consisted of five pesticidal plants (PPs) species namely *Tagetes minuta, Bidens pilosa, Ageratum conyzoides, Ocimum suave* and *Hyptis suaveolens* intercropped with common bean (Lyamungo 90) and the control (un-intercropped common bean) at a spacing of 100 cm between bean rows and 20 cm between plants. PPs were planted in between bean rows. Also two plots planted with only common bean (one infested with aphid and one un-infested) were covered with screen house net aimed at comparing the yield between the two plots to come up with the magnitude of the yield loss caused by aphids *per se*. All treatments were replicated four times with each treatment being separated by 1 m bare ground and each replication separated by 2 m border of bare ground. PPs seedlings of about 5 cm height were planted one week before planting of the common bean (21st April and 28th April, for PPs and common bean respectively.

The field plots measured 3 m x 3 m and the design of experiment used was a Randomized Complete Block Design (RCBD). Table 4 shows the source and type of material used while Table 5 shows experiment set up and arrangement of the treatment in the field.

Table 4: Materials and its source

Materials	Source
Common bean –Lyamungo 90	SARI Arusha, Tanzania
Screen house net	A - Z Arusha, Tanzania
Pesticidal plant seedlings (*Bidens pilosa, Tagetes minuta, Ageratum conyzoides Ocimum suave* and *Hyptis suaveolens*)	Farms around Nambala village
	Kibosho and Marangu respectively, Moshi Tanzania
Aphids	Infected common beans around Nambala and TPRI farms Arusha, Tanzania

Table 5: Experimental layout

R1	R2	R3	R4
HS	BP	TM	AC
Ctr	HS	SH	BP
AC	Ctr	AC	SH
TM	TM	Ctr	Ctr
ASH	ASH	ASH	OS
SH	OS	OS	ASH
OS	SH	HS	HS
BP	AC	BP	TM

R1 = Replication 1; R2 = Replication 2; R3 = Replication 3; R4 = Replication 4

HS= *Hyptis suaveolens* intercropped with common bean

Ctr = Control (Common bean only)

AC = *Ageratum conyzoides* intercropped with common bean

TM = *Targetes Minuta* intercropped with common bean

ASH = Common bean infested with black bean aphids (*Aphis fabae)* under screen house condition

SH = Common bean not infested with aphids under screen house condition

OS = *Ocimum suave* intercropped with common bean

BP = *Biden pilosa* intercropped with common bean

3.3 Data recording

Data collection started three weeks after planting the common bean and were recorded weekly until crop maturity which was about 10 weeks.

3.3.1 To assess the effect of intercropping common bean and annual pesticidal plants on abundance of natural enemies and pollinators (beneficial insects)

Assessment on diversity and abundance of beneficial insects was done based on the method described by (Ogenga-Latigo *et al.,* 1993 with minor modification).

Beneficial insects were visually observed and their number(s) were recorded on weekly basis. Counts were taken between 1100 – 1500 hr by counting insects visiting the plants in 10 minutes under each treatment.

3.3.2 To evaluate the effect of intercropping common bean and annual pesticidal plants on aphids abundance and infestation

In each plot, aphids were visually observed for incidence and severity. Incidence level was expressed as percentage (number of infested plants divided by total number of plants in a plot x 100 %). Severity scoring was done on the scale 0 - 5 as described by Ogenga-Latigo *et al*. (1993), Mkenda *et al*. (2015) and Wosula (2016) with minor modification.

Table 6: Abundance and severity scoring scale

Abundance (Numbers)	Severity of damage
1 = 1 - 150	1 = 0 %
2 = 151 - 300	2 = 1 – 25 %
3 = 301 - 450	3 = 26 – 50 %
4 = 451 - 600	4 = 51 – 75 %
5 = over 601	5 = 76 – 100 %

The lowest values were used to denote the low level of severity, whereas the high values denoted the high level of severity.

3.3.3 To assess the effect of intercropping common bean and annual pesticidal plants on yield and yield components of common bean

Common bean from the two middle rows in each plot were uprooted and counted. The number of pods in each plant was determined and the average number of pods per plant were calculated and recorded. Similarly, the average number of seeds per pod was determined where ten plants were randomly selected from the uprooted plants, pods counted thereafter threshed and all seeds were counted. The average number of seeds per pod was calculated and recorded. Then the weight of a hundred (100) seeds (g) was determined followed by estimation of grain yield in kg ha^{-1} based on plant population in a 3 m x 3 m plot.

3.3.4 To assess the magnitude of the yield loss caused by aphids

In this experiments bean plots were covered by agro nets (A - Z Company). Common bean from two middle rows in a covered plots (covered and infested with aphids plots vs covered and un - infested plots) were uprooted, manually threshed, winnowed and measured by using weighing scale and its weight in gram was recorded. Aphids' infestation was done according to Olorunju *et al*. (1991).

3.3.5 To evaluate repellency effects of pesticidal plants up on aphids

This experiment was done after harvesting intercropped bean but on the same PPs. 600 beans were planted in pots (2 beans per pot and then thinned to 1 plant per pot). Sixteen potted bean plants, infested with 60 - 80 aphids were placed in between pesticidal plant rows of each plot (termed as infested bean - IB). Also sixteen un - infested potted bean plants were placed around each plot (termed as trap bean – TB) for comparison. Weekly assessment was done for five weeks based on aphid scoring scale as described in Table 4.

3.4 Data analysis

The data obtained were subjected to STATISTICA (data analysis software system version 8.0.) to test for treatment effects over the study period. A one-way ANOVA was used to analyze the collected data. Fisher's Least Significant Difference (LSD) was used to compare treatment means at 5 % level of probability ($P = 0.05$).

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Results

4.1.1 The effect of intercropping common bean and annual pesticidal plants on abundance of natural enemies and pollinators (beneficial insects)

Generally, pesticidal plants attracted different beneficial insects at different levels throughout the study period. The main recorded beneficial insects were hoverflies, ladybirds, wasps, spiders, honey bee, stingless bee and butterflies. The less abundant species which were not included in the analysis were rove beetle, dragon fly, long ledged fly, tachinid and carpenter bee. Mean abundance of each beneficial insect over ten weeks is described below:

(i) Mean abundance of hoverfly over ten weeks on intercropped common bean

A significant difference ($P \leq 0.001$) on mean abundance of hoverfly was observed between different treatments over ten weeks (Appendix 1). The highest mean abundance was observed in the fourth week in plots intercropped with *B. Pilosa*. In the fourth and seventh week, the mean abundance for hoverfly was relatively higher in the plot intercropped with *B. Pilosa* and *T. minuta.* Other PPs attracted hoverflies almost at the same rate. The lowest level of hoverflies was observed in the control plots (Fig. 4).

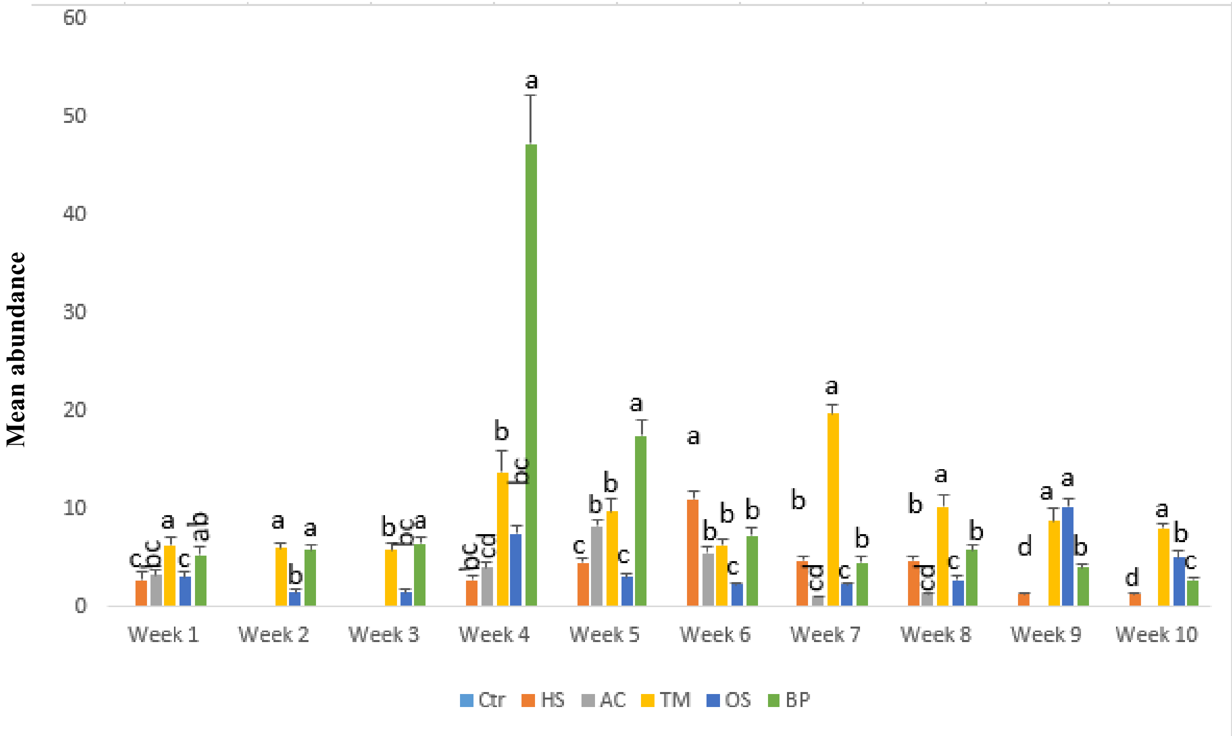

Figure 4: Mean abundance of hoverfly over ten weeks

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa*

(ii) Mean abundance of ladybird beetle over ten weeks on intercropped common bean

