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Effect of insect pollinators and natural enemies on common bean (phaseolus vulgaris l.) growth and yield in Arusha, Tanzania

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NM-AIST

EFFECT OF INSECT POLLINATORS AND NATURAL ENEMIES ON COMMON BEAN (*Phaseolus vulgaris* L.) GROWTH AND YIELD IN ARUSHA, TANZANIA

Martin Gerald Mkindi

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master's in Life Science of the Nelson Mandela African Institution of Science and Technology Arusha, Tanzania

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ABSTRACT

This study examined the potential of pollination from stingless bees in common beans, the effects of natural enemies on aphid infestation in common bean plants and the effect of natural enemies on growth, yields and yield components of common beans. Common beans of Lyamungo 90 variety were used as a test crop under natural rain fed condition throughout the growing season in a randomized block design experiment that had seven treatments replicated four times. Normal agronomic practices such as tilling, planting and weeding, coupled with the introduction of stingless bees and ladybird beetles in the pollination and pest control activities were employed. Analysis of Variance was used to determine mean aphid incidence/severity and LSD was used to separate means at p=0.05 level of probability. Results showed that there was a significant increment of pods per plant (6.278), seed per pods (3.011) and total yield per hectare (2164.328) in stingless bee pollination cages and significant aphid control by the action of ladybird beetles. This study calls for enhancements of research on ecosystem services under natural field contexts in order to obtain enough data to support adoption of the interventions to especially small scale farming communities in developing countries.

DECLARATION

I, **MARTIN GERALD MKINDI** do hereby declare to the Senate of the 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.

19-12-2017

Martin G. Mkindi | **Date**

Name and signature of candidate

The above declaration is confirmed

19/12/2017

Prof. Patrick A. Ndakidemi | **Date**

Name and signature of supervisor 1

19/12/2017

Dr. Ernest R. Mbega | **Date**

Name and signature of supervisor 2

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CERTIFICATION

This is to certify that the accompanying dissertation by MARTIN GERALD MKINDI has been accepted in partial fulfilment of the requirements for the Degree of Master's in Life science of the Nelson Mandela African Institution of Science and Technology Arusha, Tanzania.

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Prof. Patrick A. Ndakidemi **Date**

Name and signature of supervisor 1

________________________ 19/12/2017

Dr. Ernest R. Mbega 2 **Date**

Name and signature of supervisor 2

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DEDICATION

This dissertation is dedicated to my wife, Elizabeth and our children, Rickson and Nickson for their moral support and prayers towards successful completion of my studies. I love you dearly and I pray that God blesses each of you.

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LIST OF ABBREVIATIONS

UK	United Kingdom
ARI	Agriculture research institute
APLB	Aphids and Ladybirds
AP	Aphids
B’n’B	Bees ‘n Beans

CHAPTER ONE

INTRODUCTION

1.1 Background information

Beneficial insects are understood to contribute to crop yields worldwide (Kasina, 2007; Belmain *et al.,* 2013; Bishop *et al.,* 2016; Ndakidemi *et al.*, 2016). However, the beneficial insects provide pollination and biological insect control services for yield maximization in crops (Rasul, 2009; Power, 2010; Bartomeus *et al.,* 2014a). Even though some crops are self-pollinated like common beans but also they benefit from these services (The African Pollinators Initiative, 2007; Tobergte and Curtis, 2013). Attention is needed on the preservation of these vital organisms for their survival based on the fact that they are prone to environmental destruction (Kughur and Audu, 2015; Kovács-Hostyánszki *et al.,* 2017). Bee species have been documented to contribute to pollination services (Nunes-Silva *et al.,* 2013; Abou-Shaara, 2014). Stingless bees are more important in common bean pollination because of their ability to penetrate easily their mandible to reach the pollen than other species of bees (Slaa *et al.,* 2006). Many other insects are pollinators at the adult stage. On the other hand, insect pest control presents an ecological service provided through predation, parasitoids, and pathogenesis. Mechanisms of the natural enemies are perceived to benefit farmers by reducing pest control and yield improvement with low costs although many farmers do not easily notice that. Understanding these organisms, therefore, is one step to conservation for the future benefit of their services. Reducing insect pest to an acceptable level can easily be done through the use of another insect like predator, parasitoids, and pathogens.

Beans are one of the most important protein sources despite their less production quantitatively compared with carbohydrate crops which are most available (Broughton *et al.,* 2003). It provides essential elements required by the body and fit for every age (from child to adult stages) (Winham *et al.,* 2008). It is also reported that eating dry beans regularly help to reduce risks of abnormal hyperglycemia and hyperinsulinemia (type 2 diabetes), excessive body weight, excessive blood cholesterol, and cancers of the colon and rectum, breast, and prostate (Siddiq *et al.,* 2012). Constituents of beans that are important to health and nutrition include protein, complex carbohydrate, fibre and essential vitamins and minerals to the diet, yet are low in fat and sodium and contain no cholesterol (Geil and Anderson, 1994).

The importance of beans is also extended to its ability in converting atmospheric nitrogen into a form that is available and useful for plants growth thus serving as an important source of plants nutrition (Jensen *et al.,* 2012).

Beans have been observed to contribute to high yield of maize when intercropped (Mucheru Muna *et al.,* 2010). In Africa, common beans are regarded as a reliable source of income to low and medium scale farming society based its resilience against climate change stresses. It also takes shorter time from planting to mature, an advantage against effects of climate change.

Common bean growers, however, face insect pests as a great challenge in production. Insect pests have been reported to affect to a large extent, yield and quality in fields and during harvesting. As an effort against it, pesticides have been employed to minimize or eradicate possible pests. Many of the chemical formulation of the pesticides are proven harmful to groups of insects both harmful and beneficial to the environment (Johnson *et al.,* 2010; Wu *et al.,* 2011). Synthetic pesticides are also reported to be a less friendly economically to small scale African farmers. As a solution, plant based formulation have been used and proven effective against insect pests and also favoring the presence of predators and natural enemies of insect pests (Mkenda, 2015). Another promising option is insect pests control using pollinators, parasitoids, predators and natural enemies. This technology is undoubtedly an environmental friendly mechanism which enhances ecological balance. However, there is a limited literature on the potential of using pollinators, parasitoids, predators and natural enemies for pest management. This also has caused less awareness of ecological services in production to farmers. This research aimed at studying the effects of insect pollinators and natural enemies on common beans (Phaseolus vulgaris L.) growth and yield.

1.2 Problem statement and Justification

Natural enemies and pollinators are regarded as important through their contribution to the growth and improved yield of crop plants including common beans. Literatures report that bean pollination by insect pollinators contributes significantly to increased crop yields (Hoehn and Tscharntke, 2008; Kevan and Phillip, 2001; Lundin *et al.,* 2013; Kennedy *et al.,* 2013; Viana *et al.,* 2013; Garibaldi *et al.,* 2013; Vanbergen, 2013; Viana *et al.,* 2014; Lindström *et al.,* 2016). However, there exists limited information on the role of pollinators and natural enemies in bean production in Tanzania. There is also less scientific data and evidenced conclusions in Tanzania on the contribution of pollinators and natural enemies to growth and bean yield.

This study aims at evaluating the relationship of a) pollinators and b) natural enemies to bean growth yield and yield components.

1.3 significance of the study

This study will deliver data on the contribution of pollinators and natural enemies to beans growth and yield in Tanzania as an ecologically friendly way of improving food security.

The study will also contribute to the provision of cheap affordable and environmentally friendly farming mechanisms to small scale farmers in Tanzania. Again the study will set a basis for future research works on enhancing natural enemies and pollinator and their dynamics in agriculture.

1.4 General objectives

To determine the effects of a) pollinators and b) natural enemies on growth, yield and yield components of beans so that appropriate recommendations on pollinator and natural enemy management can be established for ecological and sustainable bean production in Tanzania

1.5 Specific objective

(ii) To determine effects of pollinators on growth, yields and yield components of beans

(iii) To determine effect of natural enemies on growth, yields and yield components of beans

(iiii) To assess the effect of natural enemies on aphid infestation in bean plants

1.6 Hypothesis.

(i) Null Hypothesis- Natural enemies and pollinators have no effects on aphids infestation, growth, yields and yield components of beans

(ii) Alternative Hypothesis- Natural enemies and pollinators have a positive effect on aphid infestation, bean growth, yields and yield components

CHAPTER TWO

LITERATURE REVIEW

2.1 Roles of insect pollinators, natural enemies and farmers' knowledge on improving bean production in tropical Africa[1]

Introduction

Ecosystem services in agriculture refers to any nature-based activity that is offered by providers of ecosystem services such as pollinators and natural enemies in different processes such as biological control of pests, soil formation, nutrient cycling and or other related processes (Power, 2010; Messelink *et al.,* 2014; Lacey *et al.,* 2015; Ndakidemi *et al.*, 2016). These providers of ecosystem services are very important in Agriculture. For instance, a report by Hoehn and Tscharntke (2008), Bartomeus *et al.* (2014) and Melin *et al.* (2014) indicated that more than 75% of the world crops benefit from pollinators leading to improved crop yields ranging from 25% to 99%. In a study by Ollerton *et al.* (2011) and Rader *et al.* (2015), wild and managed bees have been estimated to be effective in pollinating more than 87% of flowering plants in the tropic and temperate zones worldwide. Although some reports on ecosystem services are available for many locations, the literature shows fewer studies and hence less data on pollinators, natural enemies and their roles in agriculture in tropical Africa.

