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The potential of field margin pesticidal plants on bean production and ecosystem services in Arusha, Tanzania

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NM-AIST

THE POTENTIAL OF FIELD MARGIN PESTICIDAL PLANTS ON BEAN PRODUCTION AND ECOSYSTEM SERVICES IN ARUSHA, TANZANIA

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ABSTRACT

An experiment was undertaken in NM-AIST farms in Arusha Tanzania from January to July 2017 to assess the potential of pesticidal plants on supporting the beneficial insects, controlling pests' and influencing bean growth and yield. Six treatments were evaluated. This included: bean plots imposed close to the following field margin pesticidal plants: 1) *Tephrosia vogelii,* 2) *Lantana camara,* 3) *Tithonia diversifolia* and 4) *Lantana trifolia* 5) positive control treatments sprayed with synthetic pesticide, Lambda-Cyhalothrin, and 6) negative control, in which nothing was added. Pan traps were used to assess the abundance of both beneficial and pest insects. Growth and yield parameters were measured. The results showed a significant ($P \leq 0.05$) effect of pesticidal plants on pest control and attraction of beneficial insects. The effect on growth parameters showed a numerical difference but statistically, it was not significant. The grain yield increased with increased distance of bean row from pesticidal plants. The yield from bean rows at the distance of 50 cm from pesticidal plants were relatively less compared with the grain yields from bean rows planted at 100 cm and 150 cm respectively. Hence, proper management of pesticidal plants in bean field has a great potential of increasing crop yield with the possibly minimum inputs, thus calling for further research on possible plants that can provide significant impacts in crop production systems.

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DECLARATION

I, **SILVANUS EVARIST MRINGI** 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.

.. **...**

Silvanus Evarist Mringi **Date**

Name and signature of candidate

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CERTIFICATION

This is to certify that the accompanying dissertation by **SILVANUS EVARIST MRINGI** has been accepted in partial fulfilment of the requirements for the Degree of Environmental science and Engineering of the Nelson Mandela African Institution of Science and Technology Arusha, Tanzania.

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DEDICATION

This dissertation is dedicated to the Provincial administration on behalf of all my confreres in the Spiritan family, my beloved parents Evarist Macha and Mary Evarist as well as my brothers and sisters for their tender love and enormous moral and psychological support. May the Almighty God bless them all.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of variance
HSD	Honest Significant Difference
IPM	Integrated Pest Management
LSD	Least Significance Difference
masl	Meters above sea level
NS	Not significant
OM	Organic matter
SARI	Seliani Agricultural Research Institute
SE	Standard error of the mean
SSA	Sub-Saharan Africa
TFA	Tanzania Farmers Association

CHAPTER ONE

INTRODUCTION

1.1 Background

An ecosystem is a natural unit of living things interacting with themselves and with their physical environment (Fish, 2011). Ecosystem services refer to the conditions and processes through which natural ecosystems and the species that make them up (flora and fauna), sustain and fulfill human life and production of ecosystem goods such as seafood, forage, timber, biomass fuel, natural fiber, and pharmaceuticals (Postel *et al.,* 2012). There are also derived ecosystem services including maintenance of biodiversity, purification of water and air, pollination of crops and natural vegetation, control of majority of agricultural pests, generation and renewal of soil and soil fertility, partial stabilization of climate, mitigation of floods and drought detoxification, decomposition of wastes and non-material benefits such as recreational and spiritual benefits in natural areas.

These ecosystem services are obtained from some specific plant species. For example, *Tithonia diversifolia* extracts are reported to be effective against insect pests (De Toledo *et al.,* 2014); while *Lantana camara* is known to repel golden flea beetles due to its good repellant effect (Igogo *et al.,* 2011; Mkindi *et al.,* 2015). Furthermore, extracts from *Lantana camara* leaves are known to have a biofumigant effect and are effective against insects (Rajashekar *et al.,* 2014). Also, *Tephrosia vogelii* is reported to have higher efficacy against insect pests but with less damage to beneficial insects (Mkenda *et al.,* 2014; Mkindi *et al.,* 2015) and *Vernonia amygdalina* have been used to control bruchid and fungal disease in cowpea and vegetable pests (Akunne *et al.,* 2013). Most of these ecosystem services from plants are employed in agricultural fields to control insect pests among other benefits and hence reducing the use of synthetic pesticides which are not friendly to the environment.

Common bean (*Phaseolus vulgaris* L.) is one of the famous agricultural crops in SSA whose quality and grain yield is hindered by several factors including destructive insect pests (Mkenda *et al.,* 2014). These insect pests include bean stem maggot, ootheca and aphids (Ochilo and Nyamasyo, 2011) which may cause the yield loss of about 37 % to 100 %, 18 % - 31 % and 37 % respectively (Munyasa, 2013). In conventional agriculture, synthetic pesticides have been deployed to control such insect pest (Kapeya *et al.,* 2005) however, research evidence has demonstrated that they are costly, scarcely available to poor farmers, detrimental to environment, to human health and to the ecosystem (Prakash *et al.,* 2008). In view of the above, there is a need for best alternative ways to control insect pest such as good agronomic practices, biological and botanical control (Mwanauta *et al.*, 2015) which are eco-friendly, cheap and safe to the environment, human health and to the ecosystem.

Although considered safe to non-target natural enemies of crop pests, plant products might have the active ingredients similar to synthetic pesticides and thus cause the negative impacts to non-target natural enemies and pollinators (Sharma *et al.*, 2012).The study by Zekeya *et al.* (2014) reported *Bersama abyssinica* extracts as effective insecticidal agents against *Callosobruchus maculatus* (cowpea beetle). Mkenda *et al.* (2014) expounded that the extract from *Tephrosia vogelii* was found to be the most efficient compared to other botanicals in terms of toxicity to adults, reduction of oviposition and inhibition of adult emergence of insect pest. The above-outlined studies made use of the extract from plants. Furthermore, study by Ndakidemi *et al.* (2016) revealed different factors which affect the distribution and abundance of beneficial insects including temperature, diversity of margin plant, and rain.

This study aims at assessing a sustainable insect pest management strategy in bean fields through the use of selected field margin pesticidal plants with insecticidal properties. The field margin pesticidal plants may act by repelling the insect pest from the bean plants or may possess ant-feeding mechanisms against bean insect pests. Furthermore, they may support harborage of beneficial insects such as pollinators, predators, and parasitoids which facilitate pollination and control of insect pest and hence improving the crop yields.

The use of botanical pesticides is reported to be friendly to the environment, human health and to the ecosystem (Mkenda *et al*., 2015; Ndakidemi *et al*., 2016). Some botanical pesticides have been reported used as field margin plants especially in the smallholder sub-Saharan farming systems (Grzywacz *et al*., 2014). Some of the known botanical pesticide field margin plants include *Tephrosia vogelii*, *Lantana trifolia*, *Tithonia diversifolia*, and *Lantana camara* which are said to be good at protecting the environment, controlling insect pests and improving the biodiversity of fauna (parasitoids, predators, and pollinators). These pesticidal plants have repellent and feeding deterrents chemicals which discourage the insects from feeding the crop and most active ingredients of botanical pesticides have short life span in the environment (Mpumi *et al*., 2016); however, their potential has not been sufficiently explored. The current study aims at assessing the effect of selected pesticidal plants, *Lantana camara*, *Tithonia diversifolia*, *Lantana trifolia* and *Tephrosia vogelii* on bean productivity, growth, pest control, support of beneficial insects (natural enemies and pollinators) and ecosystem services they provide such as forage, harbourage, and nectar.

1.2 Problem statement and justification

Bean production in northern Tanzania suffers from the attack of various insect pests such as bean stem maggot, Ootheca and aphids in the field (Mkenda *et al.,* 2015; Mwanauta *et al.,* 2015) which ultimately affects bean production and productivity. The use of synthetic pesticides in controlling these pests is known to have negative side-effects to human and the environment. Therefore, there is a need for alternative methods such as those involving the use of natural products in controlling and/or reducing the population of insect pests in bean fields and finally increasing its productivity.

In northern Tanzania, little is known on the importance of field margin pesticidal plants in controlling insect pest infestation in bean fields, consequently improving crop yields and maintaining the diversity of pollinators. The findings of this study will significantly provide insight into the maintenance of selected field margin pesticidal plants for insect pest management and pollination services. The study will similarly contribute knowledge and skills to the smallholder farmers hence improve production and their economic well-being.

1.3 Overall objective

Assessment of the potential of selected field margin pesticidal plants on bean production and ecosystem services.

1.3.1 Specific objectives

i) To examine the potential of selected field margin pesticidal plants on bean pests infestation, growth, and yield.

ii) To assess the effects of selected field margin pesticidal plants on beneficial insects abundance and control of insect pest.

1.3.2 Hypothesis

Ho: The selected field margin plants will have no effect on common bean’s growth, yield, insect pest control and support of beneficial insect (natural enemies and pollinators) in bean productivity.

Ha: The selected field margin plants will have an effect on growth, yield, insect pests control and support of beneficial insect in bean productivity.

1.4 Significance of the study

The study will contribute to a cheap and safe biological technique of dealing with insect pests on the environmentally friendly basis and help increase crop yield at low cost. Also, it will unveil the opportunity and possibility of exploring ecosystem benefits from the abandoned or weedy plant species in the field margin some of which are invasive species. The study will raise awareness among smallholder farmers on the importance of pesticidal plants and the ecosystem services they provide and thus the need to preserve them to ensure their constant availability.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Pesticidal plants or botanical pesticides are plants or plant parts valued for their medicinal or therapeutic properties, flavor, and/or scent. Such qualities like deterrents, insect antifeedants or repellents are used in controlling insect pest in the field and stores depending on the intended use (Isman, 2006). Botanical pesticides are advertised as an alternative to synthetic chemicals because they are safe to the environment (Isman, 2006; Gurr *et al*., 2016; Ndakidemi *et al.,* 2016) and less costly as compared with the synthetic chemicals. Despite many benefits obtained from pesticidal plants, less effort has been done in their conservation due to the fact that they are not considered as a priority in our farming practice systems. As a result, very few farmers benefit services from botanicals due to lack of awareness and the limited knowledge on how botanicals are applied in terms of preparation, frequency, and proper dosage so as to produce the desired effect (Mugisha-Kamatenesi *et al.*, 2008; Mkenda *et al.,* 2015). This is mainly due to limited research in this area (Mugisha-Kamatenesi *et al.,* 2008). This review intends to explore the potential of pesticidal plants and suggests their conservation measures for the future benefits.

Pesticidal plants are touted as attractive alternatives to synthetic insecticides because they reputedly pose little threat to the environment and to human health (Isman, 2006). The application of pesticidal plants in controlling insect pests is not a new idea but it has been in place for centuries (Prakash and Rao, 1996). It was not until the 1980s or 90s when scientist became optimistic that plants can provide effective and environmentally friendly pesticide (Stevenson *et al*., 2016). Some studies have been done in Africa on the application of botanical pesticide based on the extracts from the locally available pesticidal plants, including *Lantana camara*, *Tephrosia vogelii*, *Lippia javanica*, *Vernonia amygdalina* and *Tithonia diversifolia* (Isman, 2008; Mkindi *et al*., 2017). This study aims at exploring the possibility of extending the uses of these plants as border plants or intercropped to attract beneficial insect-like bees, butterflies, hoverflies which are pollinators and repellent of crop pest like blister beetles, aphid, and Ootheca at the same time protecting the environment by adding up organic nutrients.

According to Isman (2015), there is a growing demand of application of botanical pesticides in controlling insect pests in the first world countries. Paradoxically, however, in Sub-

Saharan Africa (SSA), it is surprising to see only a few farmers applying botanical pesticides as compared with synthetic pesticides. This can be mainly due to lack of knowledge of its efficiency and effectiveness as compared to the existing synthetic pesticides in use. Another reason for less use of botanical pesticides by farmers is lack of their evaluation under realistic field conditions to assess their efficacy as well as their benefits to farmers (Mkindi *et al.,* 2017). Also in SSA particularly in Tanzania, farmers use other products such as cow's urine, cow dung, and ashes (Mkindi *et al.,* 2015) as an alternative to synthetic pesticides. The additional reason for low uptake of botanical pesticide is attributed to a limited field research (Mugisha-Kamatenesi *et al.,* 2008) which deprives farmers the opportunity to learn and acquire skills on appropriate methods of preparation, required dosage and the frequency of application. Another factor which contribute to the low uptake of botanical pesticide is a scarcity of pesticidal plants among smallholder farmers in SSA due to loss of biodiversity caused by increase in population which put pressure on land clearance for agriculture, settlement, infrastructures, grazing land and lastly due to excessive drought coupled with forest fires that conspire together to deplete the vegetation cover (Gurr *et al.,* 2016; Stevenson *et al.,* 2016). Based on the gravity of the entire situation, the author hereby provides this review article to discuss the significance and the potential of the pesticidal plants so as to raise awareness and encourage their conservation as a way of improving crop yield and farmers wellbeing while conserving the environment.

Experience shows that there is a trend of most farmers to rely on external inputs such as chemical fertilizers, pesticides, and herbicides, which is motivated by the high yield. The use of these synthetic inputs in pest control has been considered as cheap due to the fact that the indirect costs associated with their use such as environmental pollution, the death of non-target organisms, health problems and interference with ecosystem services are not taken into account (Pimentel, 2005). Such unrealistic approach towards the side effects of synthetic pesticides escalates their use despite the fact that they are relatively expensive, detrimental to health and entire ecosystem and worse still scarcely available. Uses of pesticidal plants will offset the use of farmers' practices that contaminate the environment and reduce the risk of toxic substances that enter the food chain.

The way forward to avoid or minimize the use of synthetic pesticides in agricultural settings is through the conservation of biodiversity, including known pesticidal plants such as *Lantana camara*, *Tephrosia vogelii*, *Lippia javanica*, *Vernonia amygdalina* and *Tithonia diversifolia* etc. This will provide a good scene for ecosystem productivity provided by the vital contribution vested on these individual species and thus ensure the protection of other natural resources such as natural enemies which may be used for insect pest control. To ensure sustainability in crop production, there is a need to identify and promote management of these pesticidal plants. This review aims at exploring the existing knowledge and information on pesticidal plants in crop production and their respective role in supporting beneficial insects so that proper conservation measures of the pesticidal plants can be taken into account to harnessing the benefit they provide.

2.2 Ecosystem services harnessed from pesticidal plants

Ecosystem services refer to the conditions and processes through which natural ecosystems and the species that make them up (flora and fauna), sustain and fulfill human life. The ecosystem services are summarized in four main groups, namely, provisioning, regulating, supporting and cultural (Assessment, 2005; Power, 2010; Ndakidemi *et al*., 2016).

Pesticidal plants provide provisional services like forage, timber, biomass fuel, natural fiber, and pharmaceuticals (Postel *et al.,* 2012; Sánchez *et al*., 2017). Another service offered by pesticidal plants is regulating services which include partial stabilization of climate and control of disease, purification of water and air, generation and renewal of soil and soil fertility, mitigation of floods and drought, detoxification, and decomposition of wastes (Postel *et al.,* 2012; Furlong, 2016), water quantity and quality assurance, buffers the movement of pollutants from land to the nearby water bodies, facilitates the movement of nutrients and water by regulating the speed of surface water flow and nutrient particles, flood control, carbon storage and waste treatment (Marshall and Moonen, 2002)

Pesticidal plants also offers supporting services like insect pest control, support to natural enemies, windbreak, erosion control, nutrient recycling, pollination and organic matter in the soil support biodiversity and enhance carbon sequestration, maintenance of biodiversity, pollination of crops (Tscharntke *et al*., 2005; Power 2010; Postel *et al.,* 2012), shelter for stock in adverse weather, windbreaker, insect harbourage, serves as the refuge for many wildlife species and provides support to a variety of invertebrates (Marshall and Moonen, 2002) including beneficial insects.

Beneficial insects are grouped into: natural enemies and pollinators which provide natural ecosystem services such as biological control of pests and pollination of plants (Altieri, 1999). According to Aquilino *et al.* (2005) and Martin *et al*. (2013) as cited by Mkenda *et al*

(2017), in the field of agriculture, the term natural enemies refer to organisms that attack and feed on other organisms, particularly on insect pests of plants leading to a type of pest regulation referred to as natural pest control or biological control. Natural enemies are a diverse group of organisms that include predators, parasitic insects (parasitoids), nematodes and microorganisms (Ndakidemi *et al*., 2016). The predators feed on the harmful insect pets while the parasitoids lay eggs in or on the bad insect pest (Russell and Arbor, 1989) which upon hatching the larvae from parasitic insects eat up the insect pest. The understanding of the suitable environment for the beneficial insects' and the manipulation of their habitat accordingly, is the best way that will favor these insects in the field (Mkenda, *et al.*, 2017). There are several natural enemies of crop insect pests such as tachinid flies, ground beetles, wasps, spiders, and ladybugs (Mack, 2007) to mention but a few. These control insect pests such as bean pod weevil (Apion), bruchid seed weevils, leafhopper, thrips, bean fly (bean stem maggot), and whitefly (Miklas *et al.*, 2006; Mkenda *et al.*, 2014).

A well-established pesticidal plantation offers cultural services like spiritual and recreational benefits, stimulate tourism through improved aesthetic values (Gurr *et al.*, 2016) used for educational purposes, as well as for traditional use whereby agricultural places or products are often used in traditional rituals and customs that bond human communities (Power, 2010). The services are summarized in Table 1.