There was significant difference ($P \leq 0.001$) in mean abundance of ladybird beetles between different treatments (Appendix 2). *B. Pilosa* attracted higher number of ladybird beetles in comparison with other treatments and the highest mean abundance was experienced from the first to fourth week. The mean abundance started to increase from the ninth week in the plots intercropped with *T. minuta*. Generally, all treatments attracted the ladybird beetles but *H. suaveolens* supported minimum level of ladybirds only in the 6th and 7th week as compared with other treatments. The lowest number of ladybird beetles was evaluated in the control (un-intercropped common bean) during the entire period of the experiment (Fig. 5).

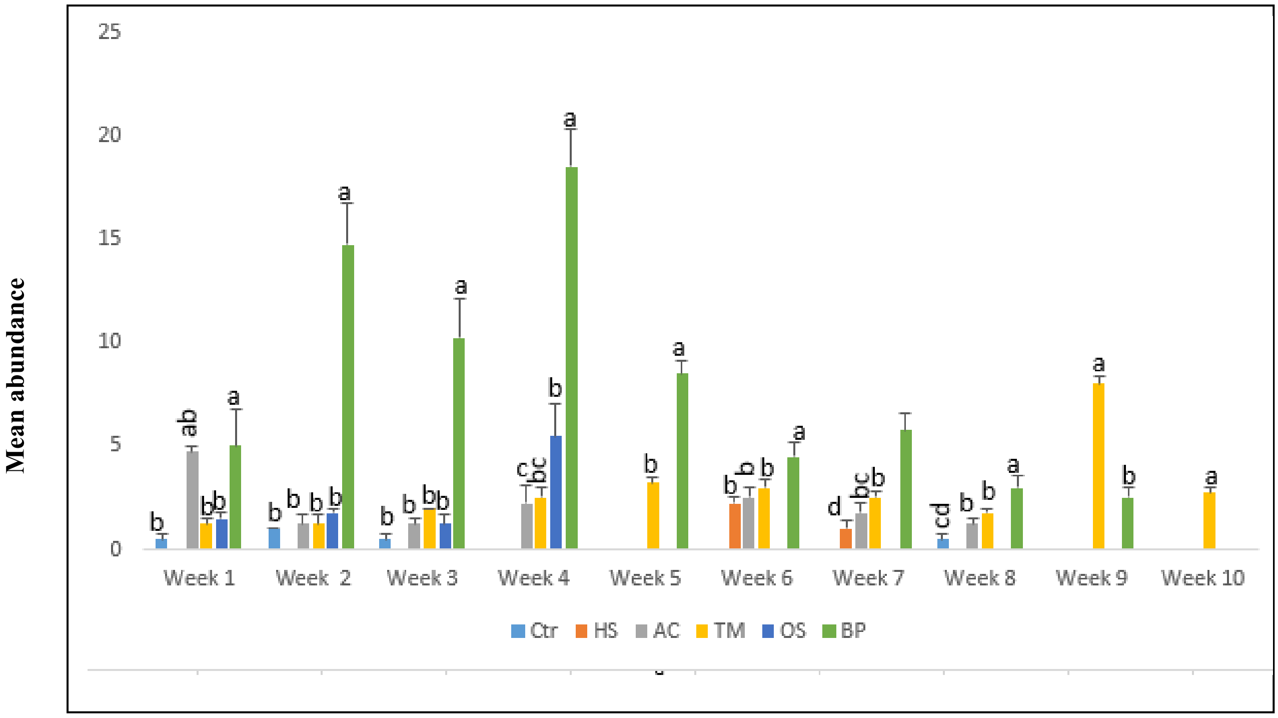

Figure 5: Mean abundance of ladybird beetle over ten weeks.

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa.*

(iii) Mean abundance of wasp over ten weeks on intercropped common bean

There was significant difference ($P < 0.05$) in mean abundance of wasp between different treatment during the study period (Appendix 3). The highest mean abundance of wasp was observed in the plots intercropped with *T. minuta*. Other treatments attracted wasps nearly at the same level. The lowest number of wasp was observed in the control (un-intercropped common bean) during the entire period of the experiment (Fig. 6).

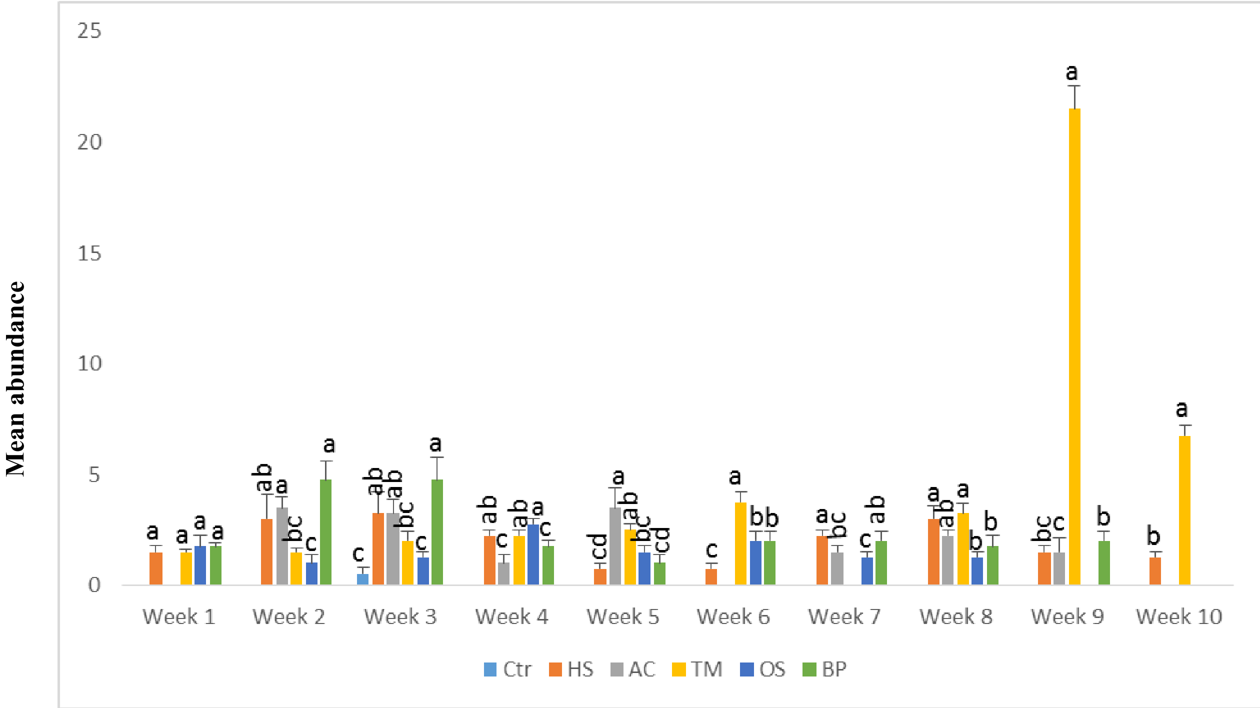

Figure 6: Mean abundance of wasp over ten weeks

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa*

(iv) Mean abundance for spider over ten weeks on intercropped common bean

There was significant difference ($P < 0.05$) in the spider mean abundance among different treatments (Appendix 4). *H. suaveolens* and *A. conyzoides* attracted spider throughout the entire period of the experiment while the rest of the treatments attracted spider only in the first two weeks (Fig. 7).