Shackelford *et al.* (2013) identified only one study in Africa on pollinators and natural enemies as compared with many studies in North America and Europe. Within this limited line of studies, it has been apparently described that Africa is endowed with massive species of flowering plants whose presence can enhance the presence of the provider of ecosystem services (Baggen and Gurr, 1998; Westphal *et al.,* 2003; Blaauw *et al*., 2015; Gaigher *et al.,* 2015). Based on this phenomenon, authors hereby provide this review article to discuss the significance, farmer's knowledge and potential of the ecosystem services for improved bean production in tropical Africa. Even though no studies on ecosystem services that were solemnly conducted in Africa, we already know well that common bean is a self-pollinating crop (Andersson *et al*., 2014) and that some studies have shown that pollinators can improve pollination in beans leading to increased yields (Kelly, 2010; Woodcock, 2012).

[1] Martin Mkindi 11(4) : 22-239 Journal of Biodiversity and Environmental Sciences

The rate of out-crossing in beans ranges from 4-89% depending on the genotype used, environmental factors, geographical area, row space and the number of pollinating insects (Musallam *et al.,* 2004; Cong *et al.,* 2014). This entails likely roles of pollination to facilitate the out-crossing process. Studies conducted in the United Kingdom (UK) and Rwanda show an increased yield of about 60% to 69% due to pollinator's involvement in bean (Garratt *et al.,* 2014).

Besides pollination services, the provider of ecosystem services particularly the natural enemies play a significant role in pest management worldwide (Gaigher *et al.*, 2015). The level of understanding and application of natural enemies in pest management particularly in beans is still under study in Africa. Therefore, it is worth exploring the significance, level of understanding of small-scale farmers and potential use of the ecosystem services for sustainable providers of ecosystem services conservation and bean production in tropical Africa.

2.2 Status and significance of Ecosystem services

Small-scale farming ecosystems are believed to provide conditions for the presence and functioning of ecosystem services if undisturbed (Garbach *et al.,* 2014). However, pollinators, natural enemies and their modes of functioning in these farming ecosystems are not well known especially in the developing countries including tropical Africa.

In other parts of the world such as the United States of America, some insects have been commercialized for different purposes including biological control of some agricultural pests (Bale *et al.,* 2008; Cranshaw, 2014; Scheper, 2015) and pollination services (Flint and Dreistadt, 2005; Scheper *et al.,* 2013; Garratt *et al.,* 2014). For instance, the USA exports parasite free colonies of bumblebees (*Bombus sp*.) globally especially to temperate countries such as those in Europe, North America, South America and Asia for pollination purposes in greenhouse crops (Velthuis and Van Doorn, 2006; Woodcock, 2012; Graystock *et al*., 2013). In tropical Africa, literature is limited on the status of use and significance of ecosystem services especially on understanding the providers of ecosystem services and their possible contribution to agriculture (Kovács-Hostyánszki *et al.,* 2017).

In addition, the providers of ecosystem services are in the danger of decreasing due to climate change, habitat loss and fragmentation, agrochemicals, spread of alien species and diseases (Colley and Luna, 2000; Jones and Gillett, 2005; Patterns *et al.,* 2010; Potts *et al.,* 2010; Vanbergen and Initiative, 2013; Goulson *et al.,* 2015; Motzke *et al.,* 2016; Tiedeken *et al.,* 2016).

Therefore, there is a need for collective choices and studies on understanding phenomenon behind providers of ecosystem services habitat, ethno ecological and social perspectives to fully preserve and utilize benefits offered by the ecosystem for sustainable crops including beans production in tropical Africa.

2.3 Key Providers of Ecosystem Services

Key providers of ecosystem services are summarized in Table 1, showing interestingly that some of the players such as insects depending on growth stages can perform more than one role in the ecosystem settings. For instance, Hoverflies (*Diptera: Syrphidae*) is both a pollinator (in adult stage) and predator of pests such as aphids, thrips, mites, and other small insects in the larval stage (Moquet *et al.,* 2017). In performing their role, the provider of ecosystem services can be very effective. For example, the Ladybird beetles have been reported by Gurney and Hussey (1970) and Eric (2017) to reduce their pray particularly aphids by 99% in a seven days' time. Other providers of ecosystem services such as Trichogramma wasps (*Trichogramma pretiosum*) appear to be the smallest of all insects but very important in biological pest control for their ability to parasitize eggs of many different orders of insects (Sarwar and Salman, 2015; Mushtaq *et al.,* 2015).

2.4 Role of provider of ecosystem services in crop pollination

Some providers of ecosystem services particularly insect pollinators have been reported to be capable of moving pollen from one flower part to the other in so providing grounds for fertilization, seed and fruit set (Heard, 1999; Amauo *et al.,* 2000; Nguyen Minh Tuan, 2003; Cruz *et al.,* 2005; Slaa *et al.,* 2006; dos Santos *et al.,* 2009; Munyuli, 2011; Cusser *et al.,* 2016). Insect pollinators including bee species such as honey bees, stingless bees, carpenter bees have been considered to play a primary role in crop pollination than as for non-animal agents such as wind pollination (London-Shefir *et al.,* 2003; Kremen *et al.,* 2007; Garibaldi *et al.,* 2013; Nunes-Silva *et al.,* 2013).

For instance, Ollerton *et al.* (2011) reported that about 308 000 species i.e. 87.5% of crops are pollinated by insects and other animals while the remaining percent is done by abiotic pollen carriers such as the wind worldwide. Pollination by insects has been reported to contribute to the yield of beans and other crops (Musallam *et al.,* 2004; Aouar-sadli *et al.,* 2008; Mireille *et al.,* 2012). For instance, Nayak *et al.* (2015) reported an increase of 18.5% of yield compared with that in self-pollinating beans.

Other providers of ecosystem services such as natural enemies including predators, pathogens, nematodes and microorganisms are as well important in crop-pest interactions (Lee *et al.,* 2001; Flint and Dreistadt, 2005; Vinyard and Hoelmer, 2016). These natural enemies vary in size and mechanism in pest control. For instance, some natural enemies such as Ladybugs (*Hippodamia convergens*) are large enough to chew their prey (Soares *et al.,* 2003), lay eggs e.g. parasitoid wasp on the host tissue (van Nouhuys and Kaartinen, 2008) while others such as bacteria, fungi and virus cause diseases in the host pests (Riddick *et al.,* 2009; Singh, 2014). In most cases, natural enemies particularly insects are most active at the larval stage (Ndakidemi *et al.,* 2016) while adults may or may not have similar food needs (Stewart *et al.,* 2007).They are considered as a promising control technique due to their safety, species-specific and long-term action on the target pests (Sanda and Sunusi, 2014). Natural enemies may occupy non-cultivated farm areas (non-crop habitats) especially with herbaceous plants as their habitat (Bianchi *et al.,* 2006; Grzywacz and Stevenson, 2014). The predilection principles behind natural enemies on prey and or habitats are basically not well-known. However, some information is available for example flower nectars and terpenoids produced by plants following damage from herbivorous species (Wei *et al.,* 2007). In pest control, natural enemies are potentially viable options to reduce numbers of insect pests to an acceptable damaging level.

Use of natural enemies as control options have been tested in open and greenhouse condition and have shown to be cheap, having a low side effect to human, animal and are environmentally friendly (Bale *et al.,* 2008; van Lenteren, 2012; Wyckhuys *et al.,* 2013; Gurr and You, 2015).

However, in tropical Africa, limited or full application of natural enemies despite the role they play has not been vividly reported and or quantified. As a general opinion, conservation of natural enemies such as ladybird beetles (*Coleoptera: Coccinellidae*), lacewings (*Neuroptera Chrysopidae*) syrphid flies, Chalcidae, Bracoidae, and Ichneumonidae is essential in crop including common bean to small scale farmers as this can regulate over-dependence and counteract the increased cost of synthetic inputs (Messelink *et al.*, 2014). These insects are effective as they can pray and parasitize other insects such as aphids, scales, mealy bugs, leafhoppers, and various types of soft-bodied insects while completing their life cycles (Evans, 2009). Some of them can feed on thousands of known insect pests. For example, Ladybird beetles can eat 5000 aphids or similar prey during its lifetime (Flint and Dreistadt, 2005; Cranshaw, 2014; Green *et al.,* 2016; Ndakidemi *et al.,* 2016; Shang *et al.,* 2016). Such action can make a significant contribution in controlling aphids in bean fields.