Table 1: The ecosystem services obtained from pesticidal plants

Pesticidal Plant	Plant part used	Potential function/service provided	Reference
Lantana camara	Dry leaves extracts	Repellent of pest such as Coleoptera: Curculionidae	Nel, (2015); Ogendo *et al.*, (2003)
	Flowers	Promote pollinators in *Mangifera indica*	Nel, (2015)
	Chloroform extract of dry *Lantana camara* 'Mozelle' leaves termite	Repellent, antifeedant and toxicity against termites	Boeke *et al.*, (2004)
		Control of eastern subterranean termite	Yuan and Hu, (2012)
	Aerial parts of *Lantana camara*	Insecticidal, antiovipositional and antifeedant activity *against Callosobruchus chinensis*	Yuan and Hu, (2012)
Tithonia diversifolia	Leaves	Repellent in Mosquito, Aquatic leeches, and mites	De Boer *et al.*, (2010)
Tephrosia vogelii	Leaves extracts	Repellent of Coleoptera: Curculionidae	Nel, (2015)
		Control of insect pest of stored cowpea, (*Callosobruchus maculatus*)	Boeke *et al.*, (2004)
	Stem and brunches	Provides firewood and construction materials	Kwesiga *et al.*, (1999)
Lantana Trifolia	Extract of methanol from the leaves	Treatment of bronchoconstriction induced by histamine, 5-HT	Achola and Munenge, (1996)
Tagetes minuta	Leaves	Repellent in Aphids and bruchid beetle	Kawuki *et al.*, (2005)
Azadirachta	Leaves,	Feeding deterrent and growth	Mpumi *et al.*, (2016)

indica		regulator	
Nicotiana tabacum	Powder from dry pounded leaves	Control of insect pest of stored cowpea, (*Callosobruchus maculatus*)	Boeke *et al.*, (2004)
Ocimum suave	Leaves and succulent stems	A source of repellents, toxicants and protectants in storage against *Sitophilus zeamais* (Mots.), *Rhyzopertha dominica* (Fab.) and *Sitotroga cerealella* (Oliv.) in maize and sorghum	Bekele *et al.*,(1996)
		Traditional medicine against stomachache, cough, and influenza	Kamatenesi-Mugisha *et al.*, (2013)
Bidens pilosa	Stem and brunches	Ornamental purposes,	Arthur *et al.*, (2012)
		Used as a folkloric medicine for the treatment of various diseases	
		Provision of food; leaves and shoots are edible	Hillocks, (1998)
Ageratum conyzoides	Leaves	Treatment: Leaves pounded to treat wounds	Hillocks, (1998)
		Remedy for stomach pains	

2.2.1 The potential of pesticidal plants in crop production

Generally, the ecosystem services provided by pesticidal plants are employed in agriculture whereby they directly or indirectly serve to improve crop production by the use of locally available resources which are friendly to the environment and secure for human health while avoiding or reducing the use of external inputs such as artificial fertilizers and synthetic pesticides. Natural pests control of plant in short-term suppresses pest damage and improves yield, while in the long-term maintains an ecological equilibrium that prevents herbivore insects from reaching pest status and these are provided by generalist and specialist predators and parasitoids, including birds, spiders, ladybugs, mantis, flies, and wasps, as well as entomopathogenic fungi (Zhang *et al.,* 2007).The pesticidal plants offer direct or indirect services to improve yield in crop production through various ways including; supplying organic matter, pollination, nutrient cycling, windbreaks, erosion control, diseases and pests management whose details are highlighted in Table 2.

Table 2: The role of pesticidal plants in crop production

Pesticidal plant	Role in ecosystem services	Country	Reference
Lantana camara	Attracts a variety of pollinators	South Africa	Nel, (2015)
	Control of storage crop pests: weevils & potato tuber moth	Ghana	Awafo and Dzisi, (2012)
	Support pollination	Tanzania	Mkenda *et al.*, (2015)
Tithonia diversifolia	Support natural enemies and increase bean yield	Tanzania	Mkindi *et al.,* (2015); Mkenda *et al.,* (2015) Mpumi *et al.*, (2016)
	-Transfer of the nutrient through the accumulating shrub	Kenya, East Africa	Sanchez, (2002)
	Increases P in the soil	SSA	Bationo, (2004)
	Improves soil fertility and increased crop yield	Zambia	Kwesiga *et al.*, (1999)
	Extracts from leaves are used as insecticides	Zambia	Kwesiga *et al.*, (1999);

Pesticidal plant	Role in ecosystem services	Country	Reference
Tephrosia vogelii		Tanzania	Mkenda *et al.*, (2015)
	Support natural enemies like ladybird beetles and hence increased bean yield	Tanzania	Mkenda *et al*., (2015); Stevenson *et al.*, (2016); Mpumi *et al.*, (2016)
	Support pollinators	Tanzania	Mkenda *et al.*, (2015); Mkindi *et al*., (2015)
Lantana trifolia	Pollination: facilitate mango flower visitation during mango flowering (*Mangifera indica*) production on commercial mango farms	South Africa	Nel, (2015)
Ocimum suave	A source of repellents, toxicants and protectants in storage against *Sitophilus zeamais* (Mots.), *Rhyzopertha dominica* (Fab.) and *Sitotroga cerealella* (Oliv.) in maize and sorghum	Kenya	Bekele *et al.*, (1996)
Tagetes minuta	Control of cabbage aphid *Brevicoryne brassica*	Lesotho.	Phoofolo *et al.*, (2013)
	Management of plant-parasitic nematodes.	Lesotho.	Krueger *et al*., (2007)
Ageratum conyzoides	Attract pollinators	Tanzania	Ngongolo *et al*., (2014)
Sesbania sesban	Improves soil fertility and increased crop yield Provides firewood and construction materials	Zambia	Kwesiga *et al*., (1999)

2.2.2 The role of pesticidal plants in diseases and pests management

In order to improve yield in crop production, it is important to make sure that plant diseases and pests that affect the crop yield are controlled. The pesticidal plants can be used to offer these ecosystem services in two ways, namely: a) directly as the extract from the pesticidal plants which serve as botanical pesticide or b) the biological control facilitated by the live plant in the crop field.

i) Pest control in crop production using extracts from pesticidal plants

For decades, laboratory investigations have revealed plants with pesticidal effect as the best alternative to synthetics (Mugisha - Kamatenesi *et al.,* 2008). However, these important findings are limited in their efficacy under field conditions (Mkindi *et al*., 2017), their economic viability and impact on beneficial insects (Mkenda *et al*., 2015). Studies on the extracts from the botanical pesticides show that the pesticidal plant treatments have the lower impact on the beneficial insects and this allows higher crop yields compared with synthetics pesticides. This is based on the fact that the plant-based pest management approach favors beneficial insects' natural enemies which contribute to the pest control (Stevenson *et al.*, 2016).

Some studies reveal that extracts from pesticidal plants have active ingredients which can be used in agriculture to control pests. According to Mpumi *et al.* (2016), the botanical pesticides are generally pest-specific, relatively harmless to non-target organisms (Mkindi *et al*., 2015) including man and natural enemies of insect pests, environmentally friendly, degrade rapidly (less persistence) in sunlight, air, and moisture, rapid in action to the insect pests, harmless to plant growth, seed viability and cooking quality of the grains and are less expensive and easily available in the farmers natural environment. The study by Mkenda *et al*. (2015) as reported by Stevenson *et al.* (2016) shows that there was higher yield of common beans when using water-based extracts of *Tephrosia vogelii* or *Tithonia diversifolia*, compared with the synthetic (Karate – lambda - cyhalothrin) suggesting that plant extract has less effect to beneficial insect which plays a great role in crop yield. For example, leaves and stem ethanol and aqueous extracts of *Lantana camara* (Verbenaceae), *Ocimum basilcum* (Lamiaceae), *Lupinus termis* (Leguminaceae), *Solenostemma argel* (Asclepiadaceae) and *Nicotiana rustica* (Solanaceae) are reported to control the field pests of tomato, African bollworm (*Helicoverpa armigera)* Hubner as elucidated by the mortality, repellency and antifeedant effects on *Helicoverpa armigera* larvae (Mohamed, 2015). Plant extracts have been used in controlling insect pests. For example, *Tephrosia vogelii*, *Azadirachta indica*, *Annona squamosa*, chill paper (*Capsicum* sp.), *Allium sativa* have been used successfully in controlling insect pests in common beans and cowpea (Koona & Dorn, 2005; Mwanauta *et al*., 2015). The value of pesticidal plants comes from the harnessing of plant defense strategies based on the production of chemicals that are repellent or toxic to specific pests or a wide range of organisms that are destructive to crops (Madzimure *et al*., 2011).

According to Mpumi *et al.* (2016), the botanical pesticides effect their toxicity in different ways; *T. vogelii* has the oral lethal dose to mammals and in the insects it limits the cellular energy production while Azadirachtin is antifeedant and growth disruptor of insects; whereas Pyrethrins are axonic poisons and have repellent effects to insects. And Sesquiterpenes lactones from *T. diversifolia,* Pentacyclic triterpenoids from *Lantana camara*, Vernodalin, Vernodalol and Epivernodalol from *V. amygdalina* have repellent and feeding deterrents chemicals which discourage the insects from feeding the crop (Mpumi *et al.*, 2016). The study by Mkenda *et al.* (2015) reported that extracts made from four abundant weed species found in northern Tanzania, *Tithonia diversifolia*, *Tephrosia vogelii*, *Vernonia amygdalina* and *Lippia javanica* offered effective control of key pest species on common bean plants (*Phaseolus vulgaris*) that was comparable with the pyrethroid synthetic - Karate. Likewise, according to Mkindi *et al*. (2017), extracts made from six abundant weed species found across sub-Saharan Africa (Tanzania and Malawi), namely, *Bidens pilosa, Lantana camara, Lippia javanica, Tithonia diversifolia, Tephrosia vogelii* and *Vernonia amygdalina*, were evaluated in the station and field trials on common bean plants (*Phaseolus vulgaris*) and all plant species offered effective control of key pest species that was comparable in terms of harvested bean yield to a synthetic pyrethroid.

Tithonia diversifolia and *Lantana camara*, have been found to have insect feeding deterrent characteristics to insect pests (Mpumi *et al.*, 2016) which makes them good in controlling insect pests in the field thus increasing crop yield and serves as an alternative to synthetic pesticides (Mpumi *et al.*, 2016). Despite the efficacy that has been reported on the use of extracts from pesticidal plants in controlling insect pest, still there is a limited knowledge among smallholder farmers in SSA about the logistics of preparation and application and on identification of pesticidal plants of such properties in the field margin or weeds in the crop field that can be used to serve the same purpose. Thus there is a need to do more research in order to determine more plants with pesticidal properties and involve farmers in the entire process of preparation and application of extracts from pesticidal plants for better results.

ii) Biological pest control of pesticidal plants in crop production

Biological control is an intentional introduction of an exotic, usually coevolved, biological control agent known as a natural enemy for the permanent establishment and long-term control of crop pests (Mkenda *et al*., 2014). According to Landis *et al*. (2000), pesticidal plants which are intercropped within the field or planted as field margin plants may serve as a source of food and habitat to natural crop pests' enemies and this is considered among the best options towards increasing ecosystem services and biodiversity conservation.

Unlike animals that can fight or fly in case of dangers, plants are immobile and thus use a biological mechanism to protect themselves against enemies. Plants do so by secreting some chemical compounds called exudes which deter/repel the insect pests which come to feed or nest in them. Farmers utilize their knowledge on this ecosystem relationship to control insect pest in the field and storage units (Stevenson *et al*., 2016).

Literatures reveal that in their natural stand the pesticidal plants can be effective in controlling insect pest in crop production through different ways including providing the natural enemies with resources such as nectar, pollen, physical refuge, alternative prey, alternative hosts and hiding sites (Gurr *et al*., 2016) as well as ensuring pest control (Dainese *et al.,* 2017) and ultimately improved crop yield.

Additionally, diversified ecosystem contributes to weed control, disease and pests control and increased pollination services (Kremen and Miles, 2012; Gurr *et al*., 2016; Ndakidemi *et al*., 2016). In a nutshell as pointed out by Zhang *et al.* (2007) farm biodiversity which includes pesticidal plants supports ecosystem function and provides services such as biological pest control and nutrient cycling that potentially reduce reliance on synthetic inputs, unlike conventional agricultural systems. This still requires further investigation on how best the environment especially plant biodiversity can be manipulated to favor more beneficial insects. The complexity of landscape increases the availability of food sources and habitat for insects ensuring the diversity and abundance of natural enemy population and with enhanced pest control (Zhang *et al.,* 2007). Studies suggest that insect predators and parasitoids account for approximately 33 percent of natural pest control (Power, 2010) and that habitat with species abundance (biodiversity) provides a favorable environment for beneficial insect (Gurr *et al.,* 2016), which play a great role in agriculture to ensure increased crop yield. Additionally, non-crop habitat provides predators and parasitoids with well-diversified habitat where beneficial insects mate, reproduce, and overwinter and also with a variety of plant resources such as nectar, pollen, sap, or seeds as alternative food sources to fuel adult flight and reproduction (Zhang *et al*., 2007).

Gurr *et al.* (2016) pointed out that simple diversification like promoting the growth of flowering plants can contribute to the ecological intensification of agricultural system by encouraging the natural enemies of some key pests of crops by ensuring the availability of nectar, pollen, fruits, and insects, which is food for natural enemies (parasitoids and predators) and thus support existence and enhance their diversity (Gurr *et al*., 2004). For instance, the study by Tooker and Hanks (2000) pointed out that parasitoid species were found visiting a limited range of host plants, which may have implications for conservation biological control and conservation biology.

Most of the predators and parasitoids such as hoverflies, predatory bugs, lady beetles, lacewings, predatory wasps, and predatory flies feed on nectar or pollen and in so doing they play a secondary beneficial role of pollinating the flowers (Kremen *et al*., 2007; Ndakidemi *et al.*, 2016). There is a need to liaise with policymakers and entrepreneurs without neglecting the scientific guidance to diversify the non-food agricultural production with as many pesticidal species as possible which would provide farmers with the best alternative to synthetics pesticides (Stevenson *et al.*, 2016). To achieve this, an understanding of the ecology of these natural enemies specifically the kind of environment that favors them is needed. Therefore, there is a need to do research to explore how best the established pesticidal plants within or along the field margins can contribute to the biological management of insect pests in the crop fields.

2.2.3 Water quantity, quality and Erosion control

A farming system which is well diversified to a great extent support ecosystems services such as greater biodiversity, soil quality, carbon sequestration, and water-holding capacity in surface soils, energy use efficiency, and resistance and resilience to climate change (Kremen and Miles, 2012) as well as controlled soil erosion. In Sub-Saharan Africa (SSA), farmers use pesticidal plants intercropped or planted as field margin and these ensure the ecosystem services such as water retention capacity of the soil and reduced or controlled soil erosion.

The farmer also uses pruned the branches of the pesticidal plants for mulching which avoid direct sunshine and raindrops on the soil thus improving soil moisture and reduced erosion rate as well as controlling weeds. All these contribute to improved crop production. The pesticidal plants serve as soil cover that holds the soil intact and ensures improved soil structure and texture for better crop production. Forest soils or a land established with vegetation tend to have a higher infiltration rate than other soils, with reduced peak flows and floods. The interception of rainwater by plant canopy reduce the runoff speed and increase water holding capacity of the soil and thus retain soil fertility and improved crop yield. Also, the deep rooting species of pesticidal plants improve the availability of both water and nutrients to other species in the ecosystem reducing the rate of soil erosion and resulting in good water quality (Power, 2010). The plant canopy facilitates the regulated capture, infiltration, retention, and flow of water across the landscape, retaining soil, modifying soil structure and producing the litter.

A slight reinforcement of pesticidal plant with forest nature may provide a wide range of goods and services to society, such as water purification, hydrologic regulation, pollination services, control of pest and pathogen populations, diverse food and fuel products, and greater resilience to climate change and extreme disturbances, reduced erosion rate while at the same time improving the sustainability of food production (Asbjornsen *et al.,* 2014). Therefore, there is a need to do research to find out more plants with pesticidal properties which are also good in preserving water sources and enhancing the availability of enough and quality water as well as reduced soil erosion with improved crop production.

2.2.4 Windbreaks

Strong winds are very destructive in crop production as they can cause a physical damage to flower buds, fruits at a tender age as well as the spread of diseases to crops or plants leading to substantial effect on crop yield. The pesticidal plants may as well provide substantial benefits in the production of crops through creation of microclimate, improving pollination and fruit set through reduced wind speed (Norton, 1988). Also, botanical pesticides planted as windbreak interrupt or slow down air fluxes and the propagules they carry **(**Burel,1996). Reduced wind speed allows for timely application and efficient use of pesticide, efficient water distribution, reduced evaporation and aid in frost management (Norton, 1988) in extremely cold regions. It is a common practice among smallholder farmers in SSA to use pesticidal plants to serve as windbreak also enhancing their pesticidal properties in pest control through deterrence, repellence, antifeedant or direct killing.