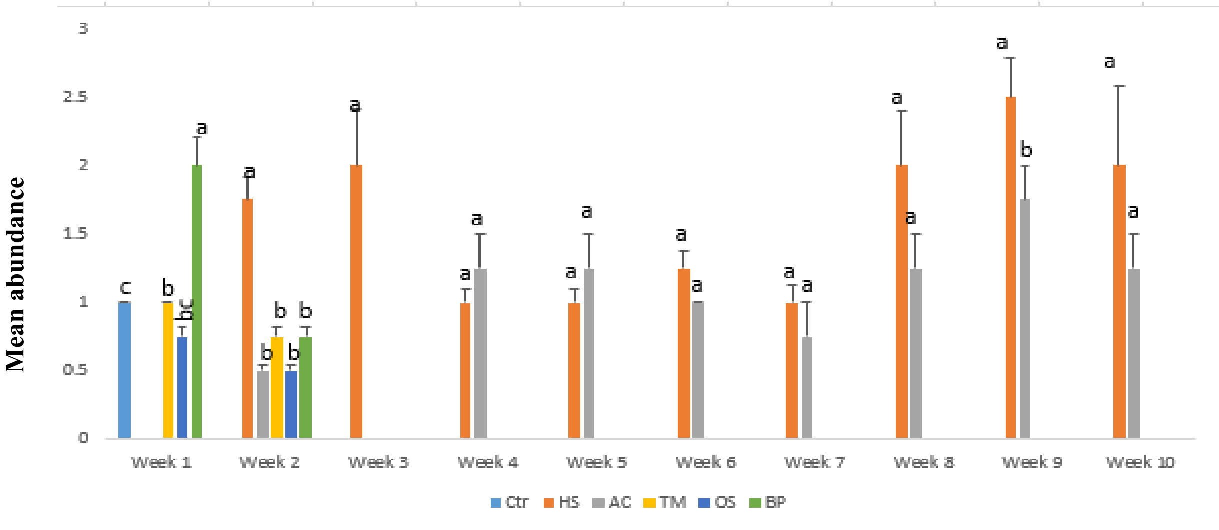

Figure 7: Mean abundance of spider over ten weeks.

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa*

(v) Mean abundance of honey bee over ten weeks on intercropped common bean

A significant difference ($P < 0.001$) was observed in the mean abundance of honey bees at different treatment (Appendix 5). The higher mean abundance of honey bees were observed in *O. suave* and *H. suaveolens* and the highest peak was attained in the sixth week for *Ocimum* and eighth week for *Hyptis* (Fig. 8).

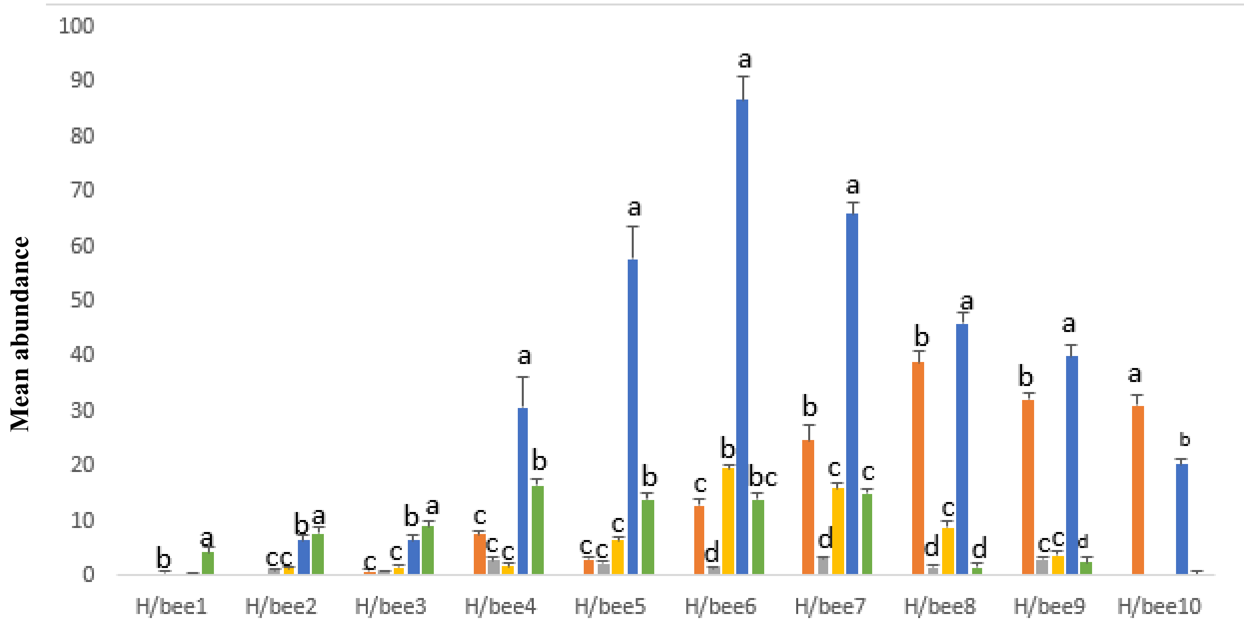

Figure 8: Mean abundance of honey bee over ten weeks

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa*

(vi) Mean abundance of stingless bee over ten weeks on intercropped common bean

There was significant difference ($P \leq 0.01$) in the stingless bee mean abundance among the different treatments (Appendix 6). The higher mean abundance of stingless bee was noticed in plots intercropped with *O. suave* and *H. suaveolens* and the highest peak was attained in the seventh week (Fig. 9).

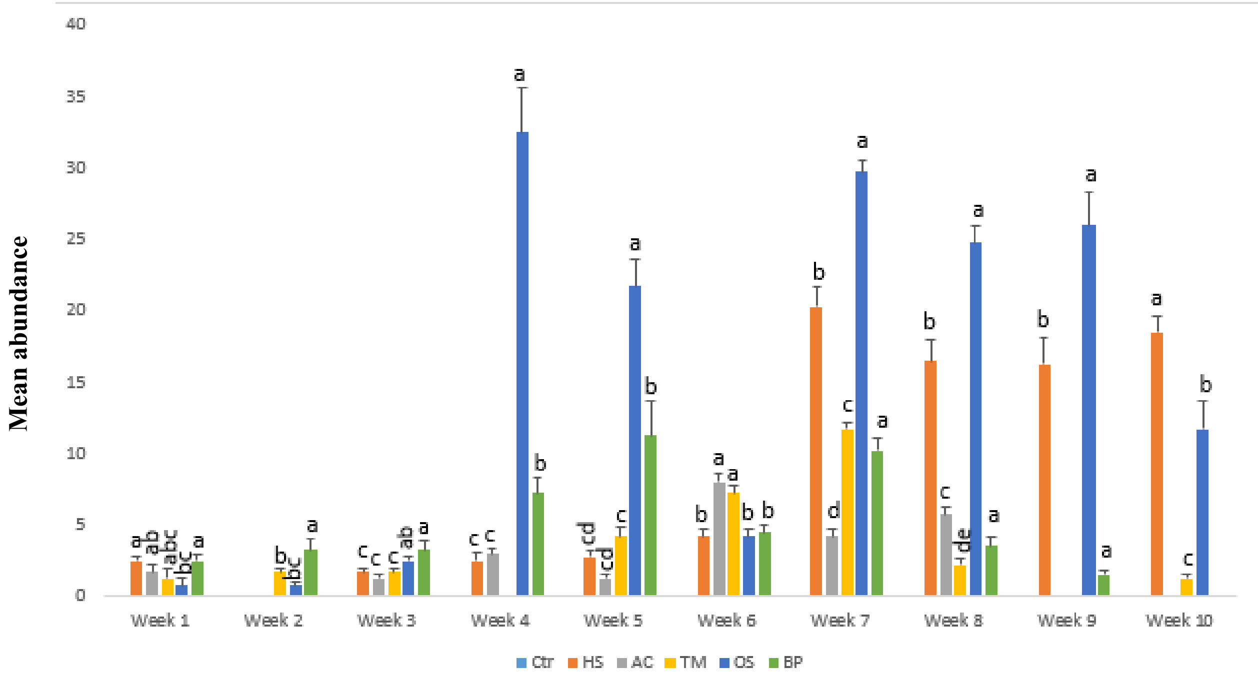

Figure 9: Mean abundance of stingless bee over ten weeks

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa*

(vii) Mean abundance of butter flies over ten weeks on intercropped common bean

There was significant difference ($P < 0.01$) in the butter flies mean abundance among different treatment (Appendix 7). The highest mean abundance of butter flies was observed in the plots intercropped with *B. pilosa* and *H. suaveolens* and the highest peak was attained in the seventh week. *A. conyzoides, T. minuta* and *O. suave* also attracted a good number of butter flies (Fig. 10).