Other providers of ecosystem services such as parasitoids whether through superparasitism, multiparasitism or hyperparasitism also play unique roles in agricultural crop protection (Lewis *et al.,* 1998). They are usually smaller than their hosts (Cohen *et al.,* 2016). Parasitoids have the characteristics of both predators and parasites (Extension, 2014; Zheng *et al.,* 2015). They can target hosts that are already infected and are among a well-known biological insect pest control strategy in the fields (Schmidt *et al.*, 2003; Mwanauta *et al.,* 2015). Their presence and effectiveness are favoured by the presence of nectar which provides them with energy as they go around to search for the host (Lewis *et al.,* 1998). Parasitoids have the ability to confiscate, change hormone and behaviour of the host pest to make a conducive environment for their development (Beckage *et al.*, 2003; Libersat *et al.,* 2009). Most common parasitoids are those from families, Dipteran (two-winged flies) and Hymenoptera (Sawflies, wasps and ants) (Hassell, 2000). They spend a significant portion of their life attached to or within a single host ultimately killing it (Libersat *et al.,* 2009). For example, to kill an aphid, larvae and pupa parasitoid pupates and grows within the aphids cuticle forming mummies (Chapman *et al.,*1981). Parasitoids often complete their life cycle more quickly and increase their numbers faster than many predators (Messelink *et al.,* 2014; Grzywacz *et al.,* 2014). Parasitoids have been reported to contribute to about 33% of natural pest control (Getanjaly *et al.*, 2015). The most known parasitoids are wasps and flies and their activity have been reported to show better results in insect control in the area where no insecticides are applied (Abate, 1996; Rehman and Powell, 2010).

Pest management with parasitoids are cost-effective when pest densities are low (Wang and Keller, 2002). They are generally more delicate than predators and hence more vulnerable to pesticides (Gill and Garg, 2014). The role of different pollinators and natural enemies in providing ecosystem services is not well documented in the subsistence farming systems found in Africa. Understanding their roles will lead to yield increment with less agricultural inputs.

2.5 Role of farmers' knowledge on enhancement of ecosystem services in tropical Africa

Farmers possess knowledge and practices acquired through series of observation, beliefs, rules, and experiences and that are communicated from elders to younger ones and from one generation to another (Gadgil *et al.*, 1993; Boafo *et al.*, 2016; Parrotta *et al.*, 2016). Farming practices involving indigenous knowledge can enhance ecosystem preservation through multiple crop species management, landscape patchiness management, and other ways of responding to and managing beans and ecosystem surprises (Berkes *et al.*, 2000).

Local knowledge can contribute to a good understanding of historical perspectives that can provide information to science (Chalmers and Fabricius, 2007; Sileshi *et al.*, 2009). Farmer's knowledge is very important in harnessing the ecosystem services because of its site specificity and practicability (Munyuli, 2011). African indigenous communities possess knowledge and perceptions of an ecosystem and their management in relation to farming activities that are local to their areas of origin (Berkes *et al.*, 2000). This knowledge has been changing according to changes in environments, the introduction of new technologies and social conditions (Parrotta *et al.*, 2016). Indigenous knowledge on types of crops, the timing of cropping, and ways of preventing the crops from pests and diseases and types of agents used for such prevention are important and traditionally practised worldwide (Ardakani and Emadi, 2008). Statistics show that 2.1 -2.5 million people that are directly involved in small hold farming are in the tropics and 500 million are from developing country (IFAD, 2013; Steward *et al.*, 2014).

However, growing population and increased demand for food have changed the cropping system to expanded land and specific cropping (monocropping) in many locations worldwide and lesser in the developing countries including tropical Africa (Abate *et al.*, 2000). Tropical Africa possesses an enormous diversity of plants species which contribute to the presence of the providers of ecosystem services (Tengo *et al.*, 2014).

However, the decision on how to manage land for obtaining services from those providers of ecosystem services are currently affected by lack of understanding of the role of providers of ecosystem services by farmers including those growing bean on one hand and different dynamics like climatic changes topographical constraint, social values, increased farming and household characteristic on the other (Lamarque *et al.*, 2014). It seems also that, there is little research attention, poor regional research collaboration and lack of clear policy support framework for the ecosystem services and providers of ecosystem services in tropical Africa (Machekano *et al.*, 2017).

It is apparent that some small scale farming communities still practice intercropping, conservation farming, mixed cropping and non-tillage cropping all of which ensure the presence of a great diversity of species that enhance natural ecosystem services (Munyuli, 2013; Puech *et al.*, 2015; Dicks *et al.*, 2016). There is information that use of pesticidal plants is positively practiced either as an extract or intercropped with crops for insect pest control (Singh *et al.*, 2017). However, farmers' indigenous knowledge on botanical pesticides need to be improved (Gakuya *et al.*, 2013; Mkindi *et al.*, 2015). Integrating processes such as botanical pesticides and providers of ecosystem services management is not demarcated or characterized in tropical Africa. For any successful invention, bottom-up approaches have shown a great success across the world in a number of technologies. Use of indigenous knowledge and experience, therefore, provides for baseline information and a way to improve agricultural sustainability through the ecosystem services management.

2.6 Potential of ecosystem services in pest management and bean production in tropical Africa

Common beans production is currently constrained by high pests pressure and poor seed set mainly due to pollen deficit (Mwanauta *et al.*, 2014). With the increasing awareness on beneficial attributes associated with ecosystem services, there is no doubt that the communities will realize their benefits and practice ways to harness the full potential of the providers of ecosystem services for improved bean production. It is already reported that the providers of ecosystem services have proved to be effective in bean pest management and pollination in other locations outside tropical Africa (Slaa *et al.*, 2006; Bale *et al.*, 2008). Though threatened, an effort of encouraging conservation of the providers of ecosystem services is being promoted at global, regional and national scales worldwide (Tscharntke *et al.*, 2012; Gill, *et al.*, 2016). More research on the utilization and conservation of the providers of ecosystem services for their effect on yield increment through pest reduction and pollination are constantly considered the most critical agenda in sustainable crops production worldwide (Cane *et al.*, 2007; Garibaldi *et al.*, 2013; Nunes-Silva *et al.*, 2013; Getanjaly *et al.*, 2015). As far as tropical Africa is concerned, it is obvious that farmers can increase beans production through the management of landscape and agricultural ecosystems which will automatically conserve the providers of ecosystem services (Munyuli, 2013).

This should go hand in hand with discouraging excessive use of synthetic pesticides which not only pose side effects on human health and are of higher costs, but also negatively affect beneficial insects including the providers of ecosystem services (Parker *et al.,* 2013; Grzywacz *et al.,* 2014; Kedia *et al.,* 2015; Mkindi *et al.,* 2015; Mwanauta *et al.,* 2015; Mkindi *et al.,* 2017). Moreover, there is need to create awareness among bean farmers and encourage collective choices for managing and harnessing the full potentiality of the providers of ecosystem services to realize what the ecosystem services is currently and will be doing in beans production in tropical Africa.

2.7 Conclusion and Research Needs

In conclusion, ecosystem services and providers of ecosystem services and other natural services are crucial for ecosystems' proper functioning and thereby sustaining plant growth, crop production and protection against pests. Use of existing natural resources particularly those obtained through ecosystem services as stipulated in this review are worth of identifying, testing and utilizing in tropical Africa. This can easily be achieved because of the diverse nature of crops, altitudes, climates and habits for the providers of ecosystem services in the region. Research, however, is needed on a rigorous understanding of ecosystem services and providers of ecosystem services and other natural services, possible dynamics and factors affecting their survival and functions and how to better harness them for improved bean and other crops production in tropical Africa.

CHAPTER THREE

MATERIAL AND METHODS

3.1 Study site

This research was carried out in the experimental fields of Nelson Mandela African Institution of Science and Technology NM-AIST, Arusha, Tanzania. The site is located at Latitude -3°24’S and Longitude 36°47’ East and at an altitude of 1168m.

The area has a mean rainfall of above 1000mm per year distributed between short rains of October/November to January and long rains of February/March to May (Meru District Council, 2013)