The pesticidal plants which offer such ecosystem services include *Tithonia diversifolia* and *Lantana camara* which are planted along the field margin to serve as windbreaker and at the same time their extracts are used in controlling the pest of stored cowpea *Callosobruchus* *maculatus* and antifeedant activity against *Callosobruchus chinensis* respectively *(*Boeke *et al.,* 2004; De Boer *et al.,* 2010; Nel, 2015*;* Yuan and Hu, 2012). Other plants like *Tephrosia vogelii* when grown in mixture with other intercropped with crops plant to serve as a windbreaker as well as to facilitate nitrogen fixation (Wang *et al.,* 2011) and control insect pest of crops like beans in the store and in the field (Mihale *et al*., 2009). Also*, Azadirachta indica* planted along the margin of the crop field acts as the windbreaker as well as pest control through feeding deterrent and growth regulator (Akunne *et al.,* 2014; Mpumi *et al*., 2016).

The pesticidal plants such as *Tithonia diversifolia* and *Lantana camara* serve as windbreaker when planted along the field margins. Simultaneously through their extracts, these pesticidal plants controls storage pest of cowpea (*Callosobruchus maculatus)* and antifeedant activity against *Callosobruchus chinensis (*Boeke *et al.,* 2004; De Boer *et al.,* 2010; Nel, 2015*;* Yuan and Hu, 2012). Other studies have also reported that *Tephrosia vogelii* do not only serve as windbreaker, just like the other pesticidal plants, but also facilitate N-fixation when intercropped with other crops (Wang *et al.,* 2011) and control insect pest of crops such as beans both in store and in the field (Mihale *et al*., 2009). Also*, Azadirachta indica* planted along the margin of the crop field acts as the windbreaker as well as pest control through feeding deterrent and growth regulator (Akunne *et al.,* 2014; Mpumi *et al*., 2016).

Generally, windbreak (field shelterbelts) ultimately increase yields of a field and forage crops throughout the world due to reduced wind erosion, improved microclimate, snow retention and reduced crop damage by high wind (Kort,1988). Pesticidal plants grown as either mono-crop or intercropped can provide a solution to different problems encountered by farmers in SSA. There is a limited knowledge among the farmers on how best they can make use of pesticidal plants and harness enormous ecosystem service they provide. Therefore, there is a need to do research to discover more plant species which can play double roles or even more like windbreak, pest control and improvement of soil fertility as the best way to protect the environment and ecosystem at large as well as increasing crop yield.

2.2.5 Nutrient cycling

Pesticidal plants contribute to the nutrient cycling directly through nitrogen fixation particularly of leguminous plants mediated by nitrogen fixation process. When these plants are buried into the soil as plant organic matter and after decomposition, enrich the soil with nutrients, improves soil fertility and increase yield. Apart from production of food in agro-ecosystems, biodiversity performs a variety of ecological services including, recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms and detoxification of noxious chemicals (Altieri, 1999). Biological diversification across ecological, spatial, and temporal scales maintains and regenerates the ecosystem services that provide critical inputs such as maintenance of soil quality, nitrogen fixation, pollination, and pest control to agriculture (Kremen & Miles, 2012). A well-diversified habitat will favor insects like beetles which dung burial (Zhang *et al*., 2007) thereby facilitating the recycling of nutrients. Plants/pesticidal plants also when they die they are subjected to decomposers and thus ensuring the recycling of nutrients (Cotrufo *et al*., 2013).

Microorganisms like bacteria, fungi and actinomycetes are critical mediators of ecosystem service that maintain soil fertility through nutrient cycling by which bacteria enhance nitrogen availability through symbiotic N-fixation process as reported in *Tephrosia vogelii* (Munthali *et al*., 2014) and *Acacia* spp. (Brockwell *et al*., 2005). In another study, Khatun *et al. (*2011) and Mihale *et al*. (2009) reported that *Acacia catechu* seeds/barks and *Tephrosia vogelii* also have pesticidal properties which are useful in pest control both in field and store.

Studies in western Kenya indicate that the incorporation of higher quality organic manures, like *Tithonia diversifolia* and *Lantana camara*, along with TSP (Triple Superphosphate) increases the effectiveness of fertilizer phosphorus (Bationo, 2004). It is reported that green leaf biomass of *Tithonia diversifolia* is high in nutrients and has high concentrations of nitrogen (N), phosphorus (P) and potassium (K) which are rapidly released in plant-available forms during decomposition (Jama *et al*., 2000; George *et al*., 2001). Studies reveal that the P concentration of *Tithonia* leaves is greater than the critical 2.5 g kg^{-1} threshold for net P mineralization meaning that addition of biomass to soil results in net mineralization rather than immobilization of P (George *et al*., 2001). According to Jama *et al.* (2000), the biomass of *Tithonia diversifolia* decomposes rapidly when they are incorporated into the soil, and become the effective source of N, P and K for crops averaging about 3.5% N, 0.37% P and 4.1% K on a dry matter basis while the boundary hedges of sole Tithonia can produce about 1 kg biomass (tender stems + leaves) m^{-1} yr^{-1} on a dry weight basis.

Therefore, pesticidal plants not only that they play the essential role in nutrient cycling to improve soil fertility but also they are important in controlling insect pest and harbor natural enemies. There is a limited knowledge among the smallholder farmers in SSA on the multiple roles of pesticidal plants which can be exploited to improve crop production in agriculture. Therefore, there is a need to conduct research to identify plants of qualities such as pest control and nutrient cycling to be used in boosting crop production and increase income for the smallholder farmers.

2.2.6 Crop Pollination

Crop pollination can be facilitated when pesticidal plants are intercropped or planted as field margins. Through their flowers, pollinators are attracted and provided with forage, pollen, and nectar. In addition the pollinators visit the food crop to facilitate their pollination the process which improves crop yield. For example, a bean field with a variety of local, native flora will attract a good diversity of local, beneficial arthropods and also will offer natural hiding sites and flowering resources for many beneficial insects (Altieri, 1999).

Different pesticidal plants are reported to attract different pollinators. For example, *Lantana camara* attracts pollinators like the butterfly (Barrows, 1976). Floral color is said to influence flower selection by butterflies while floral scents provoke behavioral responses that initiate and maintain foraging on flowers (Andersson and Dobson, 2003). The study made in Australia reported that the main pollinator of *L. camara* was the honeybee (*Apis mellifera)* and that seed set in *L.camara* was strongly correlated with honeybee abundance (Goulson and Derwent, 2004). Other pesticidal plants like Mexican sunflower (*Tithonia diversifolia*) produce nectar with abundant phenolics, including three components of the *Apis* honeybee queen mandibular pheromone and that by mimicking the honey bee pheromone blend, nectar may maintain pollinator attraction (Liu *et al*., 2015). *Tephrosia vogelii*, on the other hand, was observed to be primarily a self-pollinated species but requires an insect to trip the flowers and *Xylocopa brasilianorum* is reported to be the primary insect pollinator (Barnes, 1970).

Crop pollination is the best-known ecosystem service performed by insects (Zhang *et al*., 2007). The production of over 75% of the world's most important crops that feed humanity (Power, 2010; Zhang *et al*., 2007) and 35% (Zhang *et al*., 2007) or 65% (Power, 2010) of the food produced are dependent upon animal pollination. Though bees comprise the dominant taxa providing crop pollination services; birds, bats, moths, flies and other insects can also be important and it is reported that conserving wild pollinators in habitats adjacent to agriculture improves both the level and stability of pollination, leading to increased crop production and good income (Zhang *et al*., 2007). Pesticidal plants established in the agricultural landscapes create natural habitats that attract both wild pollinators and domesticated honey bees thus ensuring pollination as one of very important ecosystem services. It is reported that a complete loss of pollinators would cause global deficits in fruits, vegetables and stimulants and such declines in production could result in significant market disruptions as well as nutrient deficiencies (Power, 2010). Therefore, it is important to intercrop or to plant the pesticidal plants especially the flowering plants as field margin plants to ensure better ecosystem services from beneficial arthropods for the increased crop production.

Pesticidal flowering plants which are intercropped or planted as field margin support both pollinators and natural enemies of insects' pest in terms of nectar/food, and habitat. They also play the essential role in insect pest control. Unfortunately, there is a limited knowledge among the farmers on a variety of pesticidal plants which can be used to play such multiple roles. Therefore there is a need to do more research to discover a different variety of plants which can serve in controlling insect pest as well as supporting the pollinators in order to increase crop production and improve the living standard of people.

2.2.7 Organic matter for improved soil fertility

Soil color and productivity are mainly associated with the organic matter chiefly derived from decaying plant materials. The decomposition and transformation of above- and below-ground plant detritus (litter) is the main process by which soil organic matter (SOM) is formed (Cotrufo *et al*., 2013). Thus plants in general and pesticidal plants, in particular, play a great role to ensure organic matter availability in the soil. Smallholder farmers in SSA enrich the soil with organic matter through their common practice of cutting border plants and incorporate them into the soil (George *et al*., 2001). The activities of bacteria, fungi and macro-fauna, such as earthworms, termites and other invertebrates are vital to ensure soil pore structure, soil aggregation and decomposition of organic matter resulting to a well-aerated soils with abundant organic matter which are essential for nutrient acquisition by crops, as well as water retention (Turbé *et al*., 2010; Power, 2010; Bagyaraj *et al*., 2016).

Micro-organisms mediate nutrient availability through decomposition of detritus and plant residues and through nitrogen fixation (Power, 2010). Earthworms, macro- and micro-invertebrates increase soil structure via burrows or casts and enhance soil fertility through partial digestion and combination of soil organic matter (Zhang *et al*., 2007).

Pesticidal shrubs and trees, such as *Lantana camara, Tephrosia vogelii*, and *Tithonia diversifolia* are common on smallholder's farms in Eastern, Central and Southern Africa (ECSA) (Lunze *et al*., 2012) as sources of soil organic matter. *Tithonia diversifolia* for example has been studied in different countries including Rwanda, Kenya, Tanzania and DR Congo for its integration into bean-based production systems through the practice known as *Tithonia* biomass transfer that has led to a considerable bean yield increase by 227% in Rwanda and 68% in DR Congo (Lunze *et al*., 2012; Hafifah *et al*., 2016). *Tithonia diversifolia* is reported to have very high shoot vigor which is estimated to produce in nine-month a high nutrient concentrations biomass for transfer to fields at 2 t ha^{-1} kg of dry matter (Jama *et al*., 2000; Lunze *et al*., 2012).

Lantana leaves when used as mulch mixed with oak and pine leaves adds organic carbon, phosphorus, NO^{3-}N, NH^{4}-N and N-mineralization in the soil and thus may be applied for crop yield improvement and sustainable soil fertility management (Kumar *et al*., 2009). Also, the study done in Ethiopia reported *Lantana camara* biomass as essential in supplementing chemical fertilizer besides adding organic matter to the soil (Rameshwar and Argaw, 2016).

Studies reveal that the *Tephrosia* fallow biomass decompose considerably faster attaining their half-life within 2 – 3 weeks and over 95% within 8 – 25 weeks but when mixed with a low-quality farm residues decomposition was slowed down and thus *Tephrosia* fallow biomass is proposed to be used for short-term correction of soil fertility (Munthali *et al*., 2013).

The study by Ndakidemi. (2015) in in Western Usambara Mountains in northern Tanzania revealed that the locally available nutrients sources such as organic materials prunned from Tughutu (*Vernonia subligera* O. Hoffn) and Minjingu phosphate rock fertilizers when mixed in ratio of 2.5 t dry matter ha^{-1} and 26 kg P ha^{-1} improved P concentration in the tissue of bean plants and their seed yield. It is reported that the application of Tughutu alone, Minjingu phosphate rock (MPR) or triple superphosphate (TSP) alone and Tughutu combined with 26 kg P ha−1 of MPR or TSP relative to the control increased seed yield of common bean by 53%, 28% - 104% and 148% - 219% respectively and therefore this can be taken as an appropriate integrated nutrient management strategy that may increase bean yields and dollar profit to the rural poor communities in Tanzania (Ndakidemi, 2007)

Thus, given the importance of organic matter in crop production, smallholder farmers in SSA should be adviced to develop a common practice of planting the pesticidal plants which will serve as the main source of organic matter (OM) in the soil and thus increase their income through improved crop production. Therefore, there is a need to conduct a research to find out different pesticidal plants that are rich in nutrients and easily decomposable so as to ensure a constant supply of OM and improve soil fertility for better crop yield.

2.3 Ecosystem services tradeoff in crop production

Pesticide use in agricultural production conveys the benefit of reducing losses due to pests and disease (Pretty, 2012). Management practices in agro-ecosystems to ensure that the ecosystem services are accrued also influence the potential for "disservices" from agriculture, including loss of habitat for beneficial wildlife, water pollution, pesticide poisoning of biological species (Zhang *et al*., 2007; Ferrarini, 2016). Due to incompetence and the notion that synthetic chemicals are cheap, efficient (Epstein 2014) and beneficial, farmers have failed to monitor and control the pests at the most appropriate time (Lekei *et al*., 2014; Mkenda *et al.*, 2017) instead they prescribes schedules for pesticide application of which only 0.1 % meet the target organism, the rest getting lost to the environment and non-target species (Tello and Sánchez, 2013; Gurr *et al*., 2016). The environmental and health hazards like chronic illness, environmental pollution, killing of non-target organisms, pesticide resistance in pests, ground and surface water contamination (Pimentel, 2005; Rahaman and Prodhan, 2007; Mkenda *et al.*, 2014; Gurr *et al*., 2016; Peralta and Palma, 2017; Jallow *et al*., 2017) and loss of natural vegetation and biodiversity (Morton, 2007) associated with the use of synthetic chemicals (Pimentel, 2005) disqualifies the expected benefits of the use of the synthetic chemicals (Jaganathan *et al.,* 2008).

Botanical pesticides are attractive alternatives to synthetic pesticides due to fact that they are more sustainable (Mwanauta *et al*., 2015), cheap, easy to prepare, short lifespan in the ecosystem, have more than one active ingredient which work synergistically making it difficult for pests to develop resistance (Mkenda and Ndakidemi, 2014). Despite the ecosystem services accrued, while ministering botanical pesticides there are disservices involved including loss of vegetation cover while using plant extracts (Geiger *et al*., 2010; Garbach *et al.*, 2014), mortality of some beneficial insects (Maia and Moore, 2011; Ndakidemi *et al*., 2016) reduced ability of natural enemies to utilize prey (Van de Veire & Tirry, 2003; Ndakidemi *et al*., 2016). These operational challenges show that there is a need to look for alternative options which will eradicate or minimize the use of synthetic chemicals and maximize the use of pesticidal plants with minimum or no dicevices at all. This can be achieved by minimizing or supplementing plant extract by planting more pesticidal plants through intercropping or growing them as border plants and harness the ecosystem services such as conservation of biodiversity, insect pest control, nesting sites for beneficial insects as well as the provision of nectar to the pollinators.

2.4 Conclusion and Recommendation

Pesticidal plants are necessary for agro-ecosystems services such as provision of the habitat and food for natural enemies of agricultural pests and pollinators and hence increase yields of field and forage crops throughout the world due to reduced wind erosion, improved microclimate, and reduced crop damage by high wind, facilitate nutrient cycling, pollination services, favorable habitat for natural enemies all combined together to improve crop yield and hence economic gain. Thus, the use of the pesticidal plants within the farming systems accrue these benefits as well as protecting the environment and ensuring safe food products resulting from the minimum or no use of the synthetic pesticide which otherwise contaminates food product and kill the untargeted organisms including man. Plant extracts from pesticidal plants are used in controlling of crop pest.

This review, therefore, recommends to explore the possibility of additional use of the pesticidal plants in the field as live stand in the field margin or intercropped in terms of effective insect pest control, support to natural enemies through harborage, forage, and nectar as well as the provision of alternative prey or host for effective management of field crops.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The study was conducted at Nelson Mandela Institution of Science and Technology farm in Arusha Northern Tanzania from January 2017 to July 2017. The study site lies at Latitude -3°24'S and Longitude 36°47'E at an elevation of 1168 m.a.m.s.l with mean annual rainfall of above 1000 mm per year distributed between short rains of October/November to January and long rains of February/March to May (Meru District Council, 2013).