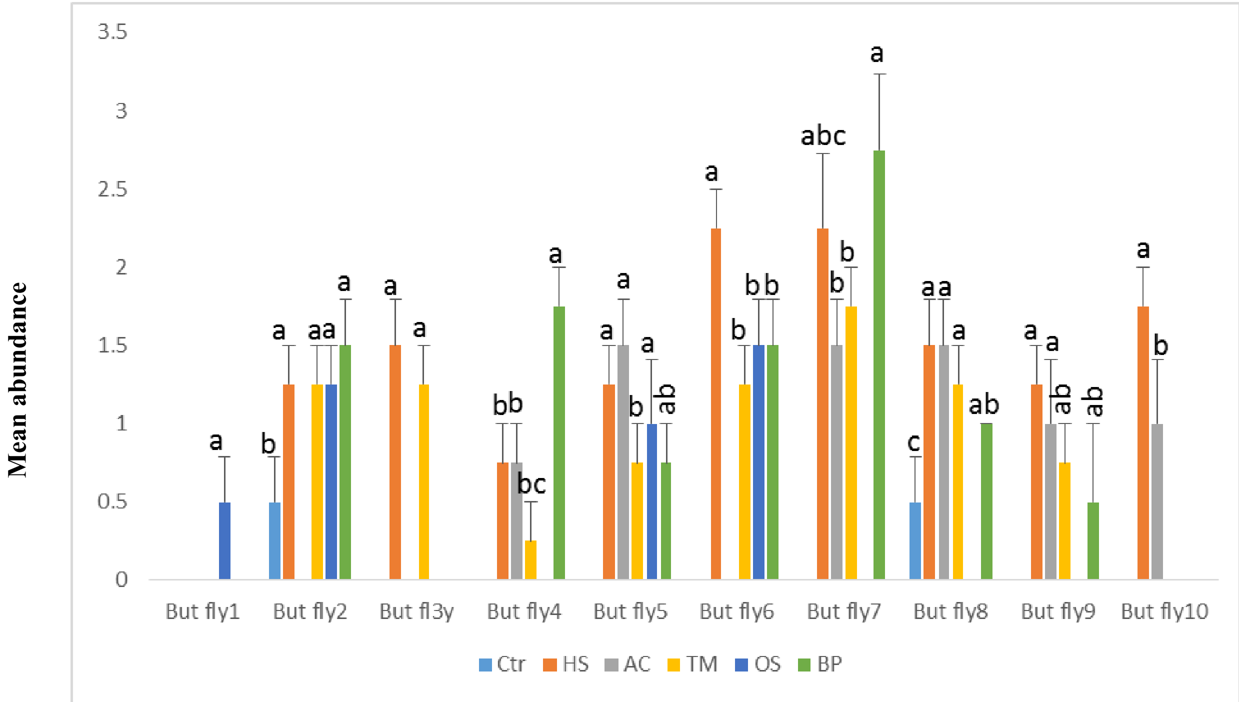

Figure 10: Mean abundance of butter fly over ten weeks.

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa*; But fly = butter fly

4.1.2 Effects of intercropping common bean and annual pesticidal plants on aphids' abundance and infestation.

There was a significant difference ($P < 0.05$) on mean damage caused by aphids from 5th - 8th week (Appendix 8). The mean damage for 4th and 9th week was not significant and there were no aphids from the 1st - 3rd week and from the 9th week to harvest period. However, the mean incidence for the same was not significant (Appendix 8). The lower aphid' damage was observed in the plots intercropped with *T. minuta* and highest was observed in un-intercropped plots (control plots) Fig. 11.

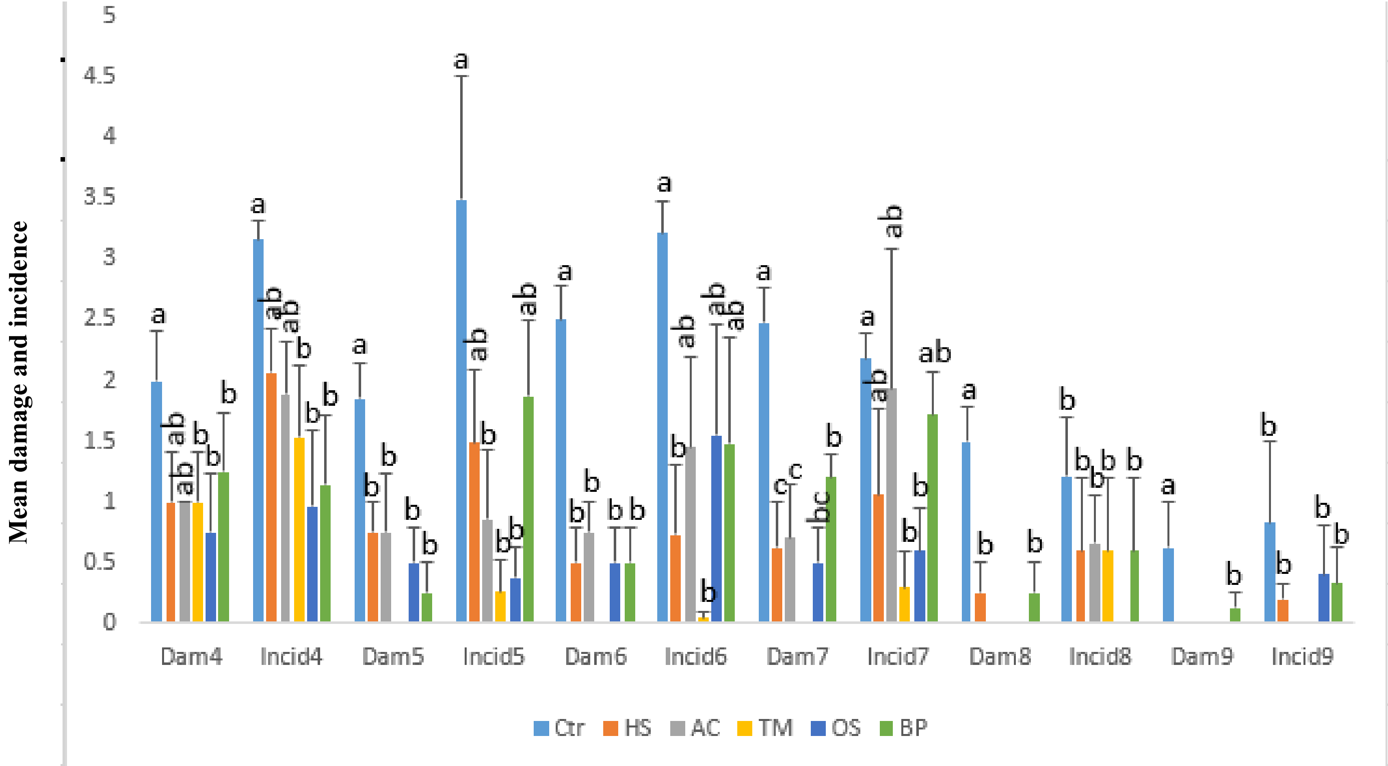

Figure 11: Mean for aphids' damage and incidence from 4th to 9th week

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa*
Dam = damage week and Incid = incidence week

4.1.3 Effect of intercropping common bean and annual pesticidal plants on yield and yield components of common bean

There were no significant difference in yields per hectare (kg), pods per plant and weight of hundred seeds in all treatment (Appendix 9). Significant difference was observed in number of seeds per pod at $P \leq 0.001$ (Fig.12).

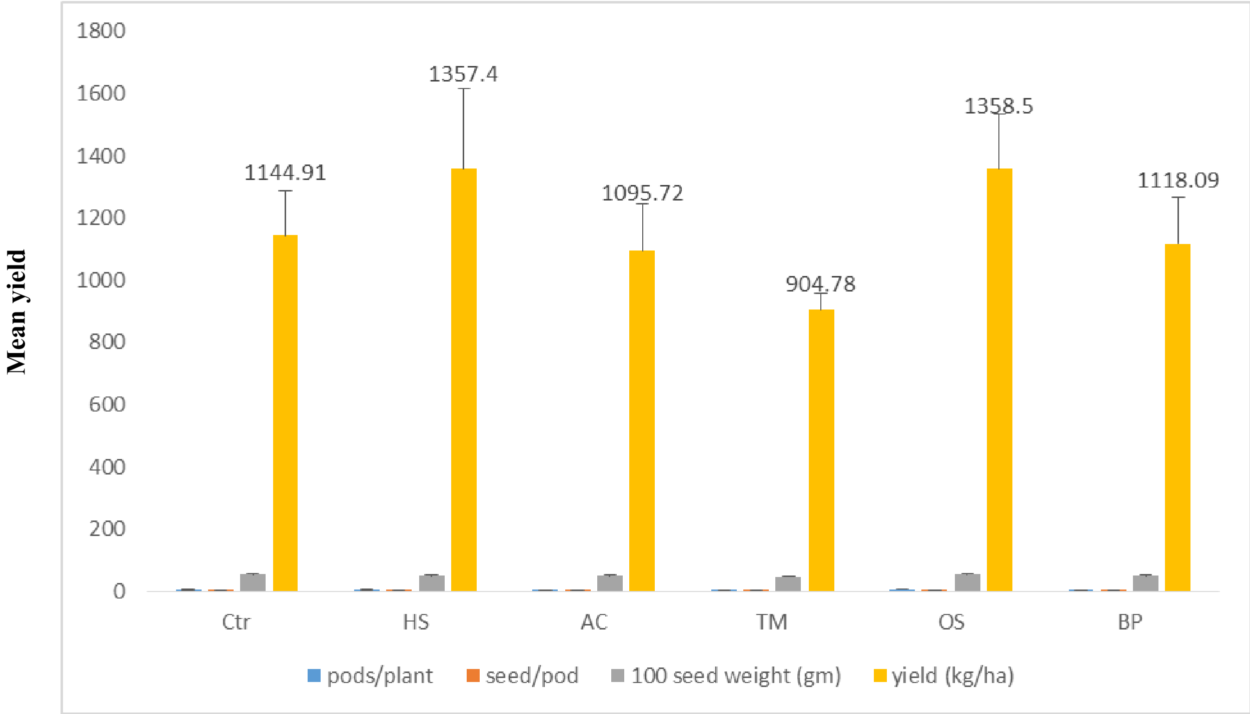

Figure 12: Means for yields and yield components

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta*, OS = *Ocimum suave* and BP = *Bidens pilosa*

4.1.4 Evaluating the magnitude of the grain yield loss caused by aphids

There were no significant grain yield loss caused by aphids when the yield of un-infested common bean covered with screen house net were compared with the yield of infested common bean covered with screen house net (Appendix 10). It was further observed that weight of 100 seed, number of pods per plant and number of seeds per pod was not significantly different when they were compared in both infested and un-infested plots (Fig. 13).