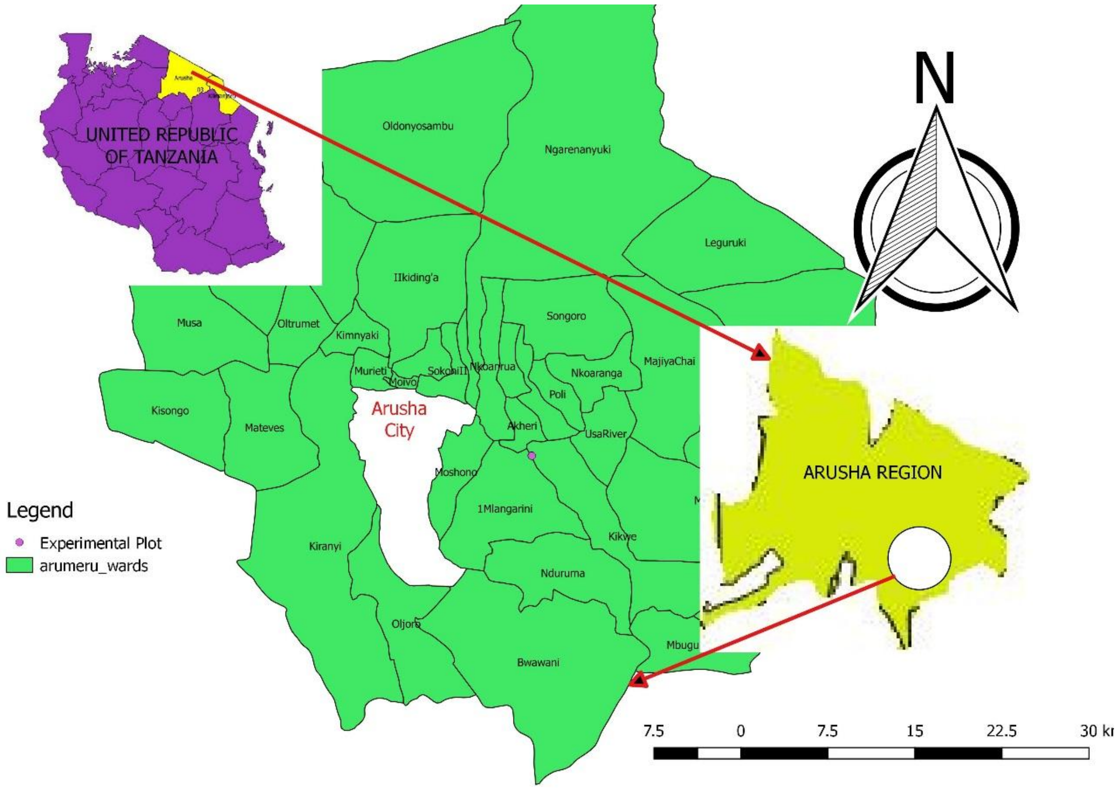

Figure 1: Map of the research area

3.2 Study Materials

Source of different material used in the study are shown in table 1. Seeds of common beans (Lyamungo 90) were purchased from Selian Agricultural Research Institute, Arusha while the insect nets obtained from Balton Tanzania. Stingless bees were obtained from Ngarananyuki in which four boxes were used for the experiment.

Common beans of Lyamungo 90 were planted in the field naturally under a rainfed condition. A randomized complete block design method was then applied in which the experiment was replicated four times for accuracy as shown in the experimental layout.

Each plot had 180 flowering bean plants in the arrangement of five rows in the space of 50cm between rows and 20cm between holes Adopted from (Bartomeus *et al.,* 2014a) with modification. Four blocks were established and each block contained 7 treatments. The treatments were applied as described in Table 2.

Aphids T2, Aphids and beetle T3 respectively were introduced for the assessment of the interaction between these groups of insects on bean yield and yield components of which aphids and lady beetle were collected manually from the pre-established plot of flowering plants. Inoculation of lady beetle and aphids was done according to (Flint and Dreistadt, 2005) with modification as recommended by the beetle seller, thus the ratio for lady beetle and aphids' were 22: 1100 respectively in T3 and 1100 aphids was infested on each plot in T2. According to (Riddick, 2017), Ladybird beetle larvae were used as the natural enemy in this case.

Stingless bees were obtained from beekeepers around Ngarananyuki village. Stingless bees have been investigated for their pollination capacity in various research works. Their lack of sting makes them suitable for pollination in closed environments such as greenhouses (Slaa *et al.,* 2001). Stingless bees are also easy to rear and therefore suitable for on-station experiments.

Four beehives with small colony of at least 500 bees were purchased for experiment following a method adopted from Cruz *et al.* (2005) and Santos *et al.* (2009) with modification where each covered plot in treatment four (T4) uses one hive. Supplementation with mellifera honey was done to avoid starvation of bees. Experiment plot in open (Natural pollination), hand pollination and insect pollination were then compared.

Prior to flowering period six weeks after planting beans, stingless bee hives were introduced in covered plots for pollination. The difference in bee's pollination, open plot and hand pollination was revealed by the pollen deficit and contribution of bees in yield and yield components of beans.

3.2.1 Hand pollination

As adopted from B'n'B (Bees 'n Beans) projects (Birkin and Goulson, 2015), pollination was done by bean breeder from Selian Agricultural Research Institute, Arusha. This was done continuously for two weeks with one raw of plant used as spare plants.

The experimental plot in open (Natural pollination), hand pollination and insect pollination was compared. All these activities were conducted at Nelson Mandela Campus as summarized in Table 1 below.

Table 1: Sources of experimental materials

Materials	Sources
Common beans (Lyamungo 90)	ARI Selian
Stingless bees	Purchased from Ngarananyuki
Lady beetle (Coleoptera: Coccinellidae*)*	Field collection
Aphids	Field collection

3.3 Experimental design

The objectives were achieved through a field trial at Nelson Mandela farm that involved 7 treatments imposed in plots with the size of 3m x 3m using randomized complete block design (RCBD) with four replications (Total area of 28m x 18m). The spacing between rows was 50cmand 20 cm between holes. Two seeds of Lyamungo 90 beans sown per holes as per breeder's directions.

Table 2: Field experimental layout and treatments

Replication	Treatments and randomization						
1	T6	T7	T1	T3	T5	T2	T4
2	T7	T4	T1	T2	T5	T3	T6
3	T1	T2	T6	T5	T7	T4	T3
4	T4	T7	T6	T2	T1	T3	T5

Where:

Treatment (T1) = Beans were planted and covered with insect net for self-pollination

Treatment (T2) = Aphids were introduced in the bean plot covered with insect net

Treatment (T3) = Aphids and their natural enemies were introduced in covered bean fields

Treatment (T4) = Insect pollinators (Stingless bees) were introduced in covered bean plot

Treatment (T5) = Uncovered bean plot with no insect pest control (Natural condition)

Treatment (T6) = Uncovered bean crop with insect pest control using pesticides

Treatment (T7) = Hand pollination.

3.3.1 Aphids Inoculation

Aphids were collected from infested common beans and inoculated into the beans under the experiment as described by (Wosula, *et al.*, 2017) with modification, where each covered plot receive 1100 aphids and was inoculated every after one meter along the bean rows.

3.4 Data collection

3.4.1 Yield components

Insects in all open plots were assessed based on their frequency; presence/absence and abundance using the categorical index as per (Mkenda *et al.*, 2015). The extent of damage was assessed by using a scale of 0-4; where 0 = No damage; 1 = Showing damage up to 25%; 2 = Damage from 26%-50%; 3 = Damage from 51%-75% and 4 = Damage more than 75% (Mkenda *et al.*, 2015). Insect visitation, their frequencies and abundance were recorded and in the covered plot the inoculated insect was also recorded accordingly. Plots were assessed from the second week of growth to identify common beneficial insect pollinators and natural enemies. Weekly observations were conducted to observe and document insect's pollinators, natural enemies and aphids. Additionally, the following data were collected: days to 50% flowering; number of pods per plant, number of flowers per plant, number of pods per plant, the number of seeds per pods, yield per plot and 100 seed weight.

3.4.2 Data Analysis

Analysis of Variance was used to determine mean aphid incidence/severity in an experimental plot with aphids and one with aphids and ladybird beetle; the same was used in yield estimate. LSD was used to separate means at the p=0.05 level of probability. STATISTICA software was used to perform all analyses mentioned above.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Average performance of yield parameters on Stingless bee's pollination, hand pollination, self-pollination control, pesticides, aphids and aphids and ladybird beetle treatment.

Impact of pollination on the average yield of common beans is shown in Table 3. There was a significant difference in the number of pods per plant at p≤0.05 with mean 6.278±0.385a, seed per pod at p≤0.05 with mean 3.011±0.112a and yield kg/ha at p≤0.01 with mean 2164.328±134.115a along all treatment. Stingless bee pollination had a higher average yield - 2164.328±134.115a compared with the hand and self-pollination. Self-pollinated beans manifested a higher average number of pods per plant although not higher than the pollination by stingless bees.

There was the lowest yield, number of pods/plant, number of seeds per pods and the total yield in the plot sprayed with the synthetic pesticides. However, there was no significant difference in the seed weight across all treatments that is stingless bee pollination, hand pollination and self-pollination. A control treatment, which was the open plot manifested higher average yield compared with the synthetic pesticides treated treatment.

On the same experiment, plots inoculated with aphids and ladybird beetles showed high performance on a number of pod/plant (5.684±0.385 and average seed yield (kg/ha) 2011.449±134.115 than the plot having only aphids with the performance of pods/plant 4.801±0.385ab and average yield 1883.814±134.115ab. The contribution of a ladybird beetle which is a natural enemy is observed in the yield increment in Table 4 where the yield of aphids and ladybird beetle was higher than the control and the plot with aphid infestation only.

Table 3: Average performance of yield parameters on stingless bee's pollination, hand pollination, self-pollination control, pesticides, aphids and aphids and ladybird beetle treatment

Treatments	No pod/plant	Seed/pod	100 seed wt. gm.	Yield (kg/ha)
Stingless bee pollination	6.278±0.385a	3.011±0.112a	64.525±2.445	2164.328±134.115a
Self-pollination	6.037±0.385ab	2.778±0.112ab	62.950±2.445	1966.776±134.115ab
Aphids and Ladybeetle	5.684±0.385ab	2.899±0.112ab	61.525±2.445	2011.449±134.115a
Hand pollination	5.978±0.385ab	2.477±0.112b	63.050±2.445	1949.754±134.115ab
Control	5.834±0.385ab	2.589±0.112ab	58.550±2.445	1601.220±134.115ab
Aphids	4.801±0.385ab	2.578±0.112ab	55.600±2.445	1883.814±134.115ab
Pesticides	4.398±0.385b	2.587±0.112ab	59.675±2.445	1367.686±134.115b
One way ANOVA F-test	3.307	3.100	1.602	4.115
P value	0.019*	0.025*	NS	0.007**

Each value is a mean ± standard error of four replicates, **is significant at $p \leq 0.01$,*is significant at $p \leq 0.05$ Means followed by the dissimilar letter in a column are significantly different from each other at $p=0.05$ according to Fischer least significance difference (LSD).