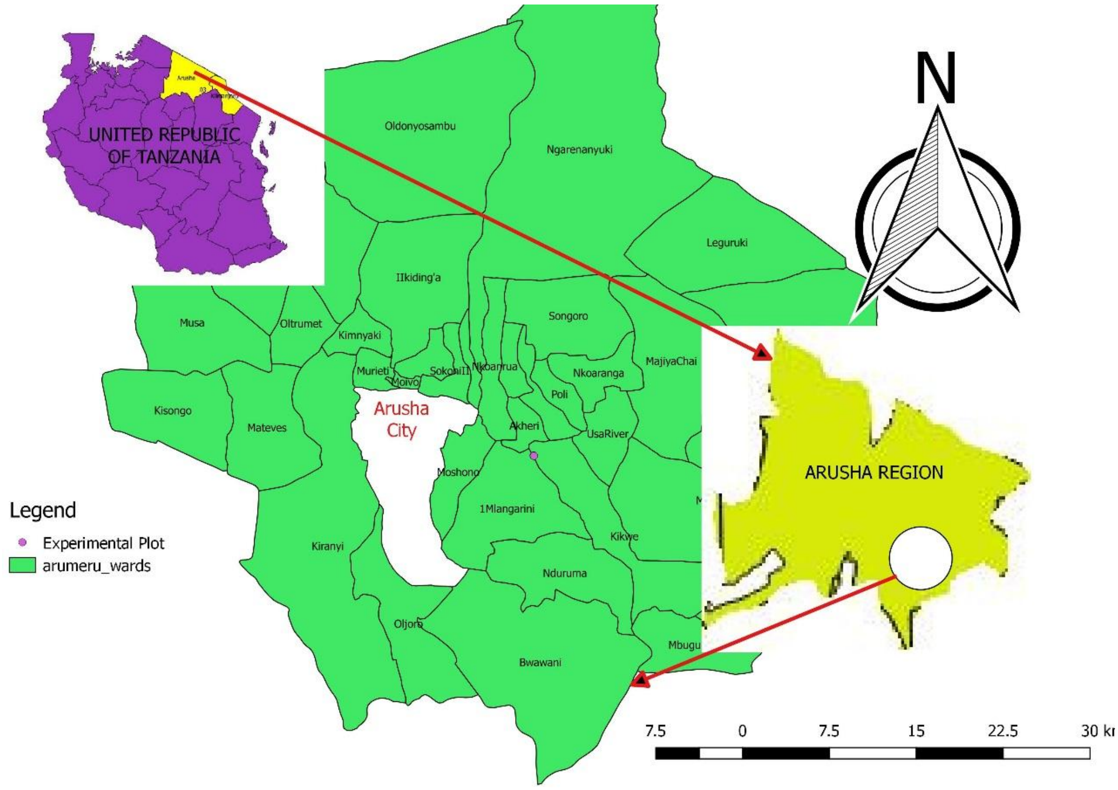

Figure 1: Map of the study area

3.2 Experimental materials

Materials used in this study included key botanicals such as *Lantana camara*, *Tephrosia vogelii*, *Tithonia diversifolia* and *Lantana trifolia* obtained from Moshi and Arusha. Bean seeds of variety Lyamungo 90 were obtained from the Selian Agricultural Research Institute (SARI), Arusha, Tanzania. Other materials used were synthetic pesticides (Lambda - Cyhalothrin) which were bought from Tanzania Farmers Association (TFA) Arusha, Tanzania and pan traps which were made locally from the neighboring workshop.

3.3 Experimental design

The field was hand-hoe-tilled and six plots sized 5 x 5 m each were established. Out of the six plots, four were planted with the selected botanical pesticidal plants in one square meter (1 x 1 m) at the middle of each plot with 50 cm spacing to mimic the natural field condition of border plants. The selected botanical pesticidal plants, namely; *Lantana camara, Tithonia diversifolia, Lantana trifolia* and *Tephrosia vogelii* were planted three months before the planting of beans, then, watered to allow them to mature enough to provide the required effect

Bean seeds were planted three months after the establishment of the selected botanical pesticidal plants with 20 cm spacing within rows and 50 cm between rows based on normal agronomical practices. Three seeds were seeded per hill and then thinned to two plants. Three seed per hill was done so that if one plant dies two would remain and if no one dies thinning was done to ensure two plants per hill. The thinning was done two weeks after germination. The experiment was managed by following usual agronomic practices such as weeding to ensure proper establishment of the bean crop.

The other two plots were negative (nothing was applied i.e. neither sprayed with synthetic nor planted with the pesticidal plant) and positive (sprayed with synthetic pesticide, "karate" or Lambda - Cyhalothrin) controls respectively. The plots were spaced at 1 m apart to minimize inter-plot effects (Bradshaw, 1989). The order: negative control, *Tithonia diversifolia, Tephrosia vogelii*, *Lantana trifolia*, *Lantana camara* and positive control represents treatments one to six respectively. This experiment was replicated five times. The arrangement of botanicals in each plot for the five replicates was by Randomized Block Design (Table 3).

3.4 Data Collection

3.4.1 Identification of beneficial insects and insect pests

Identification of insect was done weekly from week one to harvesting time. Pan traps were set in each plot and insects trapped were identified also the visual observation was done to identify the insect that happens to visit the treatment at that particular moment in time. The traps were placed in all treatment plots of each replication. The insects collected were identified to the functional group level. Plants found associated with beneficial insects were considered as the one that supports the identified insect by providing ecosystem services such as forage, nectar, and harborage. Whereas the fewer number of insect pest associated with a particular pesticidal plant would reflect the antifeedant, repellent or toxicity of that pesticidal plant against insect pests.

3.4.2 Measurement of bean growth and yield parameters

Growth and grain yield of the common beans were measured based on each treatment. Bean plant heights and the number of leaves per plant were measured from the 4th to the 8th week after germination. These parameters were recorded by sampling 10 plants from three rows (i.e. 50 cm, 100 cm and 150 cm) respectively away from the botanicals and the average was worked out for each row. Yield and yield components that were measured during harvesting period include the number of pods per plant, number of seeds per pod, the weight of 100 seeds and total yield in kg ha^{-1}. The estimates of grain yield were determined in kg per unit area from three sampled rows. The results were then extrapolated to kg per hectare (kg ha^{-1}).

Table 3: Field layout and randomization

Replications	Treatments					
1	Positive control	*Lantana camara*	*Tithonia diversifolia*	*lantana trifolia*	Negative control	*Tephrosia vogelii*
2	Negative control	*Lantana trifolia*	*Tephrosia vogelii*	*Lantana camara*	*Tithonia diversifolia*	Positive control
3	Positive control	*Tithonia diversifolia*	Negative control	*Tephrosia vogelii*	*Lantana camara*	*Lantana trifolia*
4	*Lantana trifolia*	*Tephrosia vogelii*	*Lantana camara*	*Tithonia diversifolia*	Positive control	Negative control
5	*Tithonia diversifolia*	Negative control	*Lantana trifolia*	Positive control	*Tephrosia vogelii*	*Lantana camara*

3.4.3 Data analysis

A One-way Analysis of Variance (ANOVA) was used to compare bean height, number of leaves and pods per plant, number of seeds per pod, 100 seed weight, grain yield and insect abundance in each treatment. The analysis was done using STATISTICA software program 2010. Tukey's HSD (Honest Significant Difference) test was used to compare treatment means at 5% level of probability.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The study aimed at assessing the potential of selected field margin pesticidal plants on bean production and ecosystem services. One of the specific objectives was to assess the effects of selected field margin pesticidal plants on beneficial insects' abundance and control of insect pests. The results are reported below. Another objective was to examine the potential of selected field margin pesticidal plants on bean pests' infestation, growth, and yield. The results are detailed below.

4.1.1 The effects of pesticidal plants on beneficial insects and insect pest control.

The pesticidal plants showed different effects to beneficial and pest insects. Some insects were significantly affected by pesticidal plants while others were not. The abundance of insects was recorded weekly for 14 weeks starting from the first week of germination to 14th week (the harvesting time).

i) Beneficial insect's response to the pesticidal plants

The pesticidal plants showed positive effects to some beneficial insects including; butterfly, carpenter bees, crane fly, Formicidae, honey bee, hover fly, lacewing, robber fly, spider, tachinid flies, ladybird beetle, long - legged fly, a parasitic wasp and stingless bee (Table 4). However, the pesticidal plants showed no effect to other beneficial insects like rove beetle, carabid beetle, solitary-bee, stalk-eyed fly, assassin bug and moth (Table 5). The results are reported hereunder.

The beneficial insects that showed a positive response to pesticidal plants.

During the entire period of assessment, some of the beneficial insects which showed a significant difference in response to the pesticidal plants include:

- **Butterflies (Lepidoptera: Rhopalocera)**

The number of Butterflies in bean plots differed significantly ($P \leq 0.001$) in different treatments. Their distribution in the bean field plots with different treatment is summarized by statistical analysis data in (Table 4.) whereby the bean plots with *Tithonia diversifolia* hosted the highest number of butterflies with a mean average of 12.6 ± 1.2a. The rest of the treatments showed the small number of butterflies which differed numerically but not statistically and the lowest mean average of 0.6 ± 1.2b was recorded in bean plots with negative control**.**

- **Carpenter bees (Xylocopa)**

The analysis of variance showed that there were significant ($P \leq 0.05$) differences of the number of carpenter bee across different treatments (Table 4). The bean plots planted with *Tithonia diversifolia*, *Tephrosia vogelii*, and *Lantana trifolia* were singled out as botanicals supporting the highest number of carpenter bee manifesting the difference numerical by statistically showing no difference with the mean average of 4.4 ± 0.7a, 1.8 ± 0.7ab and 1.6 ± 0.7ab respectively. All other treatments had relatively less number of carpenter bee with the least number with a mean average of 0.8 ± 0.7b in the bean plots sprayed with karate (positive control).

- **Crane fly (Tipulidae)**

Throughout the period of assessment, the abundance of crane flies was significantly ($P \leq 0.01$) higher with mean average of 4.0 ± 0.7a in bean plots planted with *Tephrosia vogelii* followed by the relatively high number of support with mean average of 3.0±0.7ab and 1.4 ± 0.7ab recorded in a bean plots planted with *Tithonia diversifolia* and *Lantana camara* respectively (Table 4) whose difference is only numerically but not statistically. Other treatments showed the small number of crane fly and the bean plots sprayed with karate (synthetic pesticide) technically known as Lambda - Cyhalothrin recorded the lowest number of crane fly with a mean average of 0.4 ± 0.7b.

- **Ants (Formicidae)**

Results also showed that the abundance of ants (Formicidae) was significantly greater ($P \leq 0.01$) at negative control (neither sprayed with Lambda - Cyhalothrin nor planted with botanicals) and positive control (sprayed with Lambda - Cyhalothrin) with a mean average of 47.2±7.0a and 20.2 ± 7.0ab. All other treatments had less number of ants and the lowest was recorded in bean plots planted with *Lantana trifolia* with a mean average of 6.2±7.0b (Table 4).

- **Honey bees (Hymenoptera: Apidae)**

During the assessment of beneficial insects, the data showed that honey bee studied were significantly ($P \leq 0.005$) supported by bean plots with *Tithonia diversifolia* and *Tephrosia vogelii* as reflected by the highest number of honey bees with a mean average of 20.4 ± 1.1a and 6.4 ± 1.1b respectively; besides, the mean average number of honey bee between the two treatments differ significantly. Other treatments reported less number of the honey bee and the lowest number was recorded in bean plots sprayed with karate with a mean average of 0.4 ± 1.1c and the mean average number of honey bee between them differed numerically but not statistically (Table 4).

- **Hoverfly (Syrphidae)**

The abundance of hoverfly in response to bean plots with different treatments evaluated in this study showed a significant difference ($P \leq 0.001$) with the highest number of hoverfly recorded in bean plots with *Tithonia diversifolia* with a mean average of 8.2 ± 0.6a. The rest of treatments reported the less number of hoverfly and the lowest support to hoverfly was observed in bean plots sprayed with synthetic insecticide, "karate" with a mean average of 1.6 ± 0.6b (Table 4).

- **Lacewing (Chrisopidae)**

The data in Table 4 show that the abundance of lacewing observed in the bean plots with *Lantana trifolia*, *Lantana camara* and *Tithonia diversifolia* were significantly high ($P \leq 0.001$) with mean averages number of 10.4 ± 1.3a, 7.6±1.3ab, and 4.8±1.3ab respectively and the mean average number between the treatments differ numerically with no significant difference. However, the number of the lacewing in other treatments was low and the smallest number was recorded in bean plots negative control with the mean average of 0.6±1.3c.

- **Robber fly (Asilidae)**

Based on the data in Table 4, the abundance of robber fly showed a significant difference at ($P \leq 0.05$). Highest numbers were observed on the bean plots planted with *Tithonia diversifolia* and *Lantana camara* with a mean average of 10.8 ± 2.0a and 3.0±2.0ab respectively. The rest of the treatments had less number of robber fly and the bean plots planted with *Lantana trifolia* recorded the smallest number of robber fly with a mean average of 0.4 ± 2.0b but statistically they showed no significant deference.

- **Spider (Araneae)**

Data in Table 4 indicate a significant difference ($P \leq 0.001$) in the mean number of spider observed during the entire period of assessment whereby the bean plots with *Tephrosia vogelii* supported the highest number with a mean average of 11.2 ± 1.0a. Statistically, all other treatment recorded a small number of spiders showing no difference between them, however numerically they differed in a mean - average number of spider and the smallest was 1.2 ± 1.0b recorded in the bean plots with negative control treatment.

- **Tachinid flies (Tachinidae)**

There was a significant difference ($P \leq 0.001$) in the mean number of tachinid flies (Table 4) as observed during assessment period whereby the highest number of tachinid was recorded in the bean plots with *Tithonia diversifolia* and *Lantana trifolia* with the mean average of 36.4 ± 2.7a and 27.4 ± 2.7ab respectively. The rest of the treatments recorded the small number of tachinid flies with scores which were different numerically but statistically the same and the lowest number was observed in bean plots sprayed with synthetic insecticide with a mean overage of 10.4 ± 2.7c.

- **Ladybird beetle (Coccinellidae)**

There was a significant support ($P \leq 0.001$) of ladybird beetle with the highest number in bean plots with *Tephrosia vogelii* with a mean average of 5.8 ± 0.7a.The record from all other treatments showed the small number of ladybird beetle which differed numerically but statistically, no significant difference and the smallest number of ladybird beetle with a mean average of 0.4 ± 0.7b was recorded in bean plots with *Lantana camara*, *Lantana trifolia* and negative control (Table 4).

- **Long - legged fly**

The number of long-legged fly was significantly ($P \leq 0.01$) high in all treatments except the negative control as indicated in (Table 4). The highest mean average of 3.0 ± 0.6a, was recorded in bean plots with *Tithonia diversifolia* and *Lantana camara* though significantly there was no statistical difference between them. The lowest record of long legged fly with mean average of 0.0±0.6b was observed in bean plots with negative control.

- **Parasitic Wasp (Hymenoptera: Braconidae)**

During field assessment the number of parasitic wasp was significantly high ($P \leq 0.001$) in all the bean plots planted with botanicals. Bean plots planted with *Tithonia diversifolia* were reported as the highest in performance in terms of the number of parasitic wasps recorded with mean average of 35.4 ± 3.4a. However, this difference in performance between the botanicals was not significant. The lowest number of parasitic wasp with mean average of 11.2 ± 3.4b was recorded in bean plots with negative control (Table 4).

- **Stingless bee (Meliponini)**

Stingless bee was significantly ($P \leq 0.001$) higher in bean plots with *Tithonia diversifolia* with a mean average of 11.6 ± 1.2a and *Lantana trifolia* ranked the second with a mean average of 8.2±1.2ab, however, they only differ numerically but there is no significant difference between them. The smallest number of stingless bee with a mean average of 0.8 ± 1.2 was observed in bean plots sprayed with karate (Table 4).

Table 4: Positive effect of pesticidal plants on mean abundance of beneficial insects

Treatment	Butterfly	Carpenter bees	Crane fly	Formicidae	Honeybee	Hoverfly	Lacewing	Robber fly	Spider	Tachinid fly	Ladybird beetle	Long-legged fly	Parasitic Wasp	Stingless bee
N.Control	0.600±1.20b	1.20±0.72b	1.00±0.67b	47.200±6.99a	3.60±1.12bc	3.20±0.643b	0.600±1.34c	1.00±1.98b	1.20±0.99b	12.00±2.73c	0.40±0.66b	0.00±0.64b	11.20±3.39b	1.60±1.24c
T.diversifolia	12.60±1.20a	4.40±0.72a	3.00±0.67ab	7.200±6.99b	20.40±1.12a	8.20±0.64a	4.80±1.34ab	10.80±1.98a	3.40±0.99b	36.40±2.73a	2.40±0.66b	3.00±0.64a	35.40±3.38a	11.60±1.24a
T. vogelii	2.80±1.20b	1.80±0.72ab	4.00±0.67a	16.40±6.99b	6.40±1.12b	3.00±0.64b	1.40±1.34c	2.00±1.98b	11.20±0.99a	20.00±2.73bc	5.80±0.66a	2.00±0.64ab	27.40±3.39a	4.00±1.24bc
L. trifolia	4.000±1.20b	1.60±0.72ab	0.400±0.67b	6.200±6.99b	3.6001.12bc	3.80±0.643b	10.40±1.34a	0.40±1.98b	2.20±0.98b	27.40±2.73ab	0.40±0.66b	2.60±0.64ab	25.40±3.39ab	8.20±1.24ab
L. camara	4.20±1.20b	1.00±0.72b	1.40±0.67ab	11.40±6.99b	1.60±1.12bc	2.00±0.64b	7.60±1.34ab	3.00±1.98ab	3.20±0.99b	19.60±2.73bc	0.40±0.66b	3.00±0.64a	33.00±3.39a	2.40±1.24c
P.Control	4.00±1.20b	0.80±0.72b	0.40±0.67b	20.20±6.99ab	0.40±1.12c	1.60±0.64b	4.20±1.34bc	2.00±1.98b	2.80±0.99b	10.40±2.73c	1.40±0.66b	0.60±0.64ab	11.40±3.386b	0.80±1.24c
One Way ANOVA F-Statistics														
F-value	11.594***	3.363*	4.899**	4.746**	43.393***	13.681***	7.625***	3.730*	13.384***	12.754***	10.182***	4.073**	9.545***	11.719***
P-value	0.000	0.019	0.003	0.004	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.008	0.000	0.0001

Values presented are means ± SE; *, **, ***: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ respectively, SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at $P = 0.05$ according to Tukey's HSD (Honest Significant Difference) test. *T.vogelii = Tephrosia vogelii*, *L.camara = Lantana camara*, *T. diversifolia = Tithonia diversifolia*, *L.trifolia = Lantana trifolia*, N. Control = Negative control (nothing was applied), P. Control = Positive control (sprayed with synthetic pesticide i.e. "karate")

The beneficial insects that showed no response to pesticidal plant

There were other beneficial insects which were widely distributed in the bean fields which did not show any response to the tested treatments. These included rove beetle, carabid beetle, solitary bee, stalk-eyed fly, assassin bug and Moth (Table 5). However, statistically, their degree of abundance had no significant difference.