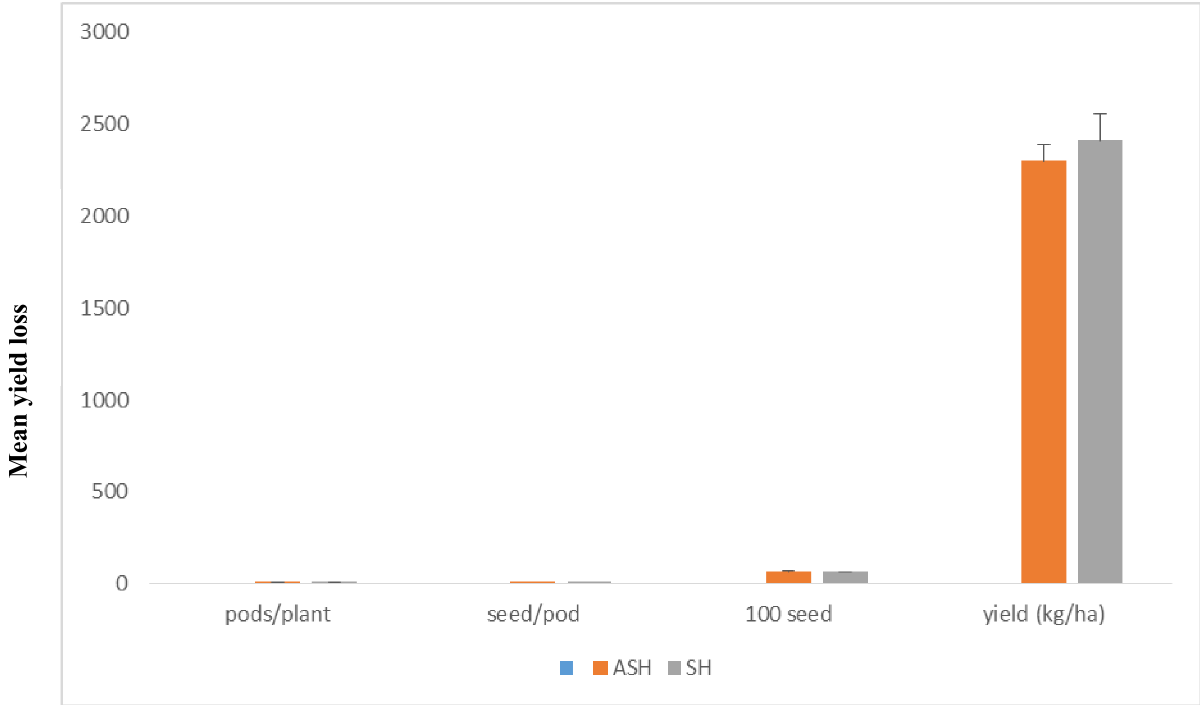

Figure 13: Means for the magnitude of the yield loss caused by aphids in common beans

ASH = un-intercropped common bean infested with aphids and covered with screen house net

SH = un-intercropped, un-infested common bean but covered with screen house net

kg = kilogram, gm = gram, ha = hectare

4.1.5 Repellency effect of pesticidal plants (PPs) against aphids

There was significant ($P < 0.05$) difference in effect of pesticidal plants on repelling aphids (Appendix 11). Control (plots with no pesticidal plants) had higher mean aphid number compared with potted common bean mixed with pesticidal plants for the whole five weeks of evaluation (Fig. 14).

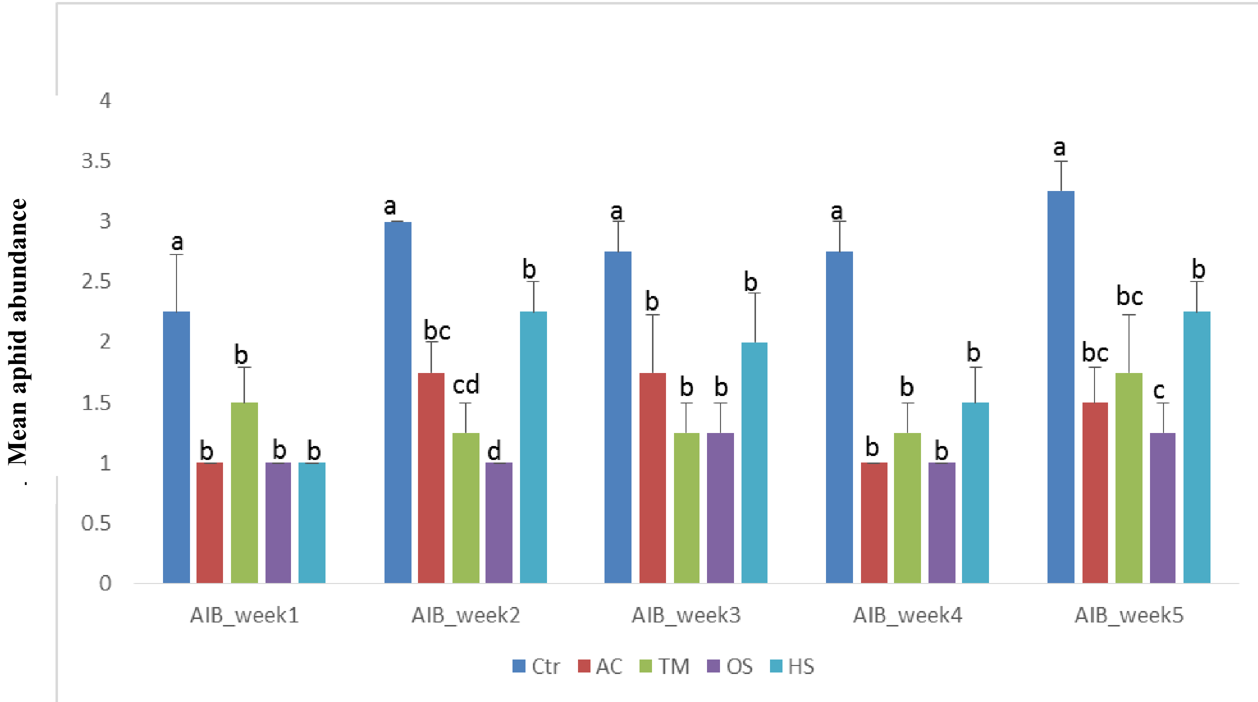

Figure 14: Repellency effect of pesticidal plant on aphids

Ctr = control, HS = *Hyptis suaveolens*, AC = *Ageratum conyzoides*, TM = *Tagetes minuta* and OS = *Ocimum suave*

4.2 Discussion

This study on intercropping annual pesticidal plants (PPs) with common bean on abundance, diversity of natural enemies (NEs) and insect pests infestation particularly aphids (*Aphis fabae*) generally indicated that, PPs attracted NEs and pollinators and reduced aphids infestation. This occurred with no or little negative effect in actual yield of the focal crop. Increased NEs and pollinators is probably attributed to plant diversity created by intercropping system, which provide a greater number of opportunities for NEs, i.e. parasitoids and pollinators to survive in agricultural system. This is similar with the research work by Cai *et al*. (2010), Beizhou *et al.* (2011) and Rodriguez-Saona (2012) which describe increased diversity and species abundance of beneficial insects in intercropping system than in mono - crop system. Further results by Hummel *et al*. (2002) revealed botanical diversity as a means of enhancing NEs. In that study abundance of ground predators such as carabids, staphylinidae and lycosid spiders increased. The same result has been revealed by Ngatimi *et al*. (2013) where the abundance of insect natural enemies in cabbage fields without herbicide application was observed to be higher compared with the field with herbicide application.

This implies that different weed species when planted with crops, they create diverse environment thus favorable condition for attraction and multiplication of beneficial insects. The study also concurs with the result by Penagos *et al*. (2003) where the number of natural enemies increased in a maize plot with weeds compared with maize plots under rigorous manual weed control. It is also in line with the study by Buruchara *et al*. (2010) which revealed increased predators and parasitoids as a result of microclimate modification through intercropping system.