4.2 Effect of natural enemies on aphid infestation in bean plants for four weeks of growth.

Table 4 below shows the incidence and severity of aphids introduced in the field over four consecutive weeks. Natural enemy (ladybird beetle larva) successfully controlled aphids in four weeks as shown in Table 4. There was a decreasing trend in the incidence and severity of aphids with time such that the first week had significantly abundant aphids than the last (fourth week) in the aphid and ladybird beetle larva treatment plot. On the contrary, a number of aphids significantly increased with time in the plots there was inoculated with aphids only. Generally, incidence and severity of aphids in the presence of ladybird beetle larva was lower than in the aphids only regardless of time.

There was an increasing trend of aphid's incidence in the aphids treated plot as well as a decreasing trend on the presence of ladybird beetle larva. There was the generally low severity of aphids both in the presence and absence of the natural enemy (Ladybird beetle larva). Although the severity decreased with time in the presence of the natural enemy.

Mean severity of both APLB and AP was 4.75±0.25b and 3.50±0.29a respectively in the first week while 5.00±0.00b of AP and 1.25±0.25a APBL was recorded in the last week.

Table 4: Effects of natural enemies on aphid infestation in bean plants for four weeks of growth

Treatment	% Incidence1	% Incidence2	% Incidence3	% Incidence 4	Severity1	Severity2	Severity 3	Severity 4
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
APLB	43.75±3.2a	25.00±2.0a	15.00±2.0a	3.75±2.4a	3.50±0.3a	2.75±0.5a	2.00±0.0a	1.25±0.3a
AP	72.50±3.2b	76.25±6.9b	83.75±7.5b	96.25±2.4b	4.75±0.3b	4.50±0.5b	4.50±0.3b	5.00±0.0b
ANOVA (F-STATISTIC)	40.6923***	50.9394***	78.9130***	746.7273**	10.7143*	6.3913*	75.0000***	225.0000***
P-Value	0.000698	0.000381	0.000113	0	0.016965	0.044794	0.000131	0.000006

APLB= Aphids and ladybird beetle, AP = Aphids.

Each value is a mean ± standard error of four replicates, *** is significant at P≤0.001, * is significant at P≤0.05. Means followed by a dissimilar letter in a column are significantly different from each other at p=0.05 according to Fischer least significance difference (LSD).

4.3 Discussion

The pollination treatment tested in this experiment show that there was a significant difference on pods per plant p≤0.05, seed per pod p≤0.05 and yields kg/h p≤0.01 but no statistical difference in 100 seed weight though differences were observed among treatments Table 3. In all pollination treatments, high performance was observed in plots whose flowers were visited by the stingless bee for pollination. Increment in yield following bee visits have been reported in other autonomous crops like cotton (*Gossypium hirsutum*), beans (*Phaseolus vulgaris*) and tomatoes (*Lycopersicum esculentum*) (Ramalho *et al.*, 1990; Heard, 1999; Cruz, 2005; Cruz *et al.,* 2005; Slaa *et al.,* 2006; dos Santos *et al.,* 2009; Nunes-Silva *et al.,* 2013). This result from this study suggests that transfer of pollen from the anther to stigma in a self-pollinated plant (*P vulgaris*) was not sufficient to fully utilize pollen produced until the pollinating insect was involved.

Stingless bees had higher performance in all yield parameters as shown in Table 3. This was obvious due to the involvement of bees as pollinators in the caged bean plant, Stingless bees are mainly pollen collectors of which in so doing they made possible the contact with stigma (Timothy, 2016). Hand pollination was numerically outcompeted by stingless bees because of hand pollination, flower damage was observed which automatically reduced flower survival and to pod setting.

In this study, there were significant differences in the number of pod/plant, seed/pod and yield (kg/ha) between some of the treatments. Stingless bee pollination produced many pods per plant, more seed per pods, heavier seed and higher yield per hectare than hand and self-pollination in the experiment, although there were no statistical differences in overall seed weight Table 3. dos Santos *et al.* (2009) also worked with greenhouse tomatoes which is a self-pollinating crop and attained similar result on the increment of yield parameters in a plant when compared with hand pollination and self-pollination. Thus, it seems that pollinators visit beans assisted in producing more yields. In this controlled experiment, such result was expected, because stingless bees using their mouth part (mandible) were able to access the pollen from the bean flowers and cross-pollinated other plants.

The number of seed/pods differs significantly only between stingless bee pollination treatment and hand pollination although seed/pod in all treatment are numerically different. The hand pollination treatment, pollination by bees and self-pollination treatments showed a higher number of seeds per pod that control and pesticide applied plots Table 4.

Closely related results were reported by Meisels (1997) in a greenhouse experiment involving sweet paper and using bees as pollinators in which the number of seeds per fruits were increased as compared with the control. It is also suggested that small native bees are efficient flower pollinators (Raw, 2000). In this regard, any ecological activity to support the existence of stingless bees in the ecosystem should be encouraged as they have proved to increase seed yield in self-pollinated crops such as common beans tested in the current study.

Aphids and ladybird beetle treatment show better performance in most of the yield parameters almost similar to stingless, hand and self-pollination because of efficient control of aphids by ladybird beetle Table 4**.** In this experiment, aphids abundance reduced within four-week from inoculation. This result concurs with studies by Riddick (2017) who reported a reduction of aphids by 50% when ladybird beetle is involved as the natural enemy. In the current study, we used ladybird beetle larvae as the predator of aphids at the ratio of 22: 1100 ladybird beetle and aphids respectively in a 3x 3m plot, the ratio used abide with the recommendation by beetle sealer which is 11–22 beetles/m^2 (Flint and Dreistadt, 2005).

Aphids only treatment showed higher average yields when compared with control Fig 5. This could be due to the slow multiplication of aphid to reach a damaging level that can affect bean yields as this growing season was having higher rainfall that leads to the cool climate which does not favour their growth. Aphids are not favoured by cool climate (Wosula *et al.*, 2017). Heavy rainfalls kill the aphids (Fievet *et al.,* 2007) and reduce their rates of multiplication. Pesticides perform poorly than in all parameters when compared with all open or uncovered plots. This was probably because of low or no at all insect activity to aid pollination in the bean flowers as a result of pesticide applied during the course of the experiment. As recommended by Ndakidemi *et al.* (2016) there is a need to shift from chemical pesticides to botanical pesticides so as to facilitate the presence and occurrence of natural enemies and pollinators to provide their useful ecosystem services.

Plots supplied with aphids and ladybird beetles showed better performance in yield parameters than in the self-pollination plots Table 4. This results disclose the contribution of insect pollinators in yield maximization observed in this experiment. These findings are similar to what was reported by Nicholls and Altieri (2013) who highlighted that Coleoptera: Coccinellidae (ladybird beetle) families encouraged pollination.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study concludes that there are several benefits of using pollinators and natural enemy in beans production systems. It became obvious that there was an increment of pods per plant, seed per pods and total yield per hectare in stingless bee pollination cages and impressive aphid control by the action of Ladybird beetles. Using natural enemy as pest control mechanism is environmentally benign and safer than synthetic pesticides. Stingless bees are very usefully in yield maximization when included as pollinators. This study concludes that farmers can manipulate the environment to support beneficial insect which will enhance natural insect pest control and facilitate pollination services. Therefore, it is important to communicate such scientific findings to the society for easy dissemination and uptake of the knowledge. However, currently, the foreseen challenge is agricultural intensification practices that threaten the presence of the suitable habitat for these beneficial insects. Therefore, this study encourages farmers to retain and manage border plants that are suitable for attracting beneficial insects such as pollinators and natural enemies.

5.2 Recommendation

From the study above, it is clear that stingless bee and Ladybird beetle are important insects in common bean fields for pollination and aphis control respectively. Including them in the field resulted in higher bean yield. The results from this study overemphasize the necessity of conservation of this beneficial insect for future benefits. Identification of beneficial insect is suggested to ensure that they are properly managed and conserved for future benefits.

There is also a need for investigating the conducive plats species that will provide suitable habitat favouring both insect pollinators and natural enemies which will be used as field margin for conservation strategies.