Table 5: No-effect response of pesticidal plants on mean abundance of beneficial insects

Treatment	Rove beetle	Carabid beetle	Solitary bee	Stalk-eyed fly	Assassin bug	Moth
N.Control	3.80±1.83a	6.00±2.23a	0.40±0.15a	0.00±0.51a	1.80±0.63a	4.80±2.00a
T.diversifolia	9.80±1.83a	9.00±2.23a	0.20±0.15a	0.80±0.51a	1.20±0.63a	10.80±2.00a
T. vogelii	9.20±1.83a	7.80±2.23a	0.00±0.15a	0.40±0.51a	0.40±0.63a	5.40±2.00a
L. trifolia	7.00±1.83a	13.60±2.23a	0.20±0.15a	1.20±0.51a	1.20±0.63a	8.20±2.00a
L. camara	10.40±1.83a	6.80±2.23a	0.00±0.15a	0.80±0.51a	2.60±0.63a	4.60±2.00a
P.Control	6.00±1.83a	5.60±2.23a	0.00±0.15a	0.00±0.51a	1.40±0.63a	6.80±2.00a
One Way ANOVA F-Statistics						
F-value	1.954ns	1.757ns	1.143ns	0.891ns	1.337ns	1.439ns
P-value	0.122	0.160	0.365	0.503	0.283	0.247

Values presented are means ± SE; ns = not significant, SE = standard error. Means followed by a dissimilar letter (s) in a column are significantly different from each other at P = 0.05 according to Tukey's HSD (Honest Significant Difference) test. *T. vogelii* = *Tephrosia vogelii*, *L.camara* = *Lantana camara*, *T.diversifolia* = *Tithonia diversifolia*, *L.trifolia* = *Lantana trifolia*, N. Control = Negative control (nothing was applied), P. Control = Positive control (sprayed with synthetic pesticide i.e. “karate”)

ii) Insect pests’ response to the pesticidal plants

The pesticidal plants showed significant effects to some pest insects including blister beetle, caterpillar, ootheca and leafhopper (Table 6). However, the pesticidal plants showed no effect to other insect pests’ like drosophila, larvae, locust, plant bugs, thrips and gal midge (Table 7). The results are reported as follows:

The positive/significant effects of pesticidal plant on insect pest control

In this evaluation, some of the insect pests showed a significant difference in response to the tested treatments. The insect pests are reported below.

- **Blister beetle (Meloidae)**

The number of blister beetle was reduced significantly ($P \leq 0.001$) in bean plots planted with all pesticidal plants and the positive control treatments. Numerically, *Lantana camara* was superior to all other treatments with the lowest mean average of 7.4 ± 4.9b.The highest number of blister beetle was recorded in negative control (unsprayed) plots with a mean average of 41.6 ± 4.9a (Table 6).

- **Caterpillar**/(Fall - army-worms) or (Spodoptera frugiperda)

It is evident in (Table 6) that the number of caterpillars observed during the entire period of assessment was reduced significantly ($P \leq 0.001$) in all bean plots planted with botanicals and those sprayed with synthetic pesticide. Numerically the bean plots with *Lantana trifolia* with a mean average of 1.0 ± 1.7b showed superiority over other treatments though there was no significant difference while in negative control the number of caterpillars was the highest with the mean average of 15.0 ± 1.7a.

- **Ootheca**

The number of Ootheca recorded was significantly ($P \leq 0.001$) lower in all pesticidal plant and positive control treatments as compared with the negative control. Numerically, the lowest number was observed in bean plots with *Tephrosia vogelii* as a field margin plants; with a mean average of 1.0 ± 2.4a while the highest number of Ootheca with a mean average of 17.4 ± 2.4a was recorded in bean plot with negative control (Table. 6).

- **Leafhopper (Cicadellidae)**

During the 14 weeks of insect assessment, the number of leafhopper observed was significantly ($P \leq 0.01$) different with the lowest number of leafhoppers recorded in bean plot treated with synthetic pesticide, Lambda - Cyhalothrin and the highest number recorded in bean plot with *Tithonia diversifolia* with a mean average of 13.6 ± 1.7a. However, there was no significant difference in a number of leafhoppers observed in the negative control and in bean plots treated with pesticidal plants except *T. diversifolia* though they differed numerically (Table 6).

Table 6: The positive effect of pesticidal plants on insect pest

Treatment	Blister beetle	caterpillar	Ootheca	Leafhopper
N.Control	41.6±4.9a	15.0±1.7a	17.4±2.4a	7.6±1.7ab
T.diversifolia	10.4±4. 9b	6.2±1.7b	3.0±2. 4b	13.6±1. 7a
T. vogelii	12.0±4. 9b	1.6±1.7b	1.0±2. 4b	6.4±1. 7ab
L. trifolia	7.8±4. 9b	1.0±1.7b	2.2±2. 4b	6.6±1. 7ab
L. camara	7.4±4. 9b	1.6±1.7b	1.2±2. 4b	9.6±1. 7ab
P.Control	9.6±4. 9b	6.2±1.7b	9.0±2. 4b	4.2±1.66b
One Way ANOVA F-Statistics				
F-value	7.354***	9.764***	7.368***	3.872*
P-value	0.000	0.000	0.000	0.010

Values presented are means ± SE; *, ***: significant at $P \leq 0.05$ and $P \leq 0.001$ respectively, SE = standard error of the mean. Means followed by dissimilar letter (s) in a column are significantly different from each other at $P = 0.05$ according to Tukey's HSD (Honest Significant Difference) test. *T.vogelii* = *Tephrosia vogelii*, *L. camara* = *Lantana camara*, *T. diversifolia* = *Tithonia diversifolia*, *L. trifolia* = *Lantana trifolia*, N. Control = Negative control (nothing was applied), P. Control = Positive control (sprayed with synthetic pesticide i.e. "karate")

The insect pests that showed no response to the pesticidal plants

The results as indicated in Table 7 show that some insect pests including drosophila, larvae, plant bugs, thrips and gal midge were widely distributed in the bean field subjected to different treatments. However, their degree of abundance shows difference numerically but statistically not significant.

Table 7: The no-effect response of pesticidal plants to the insect pest

Treatment	Drosophila	Larvae	Locust	Plant bugs	Thrips	Gal midge
N.Control	95.8±11.5a	3.4±1.1a	0.2±6.8a	90.6±12.7a	7.6±1.5a	23.6±5.2a
T.diversifolia	96.6±11. 5a	0.2±11.1a	0.0±6. 8a	82.0±12. 7a	3.0±1. 5a	39.2±5. 2a
T. vogelii	100.8±11. 5a	0.0±1.1a	0.4±6. 8a	66.0±12. 7a	1.6±1. 5a	32.8±5. 2a
L. trifolia	107.8±11. 5a	0.0±1.1a	5.6±6. 8a	51.6±12. 7a	1.2±1. 5a	24.6±5. 2a
L. camara	111.8±11. 5a	1.6±1.1a	0.4±6. 8a	60.0±12. 7a	1.8±1. 5a	23.6±5. 2a
P.Control	86.2±11. 5a	0.4±1.1a	15.8±6. 8a	85.4±12. 7a	3.6±1. 5a	17.6±5. 2a
One Way ANOVA F-Statistics						
F-value	0.636ns	1.432ns	0.868ns	1.524ns	2.618ns	2.261ns
P-value	0.674	0.249	0.517	0.220	0.050	0.081

Values presented are means ± SE; SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at $P = 0.05$ according to Tukey's HSD (Honest Significant Difference) test. *T.vogelii* = *Tephrosia vogelii*, *L.camara* = *Lantana camara*, *T. diversifolia* = *Tithonia diversifolia*, *L.trifolia* = *Lantana trifolia*, N. Control = Negative control (nothing was applied), P. Control = Positive control (sprayed with synthetic pesticide i.e. "karate")

4.1.2 Effect of pesticidal plants on growth and yield of common bean

Growth was monitored after bean germination and the growth parameters, height and number of leaves per plant were recorded from the 4th to 8th week of germination. The effect of the pesticidal plants on growth based on bean height (cm) and the number of leaves per plant was determined based on the distance 50 cm, 100 cm and 150 cm of the bean plant from the pesticidal plants. As indicated in Table 8 the height and number of leaves per plant showed no significant difference.

In the 14th week after germination which was the time of bean harvesting, yield components were recorded only once, these included the number of pods per plant, number of seeds per pod, the weight of 100 seeds and grain yield per unit area which was then extrapolated in (kg ha^{-1}). The effect of the pesticidal plants on yield components was also determined by another factor which is the distance of bean plant measured away from the pesticidal plants which were set as 50 cm, 100 cm and 150 cm. The analyzed data as shown in Table 9 shows that there was a significant effect of pesticidal plants on bean yield at some distances while in other distances there was no significant difference. The detailed report of the growth and yield parameters as affected by pesticidal plant planted at a specific distance away from the botanical is presented below.

i) Growth parameters

The plant height and the number of leaves per plant were measured. The results in Table 8 show that there was no significant difference in height and number of leaves per plant between treatments and the distance from the botanical. However, there were numerical differences between different treatments.

Table 8: Effect of distance between beans and the botanicals on growth parameter (height and number of leaves per plant) of bean

	Distance from the botanicals					
TREATMENT	50 cm	100 cm	150 cm	50 cm	100 cm	150 cm
	Height (cm)			Number of leaves		
N.Control	38.9±2.3a	36.6±2.4a	40.7±2.1a	17.3±1.1a	21.1±2.2a	16.5±1.0a
T.diversifolia	39.3±2.1a	33.2±2.0a	38.8±2.2a	18.5±1.6a	21.1±2.4a	17.5±1.1a
T.vogelii	46.4±2.8a	36.2±2.1a	41.5±2.3a	19.8±1.36a	22.8±2.4a	18.0±1.2a
L.trifolia	45.2±2.4a	35.3±2.3a	42.5±2.4a	17.3±1.0a	20.7±2.5a	18.0±1.2a
L.camara	41.1±2.1a	36.6±2.2a	41.6±2.4a	17.9±1.3a	20.8±2.5a	18.6±1.3a
P.Control	45.1±2.4a	40.8±2.9a	46.7±2.8a	17.9±1.1a	22.9±2.6a	18.9±1.4a
One Way ANOVA F-Statistics						
F-value	2.025ns	1.105ns	1.242ns	0.537ns	0.1781ns	0.476ns
P-value	0.076501	0.358685	0.290869	0.748326	0.970574	0.794240

Values presented are means ± SE; ns = not significant, SE = standard error. Means followed by dissimilar letter in a column are significantly different from each other at *P* = 0.05 according to Fischer Least Significance Difference (LSD). *T.vogelii* = *Tephrosia vogelii*, *L.camara* = *Lantana camara*, *T. diversifolia* = *Tithonia diversifolia*, *L. trifolia* = *Lantana trifolia*, N. Control= Negative control (nothing was applied), P. Control = Positive control (sprayed with synthetic pesticide i.e. “karate”), Ht = Height, No. Lfs = Number of leaves.

ii) Yield and yield components

The bean plant was harvested 14th week after germination and yield were measured in terms of number of pods per plant, number of seeds per pod, the weight of 100 seeds and grain yield per unit area The results are as detailed below.

- **Number of pods per plant and seeds per pod**

During the assessment, the treatments significantly influenced the number of pods per plant ($P \leq 0.005$) at the bean row 100 cm away from the pesticidal plants. The highest number of pods per plant was recorded in bean plots sprayed with synthetic pesticide, Lambda - Cyhalothrin ($C_{23}H_{19}ClF_3NO_3$), commonly known as "karate" with a mean average of 12.1 ± 0.9a. The second and the third highest number of pods per plant were recorded in bean plots planted with *Lantana camara* and *Tephrosia vogelii* with a mean average of 11.0 ± 0.9ab and 10.67 ± 0.90ab respectively. All these numbers of pods per plant differ numerically but no significant difference between them. The lowest was recorded in negative control bean plots, *Tithonia diversifolia* and *Lantana trifolia* with a mean average of 7.7 ± 0.9b, 7.6 ± 0.9b and 8.2 ± 0.9b respectively. Whereas the number of pods per plant in bean rows 50 cm, and 150 cm were numerically different but statistically they were not significantly different (Table 9). In all treatments at the bean plant distance of 50 cm, 100 cm and 150 cm respectively away from the pesticidal plant, the number of seeds per pod differed numerically but statistically, they were non-significant (Table 9).

- **Weight of 100 seeds**

It is evident from (Table 9) that the weight of 100 seeds was not significantly affected by the treatments with bean rows planted at 50 cm and 100 cm from the pesticidal plants. While the weight of 100 seeds of been rows planted at 150 cm from the botanical increased significantly ($P \leq 0.001$) and the highest weight (g) was recorded in bean plots treated with synthetic pesticide "karate" with a mean average of 64.4 ± 2.2a, while all other treatments with pesticidal plants and negative control recorded less weight that was numerically different but statistically no significant difference between them. The lowest numerical value was recorded in the bean plots treated with *Lantana camara* with a mean average weight (g) of 49.0 ± 2.2b.

Table 9: Effect of distance between beans and the botanical on number of seeds per pod and 100 seed weight

	Distance from botanicals								
Treatment	50 cm	100 cm	150 cm	50 cm	100 cm	150 cm	50 cm	100 cm	150 cm
	Pods/ Plant	Pods/Plan	Pods/ Plant	seeds/ Pod	seeds/ Pod	seeds/ Pod	100 seed weight	100 seed weight	100 seed weight
N.Control	9.73±1.1a	7.67±0.9b	9.20±1.2a	3.46±0.2a	3.28±0. 2a	2.94±0.2a	48.86±3.6a	52.34±3.0a	51.54±2. 2b
T.diversifolia	6.73±1. 1a	7.60±0.9b	9.53±1. 2a	3.34±0. 2a	3.64±0. 2a	3.08±0.2a	51.66±3.6a	47.76±3.0a	46.10±2. 2b
T.vogelii	8.80±1. 1**a**	10.67±0.9ab	10.00±1. 2a	3.10±0. 2a	3.02±0. 2a	3.**00**±0.2a	50.30±3.6a	49.94±3.0a	54.46±22. 2b
L.trifolia	9.**47**±1. 1**a**	8.20±0.9b	8.53±1. 2a	3.36±0. 2a	3.26±0. 2a	3.10±0.2a	48.74±3.6a	51.00±3.0a	50.04±2. 2b
L.camara	8.20±1. 1a	11.07±0.9ab	11.13±1. 2a	3.40±0. 2a	3.34±0. 2a	3.22±0.2a	56.40±3.6a	50.74±3.0a	48.92±2. 2b
P.Control	11.60±1. 1a	12.13±0.9a	11.53±1. 2a	3.14±0. 2a	3.10±0. 2a	3.02±0.2a	59.40±3.6a	60.32±3.0a	64.40±2.19a
One Way ANOVA F-Statistics									
F-value	2.267ns	4.804**	0.998ns	0.488ns	1.622ns	0.200ns	1.443ns	2.061ns	8.625***
P-value	0.080	0.003	0.440	0.782	0.192	0.959	0.245	0.106	0.000

Values presented are means ± SE; **, ***: significant at $P \leq 0.01$ and $P \leq 0.001$ respectively, SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at p=0.05 according to Tukey's HSD (Honest Significant Difference) test. *T. vogelii* = *Tephrosia vogelii*, *L. camara* = *Lantana camara*, *T.diversifolia* = *Tithonia diversifolia*, *L.trifolia* = *Lantana trifolia*, N.Control = Negative control (nothing was applied), P. Control = Positive control (sprayed with synthetic pesticide i.e. "karate")

- **Grain yield**

The distance of bean rows from all the treatments except the bean plots planted with *Tithonia diversifolia* significantly influenced the grain yield in kg.ha^{-1} ($P \leq 0.05$) at 50 cm. The highest yield was recorded in positive control bean plots (sprayed with synthetic pesticide, Lambda - Cyhalothrin), *Lantana camara*, negative control, *Lantana trifolia* and *Tephrosia vogelii* with mean average of 2,540 ± 234a kg.ha^{-1}, 1,857 ± 234ab kg.ha^{-1} , 1,616 ± 234ab kg.ha^{-1}, 1,680 ± 234ab kg.ha^{-1} and 1,521 ± 234ab kg.ha^{-1} respectively; the difference between the treatments was only numerical but not significantly different. The lowest yield was recorded in bean plots planted with *Tithonia diversifolia* with a mean average of 1,407 ± 234b kg.ha^{-1} (Table 10).