Further in this study, intercropping PPs with common bean attracted high number of ladybird beetles, a potential predator of aphids often termed as aphids eating machine. This is in consistent with the study by Schmid (1992), Lixa *et al*. (2010), Silva *et al*. (2010) and Michaud (2012) which revealed that the coccinellids have a consistent pattern of occurrence on non-crop plants and they were attracted by aromatic species particularly Apiaceae family, and they were also increased in lemon orchard with ground cover vegetation and they develop affinities to some plants regardless of prey availability respectively.

4.2.1 Intercropping common bean and PPs on aphids abundance and infestation

The low aphids' abundance thus lower damage/severity in the intercropped bean compared with pure stand (control) would be attributed to many factors and among them could be: Pesticidal plants have altered the microclimate and therefore favored the multiplication of natural enemies which preyed on aphids. This in line with the study by Risch (1979), Gianoli *et al*. (2006) and Buruchara *et al*. (2010) that intercropping creates favorable condition for NEs of common bean pests to multiply due to environmental diversity. Therefore, increased NEs density probably explains the lower incidence of aphids.

The low aphid incidence and severity in this study also in line with the study Sinthanantham *et al*. (1990), that showed low insect pest in the intercropped common bean vs pure stand; also in consistent with the study by Penagos *et al.* (2003) which revealed reduced larvae of fall armyworm larvae, *Spodoptera frugipenda* when maize was intermingled with weeds compared with weed free plots. Plant diversity enhances the abundance of NES through provision of alternative prey and other food sources such as pollen and nectar for protein and energy respectively (Altieri, 1980). This could explain the reason for low incidence and damage of aphids in the study that NEs preyed on aphids and/or parasitized them.

The low incidence and damage by aphids in this study could also be attributed to volatile organic compounds (VOC) possessed by PPs. This VOC probably repelled some aphids away from the intercropped plots. This result is in consistent with the study by Adda *et al*. (2011) that, maize stem borer, *Sesamia calamistis* were significantly reduced in the maize field intercropped with live *Hyptis suaveolens.* Furthermore study by Basedow *et al*. (2006) revealed repellency of aphids (*Aphis fabae*) when *Ocimum basilicum* L. and *Satureja hortensis* L. intercropped with faba bean (*Vicia faba* L.). Altieri and Whitcom (1979), Altieri and Letourneau (1982), Nentwig *et al*. (1998) and Gianoli *et al*. (2006) also revealed weed species as repellant of insect pests when intercropped/mixed with crop(s).

A low incidence and severity could also be due to one or combination of the following hypothesis; "The resource concentration hypothesis" and "The disruptive-crop hypothesis"

"The resource concentration hypothesis of intercropping and pest management states that it is easier for an herbivore to become abundant when the resources it needs to live and reproduce are concentrated in a monoculture than when these resources are diluted with non-host plants" (Smith and Liburd, 2012).

The disruptive - crop hypothesis, in which a second non - host plant species disrupts the ability of the pest to find its proper host plant species (Risch, 1981; Vandermeer, 1989). Volatiles produced by bean plants as a response to damage by insect pests are used as a cue by NEs to determine its host therefore reduced insect pest abundance and infestation (Kessler and Baldwin, 2001; Basedow *et al.,* 2006; Dicke and Baldwin, 2010; Hare, 2011). This is some sort of interaction between PPs, NES, bean plants and insect pests.

4.2.2 Magnitude of the grain yield loss caused by aphids

There were no significant yield losses caused by aphids when the yields of un-infested plots were compared with the yield of infested plots. This is due to unfavorable meteorological conditions (during the study period) in which the development and multiplication of aphids were not favored enough to justify the yields loss by aphids.

4.2.3 Effects of pesticidal plants on yield of common bean

In this study, PPs did not negatively affect the yield of common bean neither showed significant different. However there was numerical increase in yield when *H. suaveolens and O. suave* intercropped with common bean. This could be attributed to long flowering period of these two plant species which probably attracted more pollinators for long term and therefore combat pollen deficit in common bean through probing or stimulating good pollen coverage of the stigma. This concurs with the study by Aizen *et al*. (2009) which revealed that insect pollinators act as pollen vector between flowers and this raises total crop production to 3 – 8 %. In another study by Chen (2009) it was revealed that proportion of yield in faba bean is by self-pollination while remain part is by insect visitation. Approximately 25 % of faba bean yield is further reported to depend on insect pollinators (Al-Ghamdi *et al.,* 2003; Somerville, 1999). In the study by Drayner (1959) revealed un-abled to self - pollinate flower due to heat stress were recovered by out - crossing pollination (therefore become more dependent upon the transfer of fertile pollen by insect pollinators).

On the other side, the yield of plots intercropped with *T. minuta* was numerically lower compared with control and other treatments. This can be due to allelopathic effect of the plant that may have delayed germination and reduced growth of the crop (Meissner *et al.,* 1987). However, the plant is still used as an intercrop with different crop like maize, brinjal and tomato among others (Prakash *et al.,* 2008; Hook *et al.,* 2010). The plant is preferred by farmers due to the benefits plant offers to the cropping system, e.g. protection against plant-parasitic nematodes through provision of compounds such as α-terthienyl that are allelopathic to many species of plant-parasitic nematodes (Hooks *et al.,* 2010). Apart from nematicidal effect of *Tagetes*, the plant has also been reported to have insecticidal, antiviral and cytotoxic activity (Arnason *et al.,* 1989; Marles *et al.,* 1992). Also the plant has been reported to have repellency effect against some insect pest e.g. aphids and white flies among others (Anjarwalla *et al.,* 2016). Weed species is further described by Altieri and Whitcom (1979), Altieri and Letourneau (1982), Nentwig *et al*. (1998) and Gianoli *et al*. (2006) as repellant of insect pests when intercropped/mixed with crop(s). These could be some of the reasons as to why people are still using *T. minuta* in cropping system.

4.2.4 Repellency effects of pesticidal plants against aphids

The result of this study also showed that intercropping PPs with common bean repelled aphids from bean field. The idea is that blend of volatile organic compounds could have driven the aphids away. This is in line with the study by Basedow *et al. (*2006) and Adda *et al.* (2011) which revealed repellency of insect pests particularly aphids when pesticidal plants intercropped with crops like faba beans (*Vicia faba*).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Pesticidal plants (PPs) attracted significant number of beneficial insects in intercropped common bean. However, the degree of abundance differed with treatments. *Hyptis suaveolens* and *Ocimum suave* attracted quite a big number of pollinators compared with other treatments. On the other hand, *Bidens pilosa*, *Tagetes minuta* and *Ageratum conyzoides* attracted larger number of natural enemies (NE) compared with *Hyptis* and *Ocimum*. Likewise, abundance of aphids and hence incidence and severity was lower in the manipulated plot. This means that the manipulation reduced number of aphids. On repelling effects, all PPs repelled aphids in comparison with the control (un-intercropped common bean). Generally, intercropping common bean with selected PPs attracted beneficial insects, reduced insect pests infestation particularly aphids and repelled aphids as well.

5.2 Recommendation

Manipulation of live pesticidal plants (PPs) in bean farming system is a key achievement of insect pests' suppression and therefore important in realizing potential yields in common bean production. It is an alternative to synthetic chemical pesticides which is a major hindrance to small scale farmers' production, non - deleterious organisms, environment and health of the consumer therefore the strategy should be promoted to control aphids and other insect pest of common bean which affect negatively its grain yield in Tanzania and other African countries.

Further work is required to determine the exact cause of the yield variability in common bean intercropped with *H. suaveolens* and *O. suave* compared with the yield of the same common bean when intercropped with other treatments in the same study. Also further studies can be carried out to ascertain the cause of low yield when *T. minuta* was used as an intercrop. Blooming period of the PPs with that of the focal crop should be taken into consideration in the production system for the best results.

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LIST OF APPENDICES

Appendix 1: Mean abundance of hoverflies over 10 weeks on intercropped common bean

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
HS	2.75±0.85c	0.00±0.00c	0.00±0.00c	2.75±0.48bc	4.50±0.50c	11.00±0.82a	4.75±0.48b	4.75±0.48b	1.25±0.25c	1.25±0.25d
Ctr	0.00±0.00d	0.00±0.00c	0.00±0.00c	0.00±0.00d	0.00±0.00d	0.00±0.00d	0.00±0.00d	0.00±0.00d	0.00±0.00c	0.00±0.00e
AC	3.25±0.48bc	0.00±0.00c	0.00±0.00c	4.00±0.58cd	8.25±0.63b	5.50±0.65b	1.00±0.00cd	1.25±0.25cd	0.00±0.00c	0.00±0.00e
TM	6.25±0.85a	6.00±0.58a	5.75±0.75a	13.75±2.17b	9.75±1.38b	6.25±0.75b	19.75±0.85a	10.25±1.25a	8.75±1.25a	8.00±0.41a
OS	3.00±0.58c	1.50±0.29b	1.50±0.29b	7.50±0.87bc	3.00±0.41c	2.25±0.25c	2.25±0.25c	2.75±0.48c	10.25±0.85a	5.00±0.71b
BP	5.25±0.95ab	5.75±0.63a	6.50±0.65a	47.25±5.02a	17.50±1.50a	7.25±0.85b	4.50±0.65b	5.75±0.48b	4.00±0.41b	2.75±0.25c
One way ANOVA										
F-Statistic	9.7543***	62.1077***	52.0118***	59.7750***	46.0941***	36.7231***	221.7130***	35.1405***	48.1636***	75.7263***
P value	0.000122	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; *** significant at $P \leq 0.001$, SE = standard error. Means with different letters in the same column are significantly different at $P = 5\%$ according to Fischer Least Significance Difference (LSD).