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APPENDICES

Appendix 1: Key insect provider of ecosystem services, role in crops and their predilection sites

Name of ecosystem providers (Order : Family)	**Role in crops**	**Predilection site**	**Reference**
Honey Bees (Hymenoptera: Apidae)	Pollinator	Red flowers with short tubes, Nectar source plant, river bank and forest area	(Fothergill 2009; Padhye *et al.*, 2012; Parandhaman *et al.*, 2012; Prabakaran *et al.*, 2014)
Butterflies (Lepidoptera: Rhopalocerae)	Pollinator (adult)	Red flowers with short tubes, Nectar source plant, river bank and forest area	(Fothergill 2009; Padhye *et al.*, 2012; Parandhaman *et al.*, 2012; Prabakaran *et al.*, 2014)
Moth (Lepidoptera: Psychidae)	Pollinator (Adult)	White or pale flowers with strong fragrance producing plants	(Hopwood, 2010; (Moore and Hanks, 2004; Villanueva and Rodrigues, 2005)
Stingless bee (Hymenoptera:Apidae)	Pollinator	Wild plants and crops	(Anguilet *et al.*, 2015; Ramalho *et al.*, 1990; Free, 1966; Slaa *et al.*, 2006; Villanueva-g *et al.*, 2005)
Hoverflies (Diptera: Syrphidae)	Both predator of aphids, thrips, mites, and other small insects and	Queen Anne's lace, dill, fennel, tansy, coriander, bishop's weed, coreopsis, gloriosa daisy,	(Cooperative Extension Service (CES) 2010); Stewart *et al.*, 2007; Burgess and Morris, 2009).

	pollinator	yarrow, the cosmos, sunflower, marigolds, candytuft, sweet alyssum,	
Green Lacewing (Neuroptera: Chrysopidae)	Predator of aphids, mites, whiteflies, caterpillars, small soft-bodied prey and adult are pollinators	Melon crop	(Aldrich *et al.*, 2016; Keulder and Van den Berg, 2013; Rana *etal.*, 2017)
Assassin Bug (Hemiptera: Reduviidae)	Predator of most insects	Legumes	(Stewart *et al.*, 2007; Virla *et al.*, 2015)
Hoverflies (Diptera: Syrphidae)	Pollinator (adult) and larvae are predator of aphids, thrips, and mite	Bishop's weed, coreopsis, gloriosa daisy, yarrow, cosmos, sunflower, marigolds, candytuft, sweet alyssum, decaying vegetation	(Cooperative Extension Service (CES) 2010; Stewart *et al.* (2007); (Lee *et al.*, 2001)
Ground Beetle (Coleoptera: Carabidae)	Both adults and larvae are the predator of caterpillars, cutworms,	Arable crops, heavier soils, trees and shrubs	(Chin and Brown, 2010); (Ghahari *et al.*, 2009; Lövei and Sunderland, 1996; Woodcock *et al.*, 2014)

	ants, maggots, earthworms, slugs, and other beetles		
Lady Beetle (Coleoptera: Coccinellidae)	Predator	Pollen and nectar producing plants	(Getanjaly *et al.*, 2015; Almeida *et al.*, 2011; Frank and Mizell, 2009; Sarwar 2016; Sloggett, 2012; Snyder *et al.*, 2004)
Brown Lacewing (Neuroptera: Hemerobiidae)	Larvae are predator of insect eggs, leafhoppers, mites, red-banded thrips, mites, immature mealy bugs, moth eggs and small caterpillars.	Tree/shrub crops, flowering crops, vegetation, orchards, carrot family and sunflower family	(Lee *et al.*, 2001; Kovanci and Kovanci, 2007; Rocca and Messelink, 2016; Stange, 1997)
Green Lacewing (Neuroptera: Chrysopidae)	Larvae are predator of aphids, mites, whiteflies, caterpillars, and other small, soft-bodied prey	Melon crop	(Bezerra *et al.*, 2010; Stange, 1997; Rana *et al.*, 2017)

Long legged (Diptera: Dolichopodidae)	Predators of aphids, thrips, young caterpillars, and mites Predators or scavengers in detritus in soil.	Tree crevices, field margins, and crops	(Mahr *et al.*, 2008; James *et al*, 2016; Kautz *et al.*, 2014; Kazerani *et al.*, 2015)
Robber Flies (Diptera: Asilidae)	Predator of Flies, wasps, Grasshoppers, leafhoppers, beetles, and butterflies. Larvae feed on small insects	Rotting wood, foliage, bark and seed heads of grasses (eggs)	(Cannings, 2014; Samin *et al.*, 2011; Samin *et al.*, 2011)
Tachinid Flies (Diptera: Tachinidae)	Parasitoids of Green clover worm, bean leaf beetle, beetle larvae, grasshoppers and caterpillars	Crops pollen	Pesticide Action Network (PAN), 2014; (Bhoje, 2015; De Farias *et al.*, 2012; Gammelmo and Sagvolden, 2007; Samin *et al.*, 2011)
Spiders (Araneae: Sparassidae)	Predators of red-banded thrips, plant hoppers, caterpillars and moths	Soil, low vegetation/woody plants (perennial crops)	Cooperative Extension Service (CES) (2010; Ndakidemi *et al.*, 2016)

Trichogramma Wasps (Hymenoptera: Trichogrammatidae)	Parasitoids of army worm eggs, corn earworms, cutworms, European corn borer and bean pods borer (*Maruca vitrata*)	Closely spaced plants	(Fernandes *et al.*, 2010; Belmain *et al.*, 2013; Olson and Andow, 2006; Romeis *et al.*, 2005)

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Roles of insect pollinators, natural enemies and farmers' knowledge on improving bean production in tropical Africa

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Abstract

Ecosystem services play a significant role in sustainable agricultural development worldwide. Commonly examples of well-known groups of providers of ecosystem services are insect pollinators and natural enemies of bean pests. These providers of ecosystem services and other natural services are crucial for ecosystems' proper functioning and thereby sustaining plant growth, crop production and protection against crop pests. Literature provides evidence for a great role that the ecosystem services play in sustainable crop production. However, limited information is available on significance, farmer's knowledge and their functions in bean pest management in tropical Africa. Lack of understanding on the ecosystem services and the providers of ecosystem services can lead to improper providers of ecosystem services conservation as a consequence, increase pest pressure which can result in poor crop yields. Therefore, this review discusses the level of understanding of small scale farmers, significance and potential use of the ecosystem services (pollinators and natural enemies of bean pests) for sustainable bean production and further, outlines potential research gaps for management and optimization of the ecosystem services in the tropical Africa.

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Introduction

Ecosystem services in agriculture refers to any nature-based activity that is offered by providers of ecosystem services such as pollinators and natural enemies in different processes such as biological control of pests, soil formation, nutrient cycling and or other related processes (Power, 2010; Messelink *et al.,* 2014; Lacey *et al.,* 2015; Ndakidemi *et al.,* 2016). These providers of ecosystem services are very important in Agriculture. For instance, a report by Hoehn & Tscharntke, (2008); Bartomeus *et al.* (2014), and Melin *et al.* (2014) indicated that more than 75% of the world crops benefit from pollinators leading to improved crop yields ranging from 25% to 99%. In a study by Ollerton *et al.* (2011) and Rader *et al.* (2015), wild and managed bees have been estimated to be effective in pollinating more than 87% of flowering plants in the tropic and temperate zones worldwide. Although some reports on ecosystem services are available for many locations, the literature shows fewer studies and hence less data on pollinators, natural enemies and their roles in agriculture in the tropical Africa. Shackelford *et al.* (2013) identified only one study in Africa on pollinators and natural enemies as compared with many studies in North America and Europe. Within this limited line of studies, it has been apparently described that Africa is endowed with massive species of flowering plants whose presence can enhance the presence of the provider of ecosystem services (Blaauw *et al*., 2015; Gaigher *et al.,* 2015).

Based on this phenomenon, authors hereby provide this review article to discuss the significance, farmer's knowledge and potential of the ecosystem services for improved bean production in the tropical Africa. Even though no studies on ecosystem services that were solemnly conducted in Africa, we already know well that common bean is a self-pollinating crop (Andersson *et al*., 2014) and that some studies have shown that pollinators can improve pollination in beans leading to increased yields (Kelly, 2010; Woodcock, 2012). The rate of out crossing in beans ranges from 4-89% depending on the genotype used, environmental factors, geographical area, row space and the number of pollinating insects (Musallam *et al.,* 2004). This entails likely roles of pollination to facilitate the out crossing process. Studies conducted in the United Kingdom (UK) and Rwanda show an increased yield of about 60% to 69% due to pollinator's involvement in bean (Garratt *et al.,* 2014). Besides pollination services, the provider of ecosystem services particularly the natural enemies play a significant role in pest management worldwide (Gaigher *et al.,* 2015). The level of understanding and application of natural enemies in pest management particularly in beans is still under studied in Africa. Therefore, it is worth exploring the significance, level of understanding of small-scale farmers and potential use of the ecosystem services for sustainable providers of ecosystem services conservation and bean production in the tropical Africa.

Status and significance of Ecosystem services

Small-scale farming ecosystems are believed to provide conditions for the presence and functioning of ecosystem services if undisturbed (Garbach *et al.,* 2014). However, pollinators, natural enemies and their modes of functioning in these farming ecosystems are not well known especially in the developing countries including the tropical Africa. In other parts of the world such as the United States of America, some insects have been commercialized for different purposes including biological control of some agricultural pests (Bale *et al.,* 2008; Cranshaw, 2014) and pollination services (Garratt *et al.,* 2014; Flint & Dreistadt, 2005). For instance, the USA exports parasite free colonies of bumblebees (*Bombus sp.*) globally especially to temperate countries such as those in Europe, North America, South America and Asia for pollination purposes in greenhouse crops (Woodcock 2012; Graystock *et al.* 2013). In the tropical Africa, literature is limited on the status of use and significance of ecosystem services especially on understanding the providers of ecosystem services and their possible contribution to agriculture (Kovács-Hostyánszki *et al.,* 2017). In addition, the providers of ecosystem services are in the danger of decreasing due to climate change, habitat loss and fragmentation, agrochemicals, spread of alien species and diseases (Colley & Luna 2000; Jones & Gillett

2005; Patterns *et al.,* 2010; Potts *et al.,* 2010; Vanbergen & Initiative 2013; Goulson *et al.*, 2015; Tiedeken *et al.,* 2016). Therefore, there is a need for collective choices and studies on understanding phenomenon behind providers of ecosystem services habitat, ethno-ecological and social perspectives to fully preserve and utilize benefits offered by the ecosystem for sustainable crops including beans production in the tropical Africa.