Also the yield of bean rows planted at the distance of 100 cm from the botanicals increased significantly ($P \leq 0.05$) with the highest yield recorded in bean plots treated with synthetic pesticide with mean average of 2,585 ± 207a kg.ha^{-1} followed by other highest yields recorded in a bean plot treated with *Tithonia diversifolia*, *Tephrosia vogelii* and *Lantana* *camara* with mean average of 2,053 ± 207ab kg.ha^{-1}, 1,820 ± 207ab kg.ha^{-1} and 1,730 ± 207ab kg.ha^{-1} respectively which statistically showed no significant difference between them but differed numerically. The lowest yields were recorded in negative control bean plots and *Lantana trifolia* with a mean average of 1,594 ± 207b kg.ha^{-1} and 1,675 ± 207b kg.ha^{-1} respectively (Table 10).

The yield in bean rows planted at the distance of 150 cm from pesticidal plant increased significantly ($P \leq 0.01$) with the highest yield recorded in a bean plots treated with synthetic pesticide, Those planted with *Lantana camara*, *Tephrosia vogelii* and *Tithonia diversifolia* with mean averages of 2,977 ± 225a kg.ha^{-1}, 2,284 ± 225ab kg.ha^{-1}, 2,105 ± 225ab kg.ha^{-1} and 1,999±225ab kg.ha^{-1} respectively differed numerically but not statistically. The lowest yield was recorded in a bean plots treated with *Lantana trifolia* and negative control with mean average of 1,633 ± 225b kg.ha^{-1} and 1,818 ± 225b kg.ha^{-1} respectively (Table 10).

Table 10: Effect on distance between beans on the botanicals on grain yield

Treatment	50 cm	100 cm	150 cm
	Grain yield		
	kg.ha^{-1}	kg.ha^{-1}	kg.ha^{-1}
N.Control	1616±234ab	1594± 207b	1818± 225b
T.diversifolia	1407± 234b	2053±207ab	1999±225ab
T.vogelii	1521±234ab	1820±207ab	2105±225ab
L.trifolia	1680±234ab	1675± 207b	1633± 225b
L.camara	1857±234ab	1730±207ab	2284±225ab
P.Control	2540± 234a	2585± 207a	2977± 225a
One Way ANOVA F-Statistics			
F-value	3.014*	3.123*	4.335**
P-value	0.030	0.026	0.006

Values presented are means ± SE; *, **: significant at $P \leq 0.05$ and $P \leq 0.01$ respectively, SE = standard error. Means followed by dissimilar letter (s) in a column are significantly different from each other at $P = 0.05$ according to Tukey's HSD (Honest Significant Difference) test. *T.vogelii = Tephrosia vogelii, L.camara = Lantana camara, T.diversifolia =Tithonia diversifolia, L.trifolia = Lantana trifolia*, N. Control = Negative control (nothing was applied), P. Control = Positive control (sprayed with synthetic pesticide i.e. “karate”)

4. 2 Discussion

This study examined the effect of four *pesticidal* plants namely, *Tephrosia vogelii*, *Lantana camara*, *Tithonia diversifolia*, and *Lantana trifolia* on beneficial insects and insect pests and how their interaction affected bean growth and yield. The observed beneficial insects during the study include robber fly, spider, tachinid flies, ladybird beetle, long-legged fly, parasitic wasp, predatory wasp stingless bee and honey bees and the insect pests were Ootheca, Blister beetles (flower beetles), caterpillars (fall-army- worms) and grasshopper.

The results showed that all the pesticidal plants significantly supported the beneficial insects as compared with the control. These results are similar to the study by Gurr *et al.* (2005) which revealed that uncropped field margins plants in agricultural fields are essential in supporting beneficial arthropods. However, some pesticidal plants showed more support to one kind of beneficial insect than the other. The degree of support was determined by the level of abundance of beneficial insects in a particular treatment. *Tephrosia vogelii* for example, showed better support to crane fly, spider, and ladybird beetle. *Tithonia diversifolia* showed good support to robber fly, tachinid fly, parasitic wasp, predatory wasp, stingless bees, butterfly, carpenter bees, honey bees and hoverfly. *Lantana camara* on the other hand showed good support to robber fly and long - legged fly. *Lantana trifolia* showed good support to lacewing. The performance of pesticidal plants in supporting beneficial insect has also been reported by several authors (Altieri, 1999; Amoabeng *et al*., 2013; Sola *et al*., 2014; Grzywacz *et al*., 2014; Mkenda *et al*., 2014; Mkindi *et al*., 2015) especially in developing African countries.

The abundance of beneficial insects associated with different pesticidal plants could be attributed by the availability of food in the form of pollen and nectar, fruits, and insects, which is food for natural enemies (parasitoids and predators). They also provide a shelter such as overwintering sites, moderate microclimate and alternate hosts when primary hosts are not present (Gurr *et al*., 2004).

The studied pesticidal plants also showed repellent or antifeedant properties against various insect pests of common beans in the field. *L. camara* and *L. trifolia* performed well against blister beetles, and caterpillars (fall-army-worms). Also, *L. camara* and *T. vogelii* showed better repellent effect to Ootheca. *T. vogelii* and *L. trifolia* showed good repellence against leafhopper. Similar results on pesticidal plants controlling various insect pests are reported by different authors (Okwute, 2012; Khater, 2012; Mkindi *et al*., 2015).

The small number of insect pest in the bean plots with botanicals might be due to the abundance of natural enemies (predators and parasitoids) which feed on insect pest and thus account for their observed small numbers. This is supported by different authors (Heimpel and Jervis, 2005; Wackers and Steppuhn, 2003) who reported similar findings pointing out that many insect predators and parasitoids bank on pollen and nectar for their reproductive success and thus facilitating the suppression of pests' outbreaks.

The repellency is associated with the small number of insects pests recorded in the bean field plots with these pesticidal plants. The repellency may be due to the deterrent, antifeedant or toxicity of active ingredient contained in these plants against insect pest (Yuan *et al*., 2012). For example, *T. vogelii* has lethal compound that limits the cellular energy production in insect; also Sesquiterpenes lactones and Pentacyclic triterpenoids from *T. diversifolia* and *Lantana camara respectively*, have repellent and feeding deterrents chemicals which discourage the insects from feeding on crops (Mkenda *et al*., 2015; Mpumi *et al*., 2016; Mkindi *et al*., 2017).

The results further showed that generally, the yield increased with increased distance of bean row from pesticidal plants. The grain yield from bean rows at the distance of 50 cm from pesticidal plants were relatively less compared with the grain yields from bean rows planted at 100 cm and 150 cm respectively. However, at the distance of 50 cm the bean plots sprayed with Lambda - Cyhalothrin and all the bean plots planted with pesticidal plants except the one planted with *Tithonia diversifolia* produced higher grain yield than the negative control. The synthetic pesticide numerically showed superiority in yield compared with other treatments apart from the bean plots treated with *Tithonia diversifolia* whereby the difference was significant. The higher yield in bean plots sprayed with Lambda-Cyhalothrin may be due to the effectiveness of the synthetic pesticide in pest control compared with pesticidal plants. Similar results were reported by (Kareru *et al*., 2013; Mkindi *et al.,* 2015; Mkenda *et al*., 2015; Mwanauta *et al*., 2015).

The good performance of the pesticidal plants compared with the negative control may be due to the repellent effect of the pesticidal plants on insect pests and also due to the support of natural enemies by the pesticidal plants that feed on the insect pests (Table 4). Similar results have been reported by (Maia and Moore, 2011; Okwute, 2012; Mkindi *et al*., 2015).

The low grain yield of bean rows planted in bean plots with *Tithonia diversifolia* at the distance of 50 cm from the pesticidal plant may be accounted for by the resource competition such as water, nutrients, and light (shading effect) that affected the photosynthesis rate and thus reduced yield. Generally, there was the increment of bean grain yield with an increase in distance of bean row from pesticidal plants though different plant species manifested their influence at different intensities. Similar results have been reported by De Costa and Chandrapala (2000); AJM De Costa and Chandrapala (2000) and Tsubo and Walker (2004).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Pesticidal plants evaluated in this study, namely: *Tephrosia vogelii*, *Lantana camara*, *Tithonia diversifolia*, and *Lantana trifolia* showed a significant positive contribution on yield, insect pests' control and support of beneficial insect in bean productivity. The pesticidal plants demonstrated a great support to the abundance of beneficial insects during the study. *Tephrosia vogelii* showed great support to crane fly, spider, and ladybird beetle. *Tithonia diversifolia* favored robber fly, tachinid fly, parasitic wasp, predatory wasp, stingless bees, butterfly, carpenter bees, honey bees and hoverfly. *Lantana camara*, on the other hand showed good support to robber fly and long - legged fly. *Lantana trifolia* showed good support to lacewing. Also, the pesticidal plants were observed to promote yield in common beans. *Tephrosia vogelii* showed increasing trend of bean yield as the distance between bean plants and the pesticidal plants was increased while *Lantana trifolia* showed the contrary trend. The other two pesticidal plants, *Lantana camara* and *Tithonia diversifolia* also showed the increased yield though there was no good trend. The pesticidal plants also showed a significant contribution in controlling insect pests. The studied pesticidal plants showed repellent or antifeedant properties against various insect pests of common beans in the field. *L. camara* and *L. trifolia* performed well against blister beetles, and caterpillars (fall – army - worms). Also, *L. camara* and *T. vogelii* showed the best repellent effect to Ootheca. *T. vogelii* and *L. trifolia* showed good repellence against leafhopper. However, the performance of the positive control (sprayed with synthetic pesticide, Lambda-Cyhalothrin) in promoting yield was the highest compared with all other treatments mainly due to its high efficiency in pest control. The findings of this study show the extended use of botanicals not only as extracts but as live stand in the field where they offer enormous contribution in terms of ecosystem services and that they can be used as environmentally friendly insect pest control agent in place of synthetic pesticides which are unfriendly to the environment and the biological component of the ecosystem.

5.2 Recommendation

i) The study, recommends further research to explore the possibility of additional use of the pesticidal plants in the field margin or intercropped so as the benefit the ecosystems services they provide in terms of effective insect pest control, support to natural enemies through harborage, forage, and nectar as well as the provision of alternative prey or host for effective management of field crops.

ii) The study also recommends the deliberate effort on the conservation measures of the known pesticidal plants and suggests for more exploration on their potential for the future benefits

iii) The study recommends further researches on cost - benefit analysis of using pesticidal plants as field margin or intercropping so as to have a clear figure that will convince farmers based on the benefit achieved by applying these techniques.

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Potential of pesticidal plants in harnessing ecosystem services and crop production

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Abstract

In crop production the external inputs such as artificial fertilizers and synthetic pesticides are taken by the majority as the immediate solution. This product-driven approach overlooks the side effects like contaminated food products, the death of non-target organisms, health hazards to animals and human beings, water and soil pollution to mention but a few. This review intends to solve the challenge through crop production using locally available resources which are friendly to the environment, human health and the entire ecosystem. One way to achieve this could be by harnessing the ecosystem services provided by pesticidal plants which are valued for their medicinal, deterrents, or repellents qualities in control crop pests in field or store. They also provide nectar, forage, and habitats for beneficial insects; add organic matter to the soil, creation of micro-climate, control of soil erosion, regulation of water quantity and quality, windbreak, and nutrient cycling. However, there is a limited knowledge on how best to manage the field crop with pesticidal plants so as to accrue the mentioned services. This review intends to uncover different techniques which can be employed in field crop with pesticidal plants in a way that will lead to maximizing crop yield with the possible minimum inputs.

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Introduction

Pesticidal plants which are also known as botanical pesticides are plants or plant parts valued for their medicinal or therapeutic properties, flavor, and/or scent. Such qualities like deterrents, insect antifeedants or repellents are used in controlling insect pest in the field and stores depending on the intended use (Isman 2006). Botanical pesticides are advertised as an alternative to synthetic chemicals because they are safe to the environment (Isman 2006; Gurr *et al.*, 2016; Ndakidemi *et al.,* 2016) and less costly as compared with the synthetic chemicals. Despite many benefits obtained from pesticidal plants, less effort has been done in their conservation due to the fact that they are not considered as a priority in our farming practice systems. As a result, currently, very few farmers benefit services from botanicals due to lack of awareness and the limited knowledge on how botanicals are applied in terms of preparation, frequency, and proper dosage so as to produce the desired effect (Mugisha-Kamatenesi *et al.*, 2008; Mkenda *et al.,* 2015). This is mainly due to limited research in this area (Mugisha-Kamatenesi *et al.,* 2008). This review intends to explore the potential of pesticidal plants and suggests their conservation measures for the future benefits.

Pesticidal plants are touted as attractive alternatives to synthetic insecticides because they reputedly pose little threat to the environment and to human health (Isman, 2006). The application of botanical pesticides in controlling insect pests is not a new idea but it has been in place for centuries (Prakash & Rao, 1996). It was not until the 1980s or 90s when scientist became optimistic that plants can provide effective and environmentally friendly pesticide (Stevenson *et al.*, 2016). Some studies have been done in Africa on the application of botanical pesticide based on the extracts from the locally available pesticidal plants, including *Lantana camara, Tephrosia vogelii, Lippia javanica, Vernonia amygdalina* and *Tithonia diversifolia* (Isman, 2008; Mkindi *et al.*, 2017).

This study aims at exploring the possibility of extending the uses of these plants as border plants or intercropped to attract beneficial insect-like bees, butterflies, hoverflies which are pollinators and repellent of crop pest like blister beetles, aphid, and Ootheca at the same time protecting the environment by adding up organic nutrients.

According to Isman (2015), there is a growing demand of application of botanical pesticides in controlling insect pests in the first world countries. Paradoxically, however, in Sub-Saharan Africa (SSA), it is surprising to see only a few farmers applying botanical pesticides as compared with synthetic pesticides. This can be mainly due to lack of knowledge of its efficiency and effectiveness as compared to the existing synthetic pesticides in use. Another reason for less use of botanical pesticides by farmers is lack of their evaluation under realistic field conditions to assess their efficacy as well as their benefits to farmers (Mkindi *et al.,* 2017). Also in SSA particularly in Tanzania, farmers use other products such as cow's urine, cow dung, and ashes (Mkindi *et al.*, 2015) as an alternative to synthetic pesticides. The additional reason for low uptake of botanical pesticide is attributed to a limited field research (Mugisha-Kamatenesi *et al.,* 2008) which deprives farmers the opportunity to learn and acquire skills on appropriate methods of preparation, required dosage and the frequency of application. Another factor which contribute to the low uptake of botanical pesticide is a scarcity of pesticidal plants among smallholder farmers in SSA due to loss of biodiversity caused by increase in population which put pressure on land clearance for agriculture, settlement, infrastructures, grazing land and lastly due to excessive drought coupled with forest fires that conspire together to deplete the vegetation cover (Gurr *et al.,* 2016; Stevenson *et al.,* 2016). Based on the gravity of the entire situation, the author hereby provides this review article to discuss the significance and the potential of the pesticidal plants so as to raise awareness and encourage their conservation as a way of improving crop yield and farmers wellbeing while conserving the environment.

Experience shows that there is a trend of most farmers to rely on external inputs such as chemical fertilizers, pesticides, and herbicides, which is motivated by the high yield. The use of these synthetic inputs in pest control has been considered as cheap due to the fact that the indirect costs associated with their use such as environmental pollution, the death of non-target organisms, health problems and interference with ecosystem services are not taken into account (Pimentel, 2005). Such unrealistic approach towards the side effects of synthetic pesticides escalates their use despite the fact that they are relatively expensive, detrimental to health and entire ecosystem and worse still scarcely available. Uses of pesticidal plants will offset the use of farmers' practices that contaminate the environment and reduces the risk of toxic substances that enter the food chain.

The way forward to avoid or minimize the use of synthetic pesticides in agricultural settings is through the conservation of biodiversity, including known pesticidal plants such as *Lantana camara, Tephrosia vogelii, Lippia javanica, Vernonia amygdalina* and *Tithonia diversifolia* etc. This will provide a good scene for ecosystem productivity provided by the vital contribution vested on these individual species and thus ensure the protection of other natural resources such as natural enemies which may be used for insect pest control. To ensure sustainability in crop production, there is a need to identify and promote management of these pesticidal plants.

This review aims at exploring the existing knowledge and information on pesticidal plants in crop production and their respective role in supporting beneficial insects so that proper conservation measures of the pesticidal plants can be taken into account to harnessing the benefit they provide.

Ecosystem Services accrued from pesticidal plants

Ecosystem services refer to the conditions and processes through which natural ecosystems and the species that make them up (flora and fauna), sustain and fulfill human life. The ecosystem services are summarized in four main groups, namely, provisioning, regulating, supporting and cultural (Assessment, 2005; Power, 2010; Ndakidemi *et al.*, 2016).