Appendix 2: Mean abundance of ladybird beetles over ten weeks on intercropped common bean

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Ctr	0.50±0.29b	1.00±0.00b	0.50±0.29b	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00d	0.50±0.29cd	0.00±0.00c	0.00±0.00b
HS	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00c	0.00±0.00c	2.25±0.25b	1.00±0.41cd	0.00±0.00d	0.00±0.00c	0.00±0.00b
AC	4.75±0.25ab	1.25±0.48b	1.25±0.25b	2.25±0.85c	0.00±0.00c	2.50±0.50b	1.75±0.48bc	1.25±0.25bc	0.00±0.00c	0.00±0.00b
TM	1.25±0.25b	1.25±0.48b	2.00±0.00b	2.50±0.50bc	3.25±0.25b	3.00±0.41b	2.50±0.29b	1.75±0.25b	8.00±0.41a	2.75±0.25a
OS	1.50±0.29b	1.75±0.25b	1.25±0.48bb	5.50±1.55b	0.00±0.00c	0.00±0.00c	0.00±0.00d	0.00±0.00d	0.00±0.00c	0.00±0.00b
BP	5.00±1.78a	14.75±1.97a	10.25±1.93a	18.50±1.85a	8.50±0.65a	4.50±0.65a	5.75±0.85a	3.00±0.58a	2.50±0.50b	0.00±0.00b
One way ANOVA										
F-Statistic	8.1397***	42.9509***	21.5421***	43.341***	149.7652***	20.8326***	23.0483***	15.1384***	149.4000***	121.000***
P value	0.000365	0.000000	0.000001	0.000000	0.000000	0.000001	0.000000	0.000007	0.000000	0.000000

Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; ***: significant at $P \leq 0.001$, SE = standard error. Means with different letters in the same column are significantly different at $P = 5$ % according to Fischer Least Significance Difference (LSD).

Appendix 3: Mean abundance of wasps over ten weeks on intercropped common bean

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Ctr	0.00±0.00b	0.00±0.00c	0.50±0.29c	0.00±0.00d	0.00±0.00d	0.00±0.00c	0.00±0.00d	0.00±0.00c	0.00±0.00c	0.00±0.00c
HS	1.50±0.29a	3.00±1.08ab	3.25±0.95ab	2.25±0.25ab	0.75±0.25cd	0.75±0.25c	2.25±0.25a	3.00±0.58a	1.50±0.29bc	1.25±0.25b
AC	0.00±0.00b	3.50±0.50a	3.25±0.63ab	1.00±0.41c	3.50±0.87a	0.00±0.00c	1.50±0.29bc	2.25±0.25ab	1.50±0.65bc	0.00±0.00c
TM	1.50±0.29a	1.50±0.50bc	2.00±0.41bc	2.25±0.25ab	2.50±0.29ab	3.75±0.48a	0.00±0.00d	3.25±0.48a	21.50±1.04a	6.75±0.48a
OS	1.75±0.48a	1.00±0.41c	1.25±0.25c	2.75±0.25a	1.50±0.29bc	2.00±0.41b	1.25±0.25c	1.25±0.25b	0.00±0.00c	0.00±0.00c
BP	1.75±1.03a	4.75±0.85a	4.75±1.03a	1.75±0.25bc	1.00±0.41	2.00±0.41b	2.00±0.41ab	1.75±0.48b	2.00±0.41b	0.00±0.00c
One way ANOVA										
F-Statistic	2.9485*	7.2829***	5.40000**	14.640***	8.4327***	20.320***	15.066***	9.4364***	242.5429***	150.000***
P value	0.040767	0.000689	0.003315	0.000008	0.000296	0.000001	0.000007	0.000150	0.000000	0.000000

Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; *,**, ***: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ respectively, SE = standard error. Means with different letters in the same column are significantly different at $P = 5$ % according to Fischer Least Significance Difference (LSD).

Appendix 4: Mean abundance of spider over ten weeks on intercropped common bean

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Ctr	1.00±0.00c	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00c	0.00±0.00b
HS	0.00±0.00b	1.75±0.25a	2.00±0.41a	1.00±0.41a	1.00±0.41a	1.25±0.25a	1.00±0.41a	2.00±0.58a	2.50±0.29a	2.00±0.58a
AC	0.00±0.00c	0.50±0.29b	0.00±0.00b	1.25±0.25a	1.25±0.25a	1.00±0.00a	0.75±0.25a	1.25±0.25a	1.75±0.25b	1.25±0.25a
TM	1.00±0.00b	0.75±0.25b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00c	0.00±0.00b
OS	0.75±0.48bc	0.50±0.29b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00c	0.00±0.00b
BP	2.00±0.41a	0.75±0.48b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.00±0.00c	0.00±0.00b
One way ANOVA										
F-Statistic	8.49474***	3.86400*	24.00000***	9.00000***	9.00000***	33.00000***	5.50909**	11.52632***	51.8571***	11.52632***
P value	0.000284	0.014866	0.000000	0.000200	0.000200	0.000000	0.003004	0.000042	0.000000	0.000042

Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; *, **, ***: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, SE = standard error. Means with different letters in the same column are significantly different at $P = 5$ % according to Fischer Least Significance Difference (LSD).

Appendix 5: Mean abundance of honey bee over ten weeks on intercropped common bean

Treatments	H/bee1	H/bee2	H/bee3	H/bee4	H/bee5	H/bee6	H/bee7	H/bee8	H/bee9	H/bee10
Ctr	0.00±0.00b	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00c	0.00±0.00d	0.00±0.00d	0.00±0.00d	0.00±0.00d	0.00±0.00c
HS	0.00±0.00b	0.00±0.00c	0.75±0.48c	7.50±0.65bc	3.00±0.41c	12.75±1.38c	24.75±2.81b	39.00±1.96b	32.25±1.11b	31.00±1.96a
AC	0.50±0.29b	1.00±0.41c	0.75±0.25c	2.75±0.63c	2.25±0.63c	1.25±0.25d	3.25±0.25d	1.50±0.50d	3.00±0.41c	0.00±0.00c
TM	0.00±0.00b	1.25±0.48c	1.50±0.29c	1.75±0.48c	6.50±0.65bc	19.50±0.65b	16.00±1.08c	8.75±1.11c	3.75±0.85c	0.00±0.00c
OS	0.25±0.25b	6.50±0.96b	6.50±0.96b	30.75±5.69a	57.75±6.05a	86.75±4.33a	66.00±2.12a	46.00±1.83a	40.00±1.96a	20.25±1.11b
BP	4.25±0.48a	7.75±1.55a	9.00±1.08a	16.50±4.99b	14.00±1.29b	14.00±1.87bc	15.00±0.91c	1.50±0.50	2.50±0.29cd	0.00±0.00c
One way ANOVA										
F-Statistic	45.4667***	19.254***	33.966***	14.3865***	74.2291***	256.644***	237.0363***	291.098***	310.312***	221.227***
P value	0.000000	0.000001	0.000000	0.000009	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; ***: significant at $P \leq 0.001$, SE = standard error. Means with different letters in the same column are significantly different at $P = 5\%$ according to Fischer Least Significance Difference (LSD).

Appendix 6: Mean abundance of stingless bee over ten weeks on intercropped common bean

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Ctr	0.00±0.00c	0.00±0.00c	0.00±0.00d	0.00±0.00c	0.00±0.00d	0.00±0.00c	0.00±0.00e	0.00±0.00e	0.00±0.00c	0.00±0.00c
HS	2.50±0.29a	0.00±0.00c	1.75±0.25bc	2.50±0.65c	2.75±0.48cd	4.25±0.48b	20.25±1.49b	16.50±1.44b	16.25±1.80b	18.50±1.19a
AC	1.75±0.48ab	0.00±0.00c	1.25±0.25c	3.00±0.41c	1.25±0.25cd	8.00±0.58a	4.25±0.48d	5.75±0.48c	0.00±0.00c	0.00±0.00c
TM	1.25±0.75abc	1.75±0.25b	1.75±0.25bc	0.00±0.00c	4.25±0.63c	7.25±0.48a	11.75±0.48c	2.25±0.48de	0.00±0.00c	1.25±0.25c
OS	0.75±0.48bc	0.75±0.25bc	2.50±0.29ab	32.50±3.18a	21.75±1.93a	4.25±0.48b	29.75±0.75a	24.75±1.25a	26.00±2.38a	11.75±1.89b
BP	2.50±0.50a	3.25±0.85a	3.25±0.63a	7.25±1.03b	11.25±2.39b	4.50±0.50b	10.25±0.85c	3.50±0.65cd	1.50±0.29c	0.00±0.00c
One way ANOVA										
F-Statistic	4.3662**	12.1902***	11.0250***	80.0877***	40.5943***	37.7016***	177.113***	125.1346***	83.2998***	75.3322***
P value	0.008877	0.000029	0.000056	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; **, ***: significant at $P \leq 0.01$ and $P \leq 0.001$ respectively, SE = standard error. Means with different letters in the same column are significantly different at P = 5 % according to Fischer Least Significance Difference (LSD).