Key Providers of Ecosystem Services

Key providers of ecosystem services are summarized in Table 1, showing interestingly that some of the player such as insects depending on growth stages can perform more than one role in the ecosystem settings.

For instance, Hoverflies (*Diptera: Syrphidae*) is both a pollinator (in adult stage) and predator of pests such as aphids, thrips, mites, and other small insects in the larval stage (Moquet, *et al.,* 2017). In performing their role, the provider of ecosystem services can be very effective. For example, the Ladybird beetle have been reported by Gurney& Hussey (1970) and Eric (2017) to reduce their pray particularly aphids by 99% in a seven days' time. Other provider of ecosystem services such as Trichogramma wasps (*Trichogramma pretiosum*) appear to be the smallest of all insects but very important in biological pest control for their ability to parasitize eggs of many different orders of insects (Sarwar & Salman, 2015).

Table 1. Key insect provider of ecosystem services, role in crops and their predilection sites.

Name of ecosystem providers (Order : Family)	Role in crops	Predilection site	Reference
Honey Bees (Hymenoptera: Apidae)	Pollinator	Red flowers with short tubes, Nectar source plant, river bank and forest area	(Fothergill, 2009; Padhye, *et al.,* 2012; Parandhaman, *et al.,* 2012; Prabakaran, *et al.,* 2014)
Butterflies (Lepidoptera: Rhopalocerae)	Pollinator (adult)	Red flowers with short tubes, Nectar source plant, river bank and forest area	(Fothergill, 2009; Padhye, *et al.,* 2012; Parandhaman, *et al.,* 2012; Prabakaran, *et al.,* 2014)
Moth (Lepidoptera: Psychidae)	Pollinator (Adult)	White or pale flowers with strong fragrance producing plants	Hopwood, (2010); (Moore & Hanks, 2004; Villanueva & Rodrigues, 2005)
Stingless bee (Hymenoptera: Apidae)	Pollinator	Wild plants & crops	(Anguilet, *et al.,* 2015; Ramalho *et al.,* 1990; Slaa *et al.,* 2006; Villanueva-g, *et al.,* 2005)
Hoverflies (Diptera: Syrphidae)	Both predator of aphids, thrips, mites, and other small insects and pollinator	Queen Anne's lace, dill, fennel, tansy, coriander, bishop's weed, coreopsis, gloriosa daisy, yarrow, the cosmos, sunflower, marigolds, candytuft, sweet alyssum,	Cooperative Extension Service (CES) (2010); Stewart *et al..,* (2007)
Green Lacewing (Neuroptera: Chrysopidae)	Predator of aphids, mites, whiteflies, caterpillars, small soft-bodied prey & adult are pollinators	Melon crop	(Aldrich, *et al..,* 2016; Keulder & Van den Berg, 2013; Rana, *et al.,* 2017)
Assassin Bug (Hemiptera: Reduviidae)	Predator of most insects	Legumes	(Stewart, *et al.,* 2007; Virla, *et al.,* 2015)

Name of ecosystem providers (Order : Family)	Role in crops	Predilection site	Reference
Hoverflies (Diptera: Syrphidae)	Pollinator (adult) & larvae are predator of aphids, thrips, and mite	Bishop's weed, coreopsis, gloriosa daisy, yarrow, cosmos, sunflower, marigolds, candytuft, sweet alyssum, decaying vegetation	(Cooperative Extension Service (CES) 2010; Stewart, *et al.* (2007); (Lee, *et al.,* 2001)
Ground Beetle (Coleoptera: Carabidae)	Both adults and larvae are the predator of aterpillars, cutworms, ants, maggots, earthworms, slugs, and other beetles	Arable crops, heavier soils, trees and shrubs	(Chin, and Brown 2010); (Ghahari *et al.,* 2009; Lövei & Sunderland, 1996; Woodcock *et al.,* 2014)
Lady Beetle (Coleoptera: Coccinellidae)	Predator	Polen and nectar producing plants	(Getanjaly, *et al.,* 2015; Almeida, *et al.,* 2011; Frank & Mizell, 2009; Sarwar, 2016; Sloggett, 2012; Snyder *et al.,* 2004)
Brown Lacewing (Neuroptera: Hemerobiidae)	Larvae are predator of insect eggs, leafhoppers, mites, red-banded thrips, mites, immature mealy bugs, moth eggs and small caterpillars.	Tree/shrub crops, flowering crops, vegetation, orchards, carrot family and sunflower family	(Lee, *et al..,* 2001; Kovanci & Kovanci, 2007; Rocca & Messelink, 2016; Stange, 1997)
Green Lacewing (Neuroptera: Chrysopidae)	Larvae are predator of aphids, mites, whiteflies, caterpillars, and other small, soft-bodied prey	Melon crop	(Bezerra *et al..,* 2010; Stange, 1997; Rana *et al..,* 2017)
Long legged (Diptera: Dolichopodidae	Predators of aphids, thrips, young caterpillars, and mites predators or scavengers in detritus in soil.	Tree crevices, field margins, and crops	(Mahr, *et al.,* 2008; James, *et al,* 2016; Kautz, *et al..,* 2014; Kazerani, *et al.,* 2015)
Robber Flies (Diptera: Asilidae)	Predator of Flies, wasps, Grasshoppers, leafhoppers, beetles, and butterflies. Larvae feed on small insects	Rotting wood, foliage, bark and seed heads of grasses (eggs)	(Cannings, 2014; Samin, *et al.,* 2011; Samin *et al.,* 2011)
Tachinid Flies (Diptera: Tachinidae)	Parasitoids of Green clover worm, bean leaf beetle, beetle larvae, grasshoppers and caterpillars	Crops pollen	Pesticide Action Network (PAN), 2014; (Bhoje, 2015; De Farias, *et al.,* 2012; Gammelmo & Sagvolden, 2007; Saminet *al.,* 2011)
Spiders (Araneae: Sparassidae)	Predators of red-banded thrips, plant hoppers, caterpillars and moths	Soil, low vegetation/woody plants (perennial crops)	Cooperative Extension Service (CES) (2010; Ndakidemi *et al.,* 2016)
Trichogramma Wasps (Hymenoptera: Trichogrammatidae	Parasitoids of army worm eggs, corn earworms, cutworms, European corn borer and bean pods borer (*Marucavitrata*)	Closely spaced plants	(Fernandes, *et al.,* 2010; Belmain, *et al.,* 2013; Olson & Andow, 2006; Romeis, Babendreier, Wäckers, & Shanower, 2005)

Role of provider of ecosystem services in crop pollination

Some providers of ecosystem services particularly insect pollinators have been reported to be capable of moving pollen from one flower part to the other in so providing grounds for fertilization, seed and fruit set (Cruz *et al.,* 2005; dos Santos *et al.,* 2009; Heard, 1999; Munyuli, 2011; Slaa *et al.,* 2006). Insect pollinators including bee species such as honey bees, stingless bees, carpenter bees have been considered to play a primary role in crop pollination than as for non-animal agents such as wind pollination (Kremen *et al.,* 2007; Garibaldi *et al.,* 2013; Nunes-Silva *et al.,* 2013). For instance, Ollerton *et al.* (2011) reported that about approximately 308,000 species i.e. 87.5% of crops are pollinated by insects and other animals while the remaining percent is done by abiotic pollen carriers such as the wind worldwide. Pollination by insects has been reported to contribute to the yield of beans and other crops (Musallam *et al.,* 2004; Aouar-sadli *et al.,* 2008; Mireille *et al.,* 2012). For instance, Nayak *et al.* (2015) reported an increase by 18.5% of yield compared with that in self-pollinating beans.

Other providers of ecosystem services such as natural enemies including predators, pathogens, nematodes and microorganisms are as well important in crop-pest interactions (Lee *et al.,* 2001; Flint & Dreistadt, 2005; Vinyard & Hoelmer, 2016). These natural enemies vary in size and mechanism in pest control. For instance, some natural enemies such as Ladybugs (*Hippodamia convergens*) are large enough to chew their prey (Soares, *et al.,* 2003), lay eggs e.g. parasitoid wasp on the host tissue (van Nouhuys & Kaartinen, 2008) while others such as bacteria, fungi and virus cause diseases in the host pests (Riddick, *et al.,* 2009; Singh, 2014). In most cases, natural enemies particularly insects are most active at the larval stage (Ndakidemi *et al.,* 2016) while adults may or may not have similar food needs (Stewart, *et al,* 2007).They are considered as a promising control technique due to their safety, species specific and long-term action on the target pests (Sanda & Sunusi, 2014). Natural enemies may occupy non-cultivated farm areas (non-crop habitats) especially with herbaceous plants as their habitat (Grzywacz & Stevenson, 2014; Bianchi *et al.,* 2006).