Pesticidal plants provide provisional services like forage, timber, biomass fuel, natural fiber, and pharmaceuticals (Postel, *et al.,* 2012; Sánchez, *et al.*, 2017). Another service offered by pesticidal plants is regulating services which include partial stabilization of climate and control of disease, purification of water and air, generation and renewal of soil and soil fertility, mitigation of floods and drought, detoxification, and decomposition of wastes (Postel, *et al.,* 2012; Furlong, 2016), water quantity and quality assurance, buffers the movement of pollutants from land to the nearby water bodies, facilitates the movement of nutrients and water by regulating the speed of surface water flow and nutrient particles, flood control, carbon storage and waste treatment (Marshall & Moonen, 2002)

Pesticidal plants also offers supporting services like insect pest control, support to natural enemies, windbreak, erosion control, nutrient recycling, pollination and organic matter in the soil support biodiversity and enhance carbon sequestration, maintenance of biodiversity, pollination of crops (Tscharntke, *et al.*, 2005; Power, 2010; Postel, *et al.,* 2012), shelter for stock in adverse weather, windbreaker, insect harbourage, serves as the refuge for many wildlife species and provides support to a variety of invertebrates (Marshall & Moonen, 2002) including beneficial insects.

Beneficial insects are grouped into: natural enemies and pollinators which provide natural ecosystem services such as biological control of pests and pollination of plants (Altieri, 1999). According to Aquilino *et al.* (2005) and Martin *et al.* (2013) as cited by Mkenda *et al* (2017), in the field of agriculture, the term natural enemies refer to organisms that attack and feed on other organisms, particularly on insect pests of plants leading to a type of pest regulation referred to as natural pest control or biological control. Natural enemies are a diverse group of organisms that include predators, parasitic insects (parasitoids), nematodes and microorganisms (Ndakidemi *et al.*, 2016).

The predators feed on the harmful insect pets while the parasitoids lay eggs in or on the bad insect pest (Russell & Arbor, 1989) which upon hatching the larvae from parasitic insects eat up the insect pest. The understanding of the suitable environment for the beneficial insects' and the manipulation of their habitat accordingly, is the best way that will favor these insects in the field (Mkenda, *et al.,* 2017).

There are several natural enemies of crop insect pests such as tachinid flies, ground beetles, wasps, spiders, and ladybugs (Mack, 2007) to mention but a few.

These control insect pests such as bean pod weevil (Apion), bruchid seed weevils, leafhopper, thrips, bean fly (bean stem maggot), and whitefly (Miklas *et al.,* 2006; Mkenda *et al.,* 2014).

A well-established pesticidal plantation offers cultural services like spiritual and recreational benefits, stimulate tourism through improved aesthetic values (Gurr *et al.,* 2016) used for educational purposes, as well as for traditional use whereby agricultural places or products are often used in traditional rituals and customs that bond human communities (Power, 2010). The services are summarized in Table 1.

Table 1. Pesticidal plants in supporting ecosystem services.

Pesticidal Plant	Plant part used	Potential function/service provided	Reference
	- dry leaves extracts	- repellent of pest such as Coleoptera: Curculionidae	Nel, 2015; Ogendo, *et al.,* 2003)
	-Flowers	-Promote pollinators in *Mangifera indica*	Nel, 2015
	-Chloroform extract of dry *Lantana camara*	- repellent, antifeedant and toxicity against termites	Boeke *et al.,* 2004
Lantana camara	'Mozelle' leaves termite	- Control of eastern subterranean termite	Yuan & Hu 2012
	-Aerial parts of *Lantana camara*	-Insecticidal, antiovipositional and antifeedant activity *against Callosobruchus chinensis*	Yuan & Hu 2012
Tithonia diversifolia	-Leaves	- Repellent in Mosquito, Aquatic leeches, and mites	De Boer *et al.,* 2010
	Leaves extracts	-Repellent of Coleoptera: Curculionidae	Nel, 2015
Tephrosia vogelii		Control of insect pest of stored cowpea, (*Callosobruchus maculatus*)	Boeke *et al.,* 2004
	Stem and brunches	-Provides firewood and construction materials	Kwesiga *et al.,* 1999
Lantana Trifolia	Extract of methanol from the leaves	Treatment of bronchoconstriction induced by histamine, 5-HT	Achola & Munenge 1996
Tagetes minuta	Leaves	Repellent in Aphids and bruchid beetle	Kawuki *et al.,* 2005
Azadirachta indica	Leaves,	Feeding deterrent and growth regulator	Mpumi *et al.,* 2016
Nicotiana tabacum	Powder from dry pounded leaves	Control of insect pest of stored cowpea, (*Callosobruchus maculatus*)	Boeke *et al.,* 2004
Ocimum suave	Leaves and succulent stems	A source of repellents, toxicants and protectants in storage against *Sitophilus zeamais* (Mots.), *Rhyzopertha dominica* (Fab.) and *Sitotroga cerealella* (Oliv.) in maize and sorghum	Bekele *et al.,*1996
		- Traditional medicine against stomachache, cough, and influenza	Kamatenesi-Mugisha *et al.,* 2013
Bidens pilosa		-Ornamental purposes, - Used as a folkloric medicine for the treatment of various diseases	Arthur *et al.,* 2012
	Stem and brunches	-Provision of food; leaves and shoots are edible	Hillocks, 1998
Ageratum conyzoides	Leaves	-Treatment: Leaves pounded to treat wounds - Remedy for stomach pains	Hillocks, 1998

The potential of pesticidal plants in crop production

Generally, the ecosystem services provided by pesticidal plants are employed in agriculture whereby they directly or indirectly serve to improve crop production by the use of locally available resources which are friendly to the environment and secure for human health while avoiding or reducing the use of external inputs such as artificial fertilizers and synthetic pesticides. Natural pests control of plant in short-term suppresses pest damage and improves yield, while in the long-term maintains an ecological equilibrium that prevents herbivore insects from reaching pest status and these are provided by generalist and specialist predators and parasitoids, including birds, spiders, ladybugs, mantis, flies, and wasps, as well as entomopathogenic fungi (Zhang *et al.,* 2007). The pesticidal plants offer direct or indirect services to improve yield in crop production through various ways including; supplying organic matter, pollination, nutrient cycling, windbreaks, erosion control, diseases and pests management whose details are highlighted in Table 2.

Table 2. The role of pesticidal plants in crop production.

Pesticidal plant	Role in ecosystem services	Country	Reference
Lantana camara	-Attracts a variety of pollinators	South Africa	Nel, 2015
	-Control of storage crop pests: weevils & potato tuber moth	Ghana	Awafo & Dzisi 2012
	-Support pollination	Tanzania	Mkenda *et al.*, 2015
Tithonia diversifolia	-Support natural enemies and increase bean yield	Tanzania	Mkindi *et al.*,2015; Mkenda *et al.*, 2015 Mpumi *et al.*, 2016
	-Transfer of the nutrient through the accumulating shrub	Kenya, East Africa	Sanchez, 2002
	-Increases P in the soil	SSA	Bationo, 2004
	-Improves soil fertility and increased crop yield	Zambia	Kwesiga *et al.*, 1999
	-Extracts from leaves are used as insecticides	Zambia Tanzania	Kwesiga *et al.*, 1999; Mkenda *et al.*, 2015
Tephrosia vogelii	-Support natural enemies like ladybird beetles and hence increased bean yield	Tanzania	Mkenda *et al.*, (2015); Stevenson *et al.,* 2016; Mpumi *et al.*, 2016
	-Support pollinators	Tanzania	Mkenda *et al.*, 2015; Mkindi *et al.*, 2015
Lantana trifolia	-Pollination: facilitate mango flower visitation during mango flowering (*Mangifera indica*) production on commercial mango farms	South Africa	Nel, 2015
Ocimum suave	A source of repellents, toxicants and protectants in storage against *Sitophilus zeamais* (Mots.), *Rhyzopertha dominica* (Fab.) and *Sitotroga cerealella* (Oliv.) in maize and sorghum	Kenya	Bekele *et al.*,1996
Tagetes minuta	Control of cabbage aphid *Brevicoryne brassica*	Lesotho.	Phoofolo *et al.*, 2013
	Management of plant-parasitic nematodes.	Lesotho.	Krueger *et al.*, 2007
Ageratum conyzoides	-Attract pollinators	Tanzania	Ngongolo *et al.*, 2014
Sesbania sesban	-Improves soil fertility and increased crop yield -Provides firewood and construction materials	Zambia	Kwesiga *et al.*, 1999

The role of pesticidal plants in diseases and pests management

In order to improve yield in crop production, it is important to make sure that plant diseases and pests that affect the crop yield are controlled. The pesticidal plants can be used to offer these ecosystem services in two ways, namely, i) directly as the extract from the pesticidal plants which serve as botanical pesticide or ii) the biological control facilitated by the live plant in the crop field.

i) Pest Control in crop plants using Extracts from Pesticidal Plants

For decades, laboratory investigations have revealed plants with pesticidal effect as the best alternative to synthetics (Mugisha-Kamatenesi *et al.,* 2008). However, these important findings are limited in their efficacy under field conditions (Mkindi *et al.*, 2017), their economic viability and impact on beneficial insects (Mkenda *et al.*, 2015). Studies on the extracts from the botanical pesticides show that the pesticidal plant treatments have the lower impact on the beneficial insects and this allows higher crop yields compared with synthetics pesticides. This is based on the fact that the plant-based pest management approach favors beneficial insects' natural enemies which contribute to the pest control (Stevenson *et al.*, 2016).

Some studies reveal that extracts from pesticidal plants have active ingredients which can be used in agriculture to control pests. According to Mpumi *et al.* (2016), the botanical pesticides are generally pest-specific, relatively harmless to non-target organisms (Mkindi *et al.*, 2015) including man and natural enemies of insect pests, environmentally friendly, degrade rapidly(less persistence) in sunlight, air, and moisture, rapid in action to the insect pests, harmless to plant growth, seed viability and cooking quality of the grains and are less expensive and easily available in the farmers natural environment.

The study by Mkenda *et al.*, (2015) as reported by Stevenson *et al.* (2016) shows that there was higher yield of common beans when using water-based extracts of *Tephrosia vogelii* or *Tithonia diversifolia*, compared with the synthetic (Karate - lambda-cyhalothrin) suggesting that plant extract has less effect to beneficial insect which plays a great role in crop yield. For example, leaves and stem ethanol and aqueous extracts of *Lantana camara* (Verbenaceae), *Ocimum basilcum* (Lamiaceae), *Lupinus termis* (Leguminaceae), *Solenostemma argel* (Asclepiadaceae) and *Nicotiana rustica* (Solanaceae) are reported to control the field pests of tomato, African bollworm *Helicoverpa armigera* Hubner as elucidated by the mortality, repellency and antifeedant effects on *Helicoverpa armigera* larvae (Mohamed, 2015). Plant extracts have been used in controlling insect pests. For example, *Tephrosia vogelii*, *Azadirachta indica*, *Annona squamosa*, chill paper (*Capsicum* sp.), *Allium sativa* have been used successfully in controlling insect pests in common beans and cowpea (Koona & Dorn, 2005; Mwanauta *et al.*, 2015). The value of pesticidal plants comes from the harnessing of plant defense strategies based on the production of chemicals that are repellent or toxic to specific pests or a wide range of organisms that are destructive to crops (Madzimure *et al.*, 2011).

According to Mpumi *et al.* (2016), the botanical pesticides effect their toxicity in different ways; *T. vogelii* has the oral lethal dose to mammals and in the insects it limits the cellular energy production while Azadirachtin is antifeedant and growth disruptor of insects; whereas Pyrethrins are axonic poisons and have repellent effects to insects. And Sesquiterpenes lactones from *T. diversifolia,* Pentacyclic triterpenoids from *Lantana camara*, Vernodalin, Vernodalol and Epivernodalol from *V. amygdalina* have repellent and feeding deterrents chemicals which discourage the insects from feeding the crop (Mpumi *et al.,* 2016). The study by Mkenda *et al.* (2015) reported that extracts made from four abundant weed species found in northern Tanzania, *Tithonia diversifolia, Tephrosia vogelii, Vernonia amygdalina* and *Lippia javanica* offered effective control of key pest species on common bean plants (*Phaseolus vulgaris*) that was comparable with the pyrethroid synthetic - Karate. Likewise, according to Mkindi *et al.* (2017), extracts made from six abundant weed species found across sub-Saharan.

Africa (Tanzania and Malawi), namely, *Bidens pilosa, Lantana camara, Lippia javanica, Tithonia diversifolia, Tephrosia vogelii* and *Vernonia amygdalina*, were evaluated in the station and field trials on common bean plants (*Phaseolus vulgaris*) and all plant species offered effective control of key pest species that was comparable in terms of harvested bean yield to a synthetic pyrethroid.

Tithonia diversifolia and *Lantana camara*, have been found to have insect feeding deterrent characteristics to insect pests (Mpumi *et al.,* 2016) which makes them good in controlling insect pests in the field thus increasing crop yield and serves as an alternative to synthetic pesticides (Mpumi *et al.,* 2016). Despite the efficacy that has been reported on the use of extracts from pesticidal plants in controlling insect pest, still there is a limited knowledge among smallholder farmers in SSA about the logistics of preparation and application and on identification of pesticidal plants of such properties in the field margin or weeds in the crop field that can be used to serve the same purpose. Thus there is a need to do more research in order to determine more plants with pesticidal properties and involve farmers in the entire process of preparation and application of extracts from pesticidal plants for better results.

ii) Biological Pest Control

Biological control is an intentional introduction of an exotic, usually coevolved, biological control agent known as a natural enemy for the permanent establishment and long-term control of crop pests (Mkenda *et al.*, 2014). According to Landis *et al.* (2000), pesticidal plants which are intercropped within the field or planted as field margin plants may serve as a source of food and habitat to natural crop pests' enemies and this is considered among the best options towards increasing ecosystem services and biodiversity conservation.

Unlike animals that can fight or flight in case of dangers, plants are immobile and thus use a biological mechanism to protect themselves against enemies. Plants do so by secreting some chemical compounds called exudes which deter/repel the insect pests which come to feed or nest in them. Farmers utilize their knowledge on this ecosystem relationship to control insect pest in the field and storage units (Stevenson *et al.*, 2016). Literatures reveal that in their natural stand the pesticidal plants can be effective in controlling insect pest in crop production through different ways including providing the natural enemies with resources such as nectar, pollen, physical refuge, alternative prey, alternative hosts and hiding sites (Gurr *et al.*, 2016) as well as ensuring pest control (Dainese *et al.,* 2017) and ultimately improved crop yield.

Additionally, diversified ecosystem contributes to weed control, disease and pests control and increased pollination services (Kremen & Miles, 2012; Gurr *et al.*, 2016; Ndakidemi *et al.*, 2016). In a nutshell as pointed out by Zhang *et al.* (2007) farm biodiversity which includes pesticidal plants supports ecosystem function and provides services such as biological pest control and nutrient cycling that potentially reduce reliance on synthetic inputs, unlike conventional agricultural systems. This still requires further investigation on how best the environment especially plant biodiversity can be manipulated to favor more beneficial insects. The complexity of landscape increases the availability of food sources and habitat for insects ensuring the diversity and abundance of natural enemy population and with enhanced pest control (Zhang *et al.,* 2007). Studies suggest that insect predators and parasitoids account for approximately 33 percent of natural pest control (Power, 2010) and that habitat with species abundance (biodiversity) provides a favorable environment for beneficial insect (Gurr *et al.,* 2016), which play a great role in agriculture to ensure increased crop yield. Additionally, non-crop habitat provides predators and parasitoids with well-diversified habitat where beneficial insects mate, reproduce, and overwinter and also with a variety of plant resources such as nectar, pollen, sap, or seeds as alternative food sources to fuel adult flight and reproduction (Zhang *et al.,* 2007).

Gurr *et al.* (2016) pointed out that simple diversification like promoting the growth of flowering plants can contribute to the ecological intensification of agricultural system by encouraging the natural enemies of some key pests of crops by ensuring the availability of nectar, pollen, fruits, and insects, which is food for natural enemies (parasitoids and predators) and thus support existence and enhance their diversity (Gurr *et al*, 2004). For instance, the study by Tooker and Hanks (2000) pointed out that parasitoid species were found visiting a limited range of host plants, which may have implications for conservation biological control and conservation biology.

Most of the predators and parasitoids such as hoverflies, predatory bugs, lady beetles, lacewings, predatory wasps, and predatory flies feed on nectar or pollen and in so doing they play a secondary beneficial role of pollinating the flowers (Kremen *et al.*, 2007; Ndakidemi *et al.,* 2016). There is a need to liaise with policymakers and entrepreneurs without neglecting the scientific guidance to diversify the non-food agricultural production with as many pesticidal species as possible which would provide farmers with the best alternative to synthetics pesticides (Stevenson *et al.,* 2016). To achieve this, we need to understand the ecology of these natural enemies specifically the kind of environment that favors them. Therefore, there is a need to do research to explore how best the established pesticidal plants within the fields or along the field margins can contribute to the biological management of insect pests in the crop fields.

Water quantity, quality and Erosion control

A farming system which is well-diversified, to a great extent support ecosystems services such as greater biodiversity, soil quality, carbon sequestration, and water-holding capacity in surface soils, energy-use efficiency, and resistance and resilience to climate change (Kremen & Miles, 2012) as well as controlled soil erosion. In Sub-Saharan Africa (SSA) farmers use pesticidal plants intercropped or planted as field margin and these ensure the ecosystem services such as water retention capacity of the soil and reduced or controlled soil erosion. The farmer also uses pruned the branches of the pesticidal plants for mulching which avoid direct sunshine and raindrops on the soil thus improving soil moisture and reduced erosion rate as well as controlling weeds. All these contribute to improved crop production. The pesticidal plants serve as soil cover that holds the soil intact and ensures improved soil structure and texture for better crop production. Forest soils or a land established with vegetation tend to have a higher infiltration rate than other soils, with reduced peak flows and floods.