Appendix 7: Mean abundance of butter flies over ten weeks on intercropped common bean

Treatments	But fly1	But fly2	But fl3y	But fly4	But fly5	But fly6	But fly7	But fly8	But fly9	But fly10
Ctr	0.00±0.00b	0.50±0.29b	0.00±0.00b	0.00±0.00c	0.00±0.00b	0.00±0.00c	0.00±0.00	0.50±0.29bc	0.00±0.00b	0.00±0.00c
HS	0.00±0.00b	1.25±0.25a	1.50±0.29a	0.75±0.25b	1.25±0.25a	2.25±0.25a	2.25±0.48abc	1.50±0.29a	1.25±0.25a	1.75±0.25a
AC	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.75±0.25b	1.50±0.29a	0.00±0.00c	1.50±0.29b	1.50±0.29a	1.00±0.41a	1.00±0.41b
TM	0.00±0.00b	1.25±0.25a	1.25±0.25a	0.25±0.25bc	0.75±0.25b	1.25±0.25b	1.75±0.25b	1.25±0.25a	0.75±0.25ab	0.00±0.00c
OS	0.50±0.29a	1.25±0.25a	0.00±0.00b	0.00±0.00c	1.00±0.41a	1.50±0.29b	0.00±0.00c	0.00±0.00c	0.00±0.00ab	0.00±0.00c
BP	0.00±0.00b	1.50±0.29a	0.00±0.00b	1.75±0.25a	0.75±0.25ab	1.50±0.29b	2.75±0.48a	1.00±0.00ab	0.50±0.50ab	0.00±0.00c
One way ANOVA										
F-Statistic	3.000000*	5.68235**	21.00000***	10.60000***	3.68571*	16.8000***	13.0966***	6.9200***	2.95385*	14.67273***
P value	0.038427	0.002575	0.000001	0.000072	0.017965	0.000003	0.000018	0.000915	0.040520	0.000008

Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; *,**, ***: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, SE = standard error. Means with different letters in the same column are significantly different at $P = 5$ % according to Fischer Least Significance Difference (LSD).

Appendix 8: Means for aphids' damage and incidence over six weeks (from 4th - 9th week)

Treatment	Dam4	Incid4	Dam5	Incid5	Dam6	Incid6	Dam7	Incid7	Dam8	Incid8	Dam9	Incid9
Ctr	2.00±0.41a	3.16±0.15a	1.85±0.30a	3.49±1.02a	2.50±0.29a	3.22±0.26a	2.48±0.28a	2.18±0.22a	1.50±0.29a	1.21±0.48b	0.63±0.38a	0.83±0.67b
HS	1.00±0.41ab	2.07±0.35ab	0.75±0.25b	1.49±0.60ab	0.50±0.29b	0.73±0.57b	0.63±0.38bc	1.06±0.71ab	0.25±0.25b	0.60±0.60b	0.00±0.00b	0.20±0.13b
AC	1.00±0.00ab	1.89±0.43ab	0.75±0.48b	0.86±0.57b	0.75±0.25b	1.45±0.74ab	0.71±0.44bc	1.93±1.15ab	0.00±0.00b	0.66±0.39b	0.00±0.00b	0.00±0.00b
TM	1.00±0.41b	1.53±0.59b	0.00±0.00b	0.26±0.26b	0.00±0.00b	0.05±0.05b	0.00±0.00c	0.30±0.30b	0.00±0.00b	0.60±0.60b	0.00±0.00b	0.00±0.00b
OS	0.75±0.48b	0.96±0.63b	0.50±0.29b	0.38±0.25b	0.50±0.29b	1.55±0.91ab	0.50±0.29bc	0.60±0.35ab	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.40±0.40b
BP	1.25±0.48b	1.14±0.58b	0.25±0.25b	1.87±0.63ab	0.50±0.29b	1.48±0.88ab	1.20±0.20b	1.72±0.36ab	0.25±0.25b	0.60±0.60b	0.13±0.13b	0.33±0.33b
One way ANOVA												
F-Statistic	1.2ns	2.6676ns	4.6949	3.8682	11.52632	2.65674ns	8.24573	1.55768ns	9.84	0.602343ns	2.4ns	0.7856ns
P value	0.3485	0.0566	0.0064	0.0148	0.0000	0.0573	0.0003	0.2222	0.0001	0.6989	0.078	0.5734

ns = non-significant, Dam = damage, Inci = incidence; Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; *, **, ***: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, SE = standard error. Means with different letters in the same column are significantly different at $P = 5$ % according to Fischer Least Significance Difference (LSD).

Appendix 9: The effect of intercropping PPs with common bean on yield and yield components

Treatments	pods/plant	seed/pod	100 seed weight (gm)	yield (kg/ha)
HS	5.39±0.67	3.03±0.08a	49.75±2.14	1357.40±260.99
Ctr	5.20±0.29	2.61±0.04c	53.50±3.48	1144.91±142.49
AC	4.67±0.52	2.54±0.04bc	49.75±1.80	1095.72±151.38
TM	3.98±0.09	2.34±0.09b	48.00±1.78	904.78±54.82
OS	5.54±0.49	2.62±0.09c	53.75±3.01	1358.50±173.68
BP	4.49±0.33	2.57±0.14bc	49.00±2.35	1118.09±150.63
One way ANOVA				
F-Statistic	1.8631ns	6.785	0.928ns	1.073ns
P value	0.151201	0.001019	0.485632	0.407583

ns = non-significant, gm = gram, kg = kilogram and ha = hectare; Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; **: significant at $P \leq 0.01$, SE= standard error. Means with different letters in the same column are significantly different at $P = 5$ % according to Fischer Least Significance Difference (LSD).

Appendix 10: The magnitude of the yield loss caused by aphids

Treatments	pods/plant	seed/pod	100 seed weight (gm)	yield (kg/ha)
ASH	6.46±0.40	2.69±0.12	65.50±1.50	2301.89±84.61
SH	6.81±0.27	2.87±0.05	64.75±1.11	2411.24±148.02
One way ANOVA				
F-Statistic	0.5234ns	1.928ns	0.162ns	0.4114ns
P value	0.496615	0.214355	0.701550	0.544978

ASH = common bean infested with aphids and covered with a screen house net
SH = un-infested common bean covered with a screen house net.
ns = non-significant, gm = gram, kg = kilogram and ha = hectare; Values presented are means ± SE where SE = standard error

Appendix 11: Repellency effect of pesticidal plant on aphids

Treatments	AIB_week1	AIB_week2	AIB_week3	AIB_week4	AIB_week5
Ctr	2.25±0.48a	3.00±0.00a	2.75±0.25a	2.75±0.25a	3.25±0.25a
AC	1.00±0.00b	1.75±0.25bc	1.75±0.48b	1.00±0.00b	1.50±0.29bc
TM	1.50±0.29b	1.25±0.25cd	1.25±0.25b	1.25±0.25b	1.75±0.48bc
OS	1.00±0.00b	1.00±0.00d	1.25±0.25b	1.00±0.00b	1.25±0.25c
HS	1.00±0.00b	2.25±0.25b	2.00±0.41ab	1.50±0.29b	2.25±0.25b
One way ANOVA					
F-Statistic	5.00**	20.333***	2.92*	9.6462***	6.3333**
P value	0.004797	0.000001	0.041891	0.000131	0.001473

AIB = common bean infested with aphids 60 - 80 aphids

Ctr = Control; HS = *Hyptis suaveolens*; AC = *Ageratum conyzoides*; TM = *Tagetes minuta*; OS = *Ocimum suave*; BP = *Biden pilosa*. Values presented are means ± SE; *, **, ***: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, SE = standard error.

Mean aphids with different letter(s) within the same column are significantly different at $P = 5$ % according to Fischer Least Significance Difference (LSD).

RESEARCH OUTPUTS

A paper entitled 'Botanical pesticides in management of common bean pests : Importance and possibilities for adoption by small-scale farmers in Africa' published in *Journal of Applied Life Sciences International*. http://www.sciencedomain.org/issue/2552

A paper entitled '**Potential of intercropping pesticidal plants with common bean in promoting natural enemies for pest management in agroecosystems'** published in *Journal of Biodiversity and Environmental Sciences (JBES).* **https://goo.gl/JNWLdX**