The predilection principles behind natural enemies on prey and or habitats are basically not well-known. However, some information is available for example flower nectars and terpenoids produced by plants following damage from herbivorous species (Wei *et al.,* 2007). In pest control, natural enemies are potentially viable options to reduce numbers of insect pests to an acceptable damaging level.

Use of natural enemies as control options have been tested in open and greenhouse condition and have shown to be cheap, having a low side effect to human, animal and are environmentally friendly (Bale *et al.* 2008; van Lenteren, 2012; Wyckhuys *et al.,* 2013; Gurr & You, 2015). However, in tropical Africa, limited or full application of natural enemies despite the role they play has not been vividly reported and/ or quantified. As a general opinion, conservation of natural enemies such as lady bird beetles (*Coleoptera: Coccinellidae*), lacewings (*Neuroptera Chrysopidae*) syrphid flies, Chalcidae, Bracoidae, and Ichneumonidae is essential in crop including common bean to small scale farmers as this can regulate over-dependence and counteract the increased cost of synthetic inputs (Messelink *et al.,* 2014). These insects are effective as they can pray and parasitize other insects such as aphids, scales, mealy bugs, leaf hoppers, and various types of soft-bodied insects while completing their life cycles (Evans, 2009). Some of them can feed on thousands of known insect pests. For example, Lady bird beetles can eat 5000 aphids or similar prey during its lifetime (Flint & Dreistadt, 2005; Cranshaw, 2014; Green *et al.,* 2015; Fasulo & Halbert, 2015; Ndakidemi *et al.,* 2016). Such action can make significant contribution in controlling aphids in bean fields.

Other providers of ecosystem services such as parasitoids whether through super parasitism, multi parasitism or hyper parasitism also play unique roles in agricultural crop protection (Lewis *et al.,* 1998). They are usually smaller than their hosts (Cohen *et al.,* 2016). Parasitoids have the characteristics of both predators and parasites (Extension, 2014; Zheng *et al.,* 2015). They can target hosts that are already infected and are among a well-known biological insect pest control strategy in the fields (Schmidt *et al.*, 2003; Mwanauta *et al.,* 2015). Their presence and effectiveness are favored by the presence of nectar which provides them with energy as they go around to search for the host (Lewis *et al.,* 1998). Parasitoids have ability to confiscate, change hormone and behaviour of the host pest to make a conducive environment for their development (Beckage, *et al.*, 2003; Libersat *et al.,* 2009). Most common parasitoids are those from families, Diptera (two-winged flies) and Hymenoptera (Saw flies, wasps and ants) (Hassell, 2000). They spend a significant portion of their life attached to or within a single host ultimately killing it (Libersat *et al.,* 2009). For example, to kill an aphid, larvae and pupa parasitoid pupates and grows within the aphids cuticle forming mummies (Chapman *et al.,* 1981). Parasitoids often complete their life cycle more quickly and increase their numbers faster than many predators (Messelink *et al.,* 2014; Grzywacz *et al.,* 2014). Parasitoids have been reported to contribute to about 33% of natural pest control (Getanjaly, *et al.*, 2015). The most known parasitoids are wasps and flies and their activity have been reported to show better results in insect control in the area where no insecticides are applied (Ampofo, 1996; Rehman & Powell, 2010). Pest management with parasitoids are cost-effective when pest densities are low (Wang & Keller, 2002). They are generally more delicate than predators and hence more vulnerable to pesticides (Gill & Garg, 2014). The role of different pollinators and natural enemies in providing ecosystem services is not well documented in the subsistence farming systems found in Africa. Understanding their roles will lead into yield increment with less agricultural inputs.

Role of farmers' knowledge on enhancement of ecosystem services in tropical Africa

Farmers possess knowledge and practices acquired through series of observation, beliefs, rules, and experiences and that are communicated from elders to younger ones and from one generation to another (Gadgil *et al.*, 1993; Boafo *et al.,* 2016; Parrotta *et al.,* 2016). Farming practices involving indigenous knowledge can enhance ecosystem preservation through multiple crop species management, landscape patchiness management, and other ways of responding to and managing beans and ecosystem surprises (Berkes *et al.,* 2000). Local knowledge can contribute to a good understanding of historical perspectives that can provide information to science (Chalmers & Fabricius, 2007; Sileshi *et al.,* 2009). Farmer's knowledge is very important in harnessing the ecosystem services because of its site specificity and practicability (Munyuli, 2011). African indigenous communities possess knowledge and perceptions on an ecosystem and their managements in relation to farming activities that are local to their areas of origin (Berkes *et al.,* 2000). This knowledge has been changing according to changes in environments, introduction of new technologies and social conditions (Parrotta *et al.,* 2016). Indigenous knowledge on types of crops, the timing of cropping, and ways of prevention the crops from pests and diseases and types of agents used for such prevention are important and traditionally practiced worldwide (Ardakani & Emadi, 2008). Statistics show that 2.1 -2.5 million people that are directly involved in small hold farming are in the tropics and 500 million are from developing country (IFAD 2013; Steward *et al.,* 2014). However, growing population and increased demand for food have changed the cropping system to expanded land and specific cropping (monocropping) in many locations worldwide and lesser in the developing countries including tropical Africa (Abate *et al.,* 2000). Tropical Africa possesses an enormous diversity of plants species which contribute to the presence of the providers of ecosystem services (Brondizio *et al.,* 2014). However, the decision on how to manage land for obtaining services from those providers of ecosystem services are currently affected by lack of understanding of the role of providers of ecosystem services by farmers including those growing bean on one hand and different dynamics like climatic changes topographical constraint, social values, increased farming and household characteristic on the other (Lamarque *et al.,* 2014). It seems also that, there is little research attention, poor regional research collaboration and lack of clear policy support framework for the ecosystem services and providers of ecosystem services in tropical Africa (Machekano *et al.,* 2017). It is apparent that some small scale farming communities still practice intercropping, conservation farming, mixed cropping and non-tillage cropping all of which ensure the presence of a great diversity of species that enhance natural ecosystem services (Munyuli, 2013; Dicks *et al.,* 2016; Puech *et al.,* 2015). There is information that use of pesticidal plants is positively practiced either as extract or intercropped with crops for insect pest control (Singh *et al.,* 2017). However, farmers' indigenous knowledge on botanical pesticides need to be improved (Mkindi *et al.,* 2015). Integrating processes such as botanical pesticides and providers of ecosystem services management is not demarcated or characterized in the tropical Africa. For any successful invention, bottom up approaches have shown a great success across the world in a number of technologies. Use of indigenous knowledge and experience therefore provides for baseline information and a way to improve agricultural sustainability through the ecosystem services management.

Potential of ecosystem services in pest management and bean production in tropical Africa

Common beans production is currently constrained by high pests pressure and poor seed set mainly due to pollen deficit (Mwanauta, *et al.,* 2014). With the increasing awareness on beneficial attributes associated with ecosystem services, there is no doubt that the communities will realize their benefits and practice ways to harness full potential of the providers of ecosystem services for improved bean production. It is already reported that the providers of ecosystem services have proved to be effective in bean pest management and pollination in other locations outside the tropical Africa (Bale *et al.,* 2008; Slaa *et al.,* 2006). Though threatened, effort of encouraging conservation of the providers of ecosystem services is being promoted at global, regional and national scales worldwide (Gill, *et al.,* 2016; Tscharntke *et al.*, 2012). More research on the utilization and conservation of the providers of ecosystem services for their effect on yield increment through pest reduction and pollination are constantly considered the most critical agenda in sustainable crops production worldwide (Cane *et al.,* 2007; Garibaldi *et al.,* 2013; Nunes-Silva, *et al.,* 2013; Getanjaly, *et al.,* 2015). As far as the tropical Africa is concerned, it is obvious that farmers can increase beans production through the management of landscape and agricultural ecosystems which will automatically conserve the providers of ecosystem services (Munyuli, 2013). This should go hand in hand with discouraging excessive use of synthetic pesticides which not only pose side effects on human health and are of higher costs, but also negatively affect beneficial insects including the providers of ecosystem services (Grzywacz, *et al.,* 2014; Kedia, *et al.,* 2015; Mkindi *et al.,* 2015; Mwanauta *et al.,* 2015; Parker, *et al.,* 2013; Mkindi *et al.,* 2017). Moreover, there is need to create awareness among bean farmers and encourage collective choices for managing and harnessing the full potentiality of the providers of ecosystem services to realize what the ecosystem services is currently and will be doing in beans production in the tropical Africa.

Conclusion and research needs

In conclusion, ecosystem services and providers of ecosystem services and other natural services are crucial for ecosystems' proper functioning and thereby sustaining plant growth, crop production and protection against pests. Use of existing natural resources particularly those obtained through ecosystem services as stipulated in this review are worth of identifying, testing and utilizing in the tropical Africa. This can easily be achieved because of the diverse nature of crops, altitudes, climates and habits for the providers of ecosystem services in the region. Research however is needed on rigorous understanding of ecosystem services and providers of ecosystem services and other natural services, possible dynamics and factors affecting their survival and functions and how to better harness them for improved bean and other crops production in the tropical Africa.

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