The interception of rainwater by plant canopy reduces the runoff speed and increase water holding the capacity of the soil and thus retain soil fertility and thus improved crop yield. Also, the deep rooting species of pesticidal plants improve the availability of both water and nutrients to other species in the ecosystem reducing the rate of soil erosion and resulting in good water quality (Power, 2010). The plant canopy facilitates the regulated capture, infiltration, retention, and flow of water across the landscape, retaining soil, modifying soil structure and producing the litter.

A slight reinforcement of pesticidal plant with forest nature may provide a wide range of goods and services to society, such as water purification, hydrologic regulation, pollination services, control of pest and pathogen populations, diverse food and fuel products, and greater resilience to climate change and extreme disturbances, reduced erosion rate while at the same time improving the sustainability of food production (Asbjornsen *et al.,* 2014). Therefore, there is a need to do research to find out more plants with pesticidal properties which are also good in preserving water sources and enhancing the availability of enough and quality water as well as reduced soil erosion with improved crop production.

Windbreaks

Strong winds are very destructive in crop production as they can cause a physical damage to crops or plants, such as destruction of flower buds, loss of fruits at a tender age as well as the spread of diseases which ultimately can substantially affect crop yield. When pesticidal plants are applied as windbreak plants, they may provide substantial benefits in the production of crops through different ways such as in the creation of microclimate within the crop field, improving conditions for pollination and fruit set through reduced wind speed thus reducing tree deformation and root breakage in young fruit trees, the amount of mechanical damage caused by the whipping of leaves, branches, buds, flowers and fruits which ultimately improves fruit quality and results in substantial economic gain spearheaded by greater yields (Norton, 1988).

Also, botanical pesticides planted as windbreak interrupt or slow down air fluxes and the propagules they carry (Burel, 1996). Reduced wind speed allows for timely application and efficient use of pesticide, enhanced water management is by enabling efficient water distribution and reduced evaporation and aid in frost management (Norton, 1988) extremely cold regions. It is a common practice among smallholder farmers in SSA to use pesticidal plants to serve as windbreak also enhancing their pesticidal properties in pest control through deterrence, repellence, antifeedant or direct killing.

The pesticidal plants which offer such ecosystem services include *Tithonia diversifolia* and *Lantana camara* which are planted along the field margin to serve as windbreaker and at the same time their extracts are used in controlling the pest of stored cowpea *Callosobruchus maculatus* and antifeedant activity against *Callosobruchus chinensis* respectively (Boeke *et al.,* 2004; De Boer *et al.,* 2010; Nel, 2015; Yuan & Hu 2012). Other plants like *Tephrosia vogelii* are intercropped with crop plant to serve as a windbreaker as well as to facilitate nitrogen fixation (Wang *et al.,* 2011) and control insect pest of crops like beans in the store and in the field (Mihale *et al.*, 2009). Also, *Azadirachta indica* planted along the margin of the crop field acts as the windbreaker as well as pest control through feeding deterrent and growth regulator (Akunne *et al.,* 2014; Mpumi *et al.*, 2016).

Generally, windbreak (field shelterbelts) ultimately increase yields of a field and forage crops throughout the world due to reduced wind erosion, improved microclimate, snow retention and reduced crop damage by high wind (Kort,1988). Planting pesticidal plant as field margin or intercropped can provide a solution to different problems encountered by farmers in SSA. There is a limited knowledge among the farmers on how best they can make use of pesticidal plants and harness enormous ecosystem service they provide. Therefore, there is a need to do research to discover more plant species which can play double roles or even more like windbreak, pest control and improvement of soil fertility as the best way to protect the environment and ecosystem at large as well as increasing crop yield.

Nutrient cycling

Pesticidal plants contribute to the nutrient cycling directly through nitrogen fixation particularly of leguminous plant-mediated by nitrogen-fixing bacterial also enrich the soil with nutrient when they are buried into the soil as plant organic matter and subjected to the decomposers all of which improve soil fertility and increase crop yield. Apart from production of food in agro-ecosystems, biodiversity performs a variety of ecological services including, recycling of nutrients, regulation of microclimate and local hydrological processes, suppression of undesirable organisms and detoxification of noxious chemicals (Altieri, 1999). Biological diversification across ecological, spatial, and temporal scales maintains and regenerates the ecosystem services that provide critical inputs such as maintenance of soil quality, nitrogen fixation, pollination, and pest control to agriculture (Kremen & Miles, 2012). A well-diversified habitat will favor insects like beetles which dung burial (Zhang *et al.*, 2007) thereby facilitating the recycling of nutrients. Plants/pesticidal plants also when they die they are subjected to decomposers and thus ensuring the recycling of nutrients (Cotrufo *et al.*, 2013).

Microorganisms like bacteria, fungi and actinomycetes are critical mediators of ecosystem service that maintain soil fertility through nutrient cycling by which bacteria enhance nitrogen availability through the fixation of nitrogen from the atmosphere facilitated by plants that have symbiotic relationships with N-fixing bacteria such as Tephrosia *vogelii* (Munthali *et al.*, 2014), and *Acacia* spp. (Brockwell *et al.*, 2005) thereby ensuring nutrient cycling. *Acacia catechu* seeds/barks. (Khatun *et al.,* 2011) and *Tephrosia vogelii* also have pesticidal properties which are useful in pest control in field and store (Mihale *et al.*, 2009).

Studies in western Kenya indicate that the incorporation of higher quality organic manures, like *Tithonia diversifolia* and *Lantana camara*, along with TSP (Triple Superphosphate) increases the effectiveness of fertilizer phosphorus (Bationo, 2004).

It is reported that green leaf biomass of *Tithonia diversifolia* is high in nutrients and has high concentrations of nitrogen (N), phosphorus (P) and potassium (K) which are rapidly released in plant-available forms during decomposition (Jama *et al.*, 2000; George *et al.*, 2001). Studies reveal that the P concentration of tithonia leaves is greater than the critical 2.5g kg^{-1} threshold for net P mineralization meaning the addition of biomass to soil results in net mineralization rather than immobilization of P (George *et al.*, 2001). According to Jama *et al.* (2000), the biomass of *Tithonia diversifolia* decomposes rapidly when they are incorporated into the soil, and become the effective source of N, P and K for crops averaging about 3.5% N, 0.37% P and 4.1% K on a dry matter basis while the boundary hedges of sole tithonia can produce about 1kg biomass (tender stems + leaves) $m^{-1}yr^{-1}$ on a dry weight basis.

Therefore, pesticidal plants not only that they play the essential role in nutrient cycling to improve soil fertility but also they are important in controlling insect pest and harbor natural enemies. There is a limited knowledge among the smallholder farmers in SSA on the multiple roles of pesticidal plants which can be exploited to improve crop production in agriculture. Therefore, there is a need to conduct research to identify plants of qualities such as pest control and nutrient cycling to be used in boosting crop production and increase income for the smallholder farmers.

Crop Pollination

Pesticidal plants when intercropped or planted as field margins through their flowers attract pollinators and provide them with forage, pollen, and nectar and in the process, the pollinators also visit the food crop to facilitate their pollination the process which improves crop yield. For example, a bean field with a variety of local, native flora will attract a good diversity of local, beneficial arthropods and also will offer natural hiding sites and flowering resources for many beneficial insects (Altieri, 1999).

Different pesticidal plants are reported to attract different pollinators. For example, *Lantana camara* attracts pollinators like the butterfly (Barrows,1976). Floral color is said to influence flower selection by butterflies while floral scents provoke behavioral responses that initiate and maintain foraging on flowers (Andersson & Dobson, 2003). The study made in Australia reported that the main pollinator of L. camara was the honeybee, *Apis mellifera* and that seed set in *L.cmara* was strongly correlated with honeybee abundance (Goulson & Derwent, 2004). Other pesticidal plants like Mexican sunflower (*Tithonia diversifolia*) produce nectar with abundant phenolics, including three components of the *Apis* honeybee queen mandibular pheromone and that by mimicking the honey bee pheromone blend, nectar may maintain pollinator attraction (Liu *et al.*, 2015). *Tephrosia vogelii*, on the other hand, was observed to be primarily a self-pollinated species but requires an insect to trip the flowers and *Xylocopa brasilianorum* is reported to be the primary insect pollinator (Barnes,1970).

Crop pollination is the best-known ecosystem service performed by insects (Zhang *et al.*, 2007). The production of over 75% of the world's most important crops that feed humanity (Power, 2010; Zhang *et al.*, 2007) and 35% (Zhang *et al.*, 2007) or 65% (Power, 2010) of the food produced are dependent upon animal pollination. Though bees comprise the dominant taxa providing crop pollination services; birds, bats, moths, flies and other insects can also be important and it is reported that conserving wild pollinators in habitats adjacent to agriculture improves both the level and stability of pollination, leading to increased crop production and good income (Zhang *et al.*, 2007). Pesticidal plants established in the agricultural landscapes create natural habitats that attract both wild pollinators and domesticated honey bees thus ensuring pollination as one of very important ecosystem services. It is reported that a complete loss of pollinators would cause global deficits in fruits, vegetables and stimulants and such declines in production could result in significant market disruptions as well as nutrient deficiencies (Power, 2010).

Therefore, it is important to intercrop or to plant the pesticidal plants especially the flowering plants as field margin plants to ensure better ecosystem services from beneficial arthropods for the increased crop production.

Pesticidal flowering plants which are intercropped or planted as field margin support both pollinators and natural enemies of insects' pest in terms of nectar/food, and habitat. They also play the essential role in insect pest control. Unfortunately, there is a limited knowledge among the farmers on a variety of pesticidal plants which can be used to play such multiple roles. Therefore there is a need to do more research to discover a different variety of plants which can serve in controlling insect pest as well as supporting the pollinators in order to increase crop production and improve the living standard of people.

Organic matter for improved soil fertility

Soil color and productivity are mainly associated with the organic matter chiefly derived from decaying plant materials. The decomposition and transformation of above- and below-ground plant detritus (litter) is the main process by which soil organic matter (SOM) is formed (Cotrufo *et al.*, 2013). Thus plants in general and pesticidal plants, in particular, play a great role to ensure organic matter availability in the soil. Smallholder farmers in SSA enrich the soil with organic matter through their common practice of cutting border plants and incorporate them into the soil (George *et al.*, 2001). The activities of bacteria, fungi and macro-fauna, such as earthworms, termites and other invertebrates are vital to ensure soil pore structure, soil aggregation and decomposition of organic matter resulting to a well-aerated soils with abundant organic matter which are essential for nutrient acquisition by crops, as well as water retention (Turbé *et al.*, 2010; Power, 2010; Bagyaraj *et al.*, 2016).

Micro-organisms mediate nutrient availability through decomposition of detritus and plant residues and through nitrogen fixation (Power, 2010). Earthworms, macro- and micro-invertebrates increase soil structure via burrows or casts and enhance soil fertility through partial digestion and combination of soil organic matter (Zhang *et al.*, 2007).

Pesticidal shrubs and trees, such as *Lantana camara*, *Tephrosia vogelii, and Tithonia diversifolia* are common on smallholder's farms in Eastern, Central and Southern Africa (ECSA) (Lunze *et al.*, 2012) as sources of soil organic matter. *Tithonia diversifolia* for example has been studied in different countries including Rwanda, Kenya, Tanzania and DR Congo for its integration into bean-based production systems through the practice known as *Tithonia* biomass transfer that has led to a considerable bean yield increase by 227% in Rwanda and 68% in DR Congo (Lunze *et al.*, 2012; Hafifah *et al.*, 2016). *Tithonia diversifolia* is reported to have very high shoot vigor which is estimated to produce in nine-month a high nutrient concentrations biomass for transfer to fields at 2t ha^{-1}kg of dry matter (Jama *et al.*, 2000; Lunze *et al.*, 2012).

Lantana leaves when used as mulch mixed with oak and pine leaves adds organic carbon, phosphorus, NO^{3-}N, NH^{4}-N and N-mineralization in the soil and thus may be applied for crop yield improvement and sustainable soil fertility management (Kumar *et al.*, 2009). Also, the study done in Ethiopia reported *Lantana camara* biomass as essential in supplementing chemical fertilizer besides adding organic matter to the soil (Rameshwar & Argaw, 2016).

Studies reveal that the *Tephrosia* fallow biomass decompose considerably faster attaining their half-life within 2–3 weeks and over 95% within 8–25 weeks but when mixed with a low-quality farm residues decomposition was slowed down and thus *Tephrosia* fallow biomass is proposed to be used for short-term correction of soil fertility (Munthali *et al.*, 2013).

The study by Ndakidemi, (2015) in in Western Usambara Mountains in northern Tanzania revealed that the locally available nutrients sources such as organic materials prunned from Tughutu (*Vernonia subligera* O. Hoffn) and Minjingu phosphate rock fertilizers when mixed in ratio of 2.5 t dry matter ha^{-1} and 26 kg P ha^{-1} improves P concentration in the tissue of bean plants and their seed yield. It is reported that the application of Tughutu alone, Minjingu phosphate rock (MPR) or triple superphosphate (TSP) alone and Tughutu combined with 26kg P ha−1 of MPR or TSP relative to the control increased seed yield of common bean by 53%, 28%-104% and 148%-219% respectively and therefore this can be taken as an appropriate integrated nutrient management strategy that may increase bean yields and dollar profit to the rural poor communities in Tanzania (Ndakidemi, 2007)

Thus, given the importance of organic matter in crop production, smallholder farmers in SSA should be adviced to develop a common practice of planting the pesticidal plants which will serve as the main source of organic matter in the soil and thus increase their income through improved crop production. Therefore, there is a need to conduct a research to find out different pesticidal plants that are are rich in nutrients and easily decomposable so as to ensure a constant supply of organic matter and improve soil fertility for better crop yield.

Ecosystem Services Tradeoff in Crop Production

Pesticide use in agricultural production conveys the benefit of reducing losses due to pests and disease (Pretty, 2012). Management practices in agro-ecosystems to ensure that the ecosystem services are accrued also influence the potential for "disservices" from agriculture, including loss of habitat for beneficial wildlife, water pollution, pesticide poisoning of biological species (Zhang *et al.*, 2007; Ferrarini, 2016). Due to incompetence and the notion that synthetic chemicals are cheap, efficient (Epstein 2014) and beneficial, farmers have failed to monitor and control the pests at the most appropriate time (Lekei *et al.*, 2014; Mkenda *et al.,* 2017) instead they have prescribes schedules for pesticide application of which only 0.1% meet the target organism, the rest getting lost to the environment and non-target species (Tello & Sánchez 2013; Gurr *et al.*, 2016). The environmental and health hazards like chronic illness, environmental pollution, killing of non-target organisms, pesticide resistance in pests, ground and surface water contamination (Pimentel, 2005; Rahaman and Prodhan, 2007; Mkenda *et al.*, 2014; Gurr *et al.*, 2016; Peralta & Palma, 2017; Jallow, *et al.*, 2017) and loss of natural vegetation and biodiversity (Morton, 2007) associated with the use of synthetic chemicals (Pimentel, 2005) disqualifies the expected benefits of the use of the synthetic chemicals (Jaganathan *et al.,* 2008).

Botanical pesticides are attractive alternatives to synthetic pesticides due to fact that they are more sustainable (Mwanauta *et al.*, 2015), cheap, easy to prepare, short lifespan in the ecosystem, have more than one active ingredient which work synergistically making it difficult for pests to develop resistance (Mkenda & Ndakidemi 2014). Despite the ecosystem services accrued, while ministering botanical pesticides there are disservices involved including loss of vegetation cover while using plant extracts (Geiger *et al.*, 2010; Garbach *et al.*, 2014), mortality of some beneficial insects (Maia & Moore, 2011; Ndakidemi *et al.*, 2016) reduced ability of natural enemies to utilize prey (Van de Veire & Tirry 2003; Ndakidemi *et al.*, 2016). These operational challenges show that there is a need to look for alternative options which will eradicate or minimize the use of synthetic chemicals and maximize the use of pesticidal plants with minimum or no dicevices at all. This can be achieved by minimizing or supplementing plant extract by planting more pesticidal plants through intercropping or growing them as border plants and harness the ecosystem services such as conservation of biodiversity, insect pest control, nesting sites for beneficial insects as well as the provision of nectar to the pollinators.

Conclusion and recommendation

Pesticidal plants are necessary for agro-ecosystems services such as provision of the habitat and food for natural enemies of agricultural pests and pollinators and hence increase yields of field and forage crops throughout the world due to reduced wind erosion, improved microclimate, and reduced crop damage by high wind, facilitate nutrient cycling, pollination services, favorable habitat for natural enemies all combined together to improve crop yield and hence economic gain.

Thus the use of the pesticidal plants within the farming systems accrue these benefits as well as protecting the environment and ensuring safe food products resulting from the minimum or no use of the synthetic pesticide which otherwise contaminates food product and kill the untargeted organisms including man. Plant extracts from pesticidal plants are used in controlling of crop pest. This review, therefore, recommends to explore the possibility of additional use of the pesticidal plants in the field as live stand in the field margin or intercropped in terms of effective insect pest control, support to natural enemies through harborage, forage, and nectar as well as the provision of alternative prey or host for effective management of field crops.

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