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Potential of intercropping pesticidal plants with common bean in promoting natural enemies for pest management in agroecosystems

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Abstract

Use of pesticidal plants (PPs) is now evolving as one of the essential means to be used in protection of crop plants or produces from pest attack and substitute synthetic chemical pesticides. The PPs possess an array of properties such as toxicity, anti-feedance, repellency, deterrents and attractants and insect growth regulatory activities against important pests. Planting different crops in the same fields at the same time (intercropping/mixed or strip cropping) encourages biodiversity and abundance of natural enemies (NEs). Also, intercropping crops with non-crops encourages the abundance of NEs and parasitoids and therefore, effective biological control strategy in an economically and environmentally sound way of managing pests for grasping the maximum yield potential of crop. Examples of PPs which have been reported to portray a good result in terms of repelling pests and NE enhancement when allowed to grow with crop plants are *Tagetes minuta*, *Bidens Pilosa*, *Ageratum conyzoides*, *Galinsoga parviflora*, *Cleome rutidospema*, *Ocimum suave, Hyptis suaveolens* and *Nasturtium indicum*. In this study, comprehensive information on the use of PPs as repellants to insect pests and promotion of natural enemies in common bean production is discussed.

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Introduction

Common bean (*Phaseolus vulgaris* L.) is an essential sustenance grain legume in the world, which provides 15% and 30% of the protein and calories, respectively to the world's population (McConnell *et al.*, 2010; Kalavacharla *et al.*, 2011). The common bean forms 50% of the most common grain legume consumed by a global population and it is nearly twice the production of chickpea, which is the second most important grain legume globally (Broughton *et al.*, 2003). It covers 46% of the global legume production followed by chickpea which occupies 22% and the rest cover less than 10% (Akibode and Maredia, 2011). Legume seeds with no exception to common bean are rich in amino acid lysine, complementing the nutritional profiles of cereals, roots and tubers (Phillips, 1993; Broughton *et al.*, 2003; Hillock *et al.*, 2006; Catherine, *et al.*, 2015). Regularly, they represent essential supplement to other protein sources (Duranti and Gius, 1997; Duranti, 2006; Graham and Vance, 2003). Common bean occupies an important place in human nutrition in East and Great Lakes Regions of Africa by improving the nutritional status of most low earning populations (Doughty and Walker, 1982; Shimelis and Rakshit, 2005; Shimelis *et al.*, 2006). It also maintains animal health especially in developing countries where meat and dairy production is almost solely dependent upon forage legumes and grasses (Russelle, 2001; Wattiaux and Howard, 2001; Dorry, 2008; Graham and Vance, 2003).

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

Selected insect pests of economic importance in common bean

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

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

Aphid is one of the most significant pests of numerous cultivated crops throughout the world (Volkl and Stechmann 1998). It is the principal insect pest directly damaging common bean in Africa (Remaudire *et al.*, 1985). It has been reported that large colonies may be very damaging, cause direct damage by phloem feeding, resulting in significant impairment of plant growth and grain yield (Parker and Biddle 1998; Shannag and Ababneh 2007b). The colonies around the stem, leaves and growing points; suck sap from plants through narrow piercing-sucking mouthparts called stylets and cause seedlings to wilt and die (Karel and Autrique, 1989; Iwona *et al.*, 2011; IPM legume manual, 2016).

Fischer *et al.* (2005) and Bahar *et al.* (2007) reported the secretion of honeydew from the affected plants which enhances the growth of sooty moulds and hence interferes with the photosynthetic ability of plants. According to the study by Basedow *et al.* (2006) and Abate *et al.* (2000), the relationship between injuries caused by aphid and crop yield depends on the growth stage of the host at the time of invasion. Further, study by Wosula, (2016) showed that in common bean production, a yield loss ranging from 37 to 90% is caused by aphids. Due to the complexity in the life cycle and high reproduction rate of this insect (Rusin *et al.*, 2017), it has become difficult to control using synthetic pesticides. Therefore, there is a need of developing other strategies such as the use of agronomic, cultural, biological and pesticidal plants (PPs) as control methods which target the insect during the specific time of damage. Some of the PPs which have been reported to control this insect include *Azadirachta indica*, *Eucalyptus globules*, *Bidens pilosa*, *Tagetes minuta*, *Ageratum conyzoides* and *Ocimum basilicum* which were reported to have maximum repellency against aphids (Singh *et al.*, 2012; Anjarwalla *et al.*, 2016; Verma *et al.*, 2016; Rioba and Stevenson, 2017). Thus the use of live PPs can be manipulated in the cropping system (intercropping/mixed/strip cropping) to repel insect pests and attract the natural enemies which feed on aphids and other pests. This is an eco-friendly and low-cost method of controlling this insect pest and eventually improved common bean production. It is therefore necessary to carry out further studies on intercropping PPs with common bean to acquire information that can be used as the basis for potential plants that repels this insect pest and enhance abundance of NEs that prey on them.

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

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

Bean Foliage Beetle – BFB (Ootheca spp)

Ootheca species are seedling pest which is widely distributed in Africa (Allen *et al.*, 1996). The presence of young bean seedlings has been reported to be a favorable condition appears to stimulate adult emergence of the BFB from hibernation in the soil (Buruchara *et al.*, 2010). The larva of this insect cause below ground damage and above ground damage is caused by the adult (Ampofo *et. al.*, 2002). However, both damages disrupt nutrients transport and potential for nitrogen fixation (Minja, 2005). Karel and Rweyemamu, (1984) reported an adult *Ootheca* to cause 18-30% yield loss. Studies by Ampofo and Massomo, (1998) revealed that heavy infestation of *Ootheca* is the result of crop intensification i.e. continuous cultivation of the same crop in the same piece of land without rotation or fallowing. Since common bean production in Africa is carried out by small-scale farmer with farms not exceeding one hectare, then fallowing or crop rotation is not practicable.

Therefore, alternative method(s) to deal with this insect pest is inevitable. It has been reported that applying combinations of strategies including different forms of PPs such as neem seed extracts deter infestation and reduces the damage (Buruchara *et al.*, 2010). It's likely that if live PPs are intercropped/mixed with common bean can work in control of the foliage beetle problem at no or lower cost. Little is known on potential of some plant species in controlling of this pest. Thus, there is a need of exploring more plants particularly live PPs for bean protection.

Whitefly (Bemisia tabaci)

B. tabaci is the most economically important whitefly species which pose a challenge to beans production worldwide (Gerling, 1990). It has been reported to cause severe economic damage in over 60 crop plants (including common bean) as a phloem sap-sucking pest or as a vector of viral diseases (Navas-Castillo *et al.*, 2011; Naveen *et al.*, 2017). In Africa, the pest occurs almost in all bean growing ecologies (Buruchara *et al.*, 2010) and a yield loss of 14-86% has been reported by in Sudan (Salifu, 1986). The larvae of this insect pest need a lot of protein for growth thus consume a large quantity of plant sap and the excess is excreted as honey dew (Malais *et al.*, 2003) and this makes it to be a serious pest of common bean. The honey dew on the surface of leaves encourages growth of fungal moulds whereas heavy growth of sooty moulds reduces photosynthesis affecting plant growth (Henneberry *et al.*, 1996). Both nymphs and adults suck sap from leaves, causing them to become mottled, with light yellowish spots on the upper surface. Whitefly populations may build up in large colonies on the underside of leaves. The adults may transmit the cowpea mild mottle virus in beans.

Whiteflies tend to breed all year, moving from one host to another as plants are harvested or dry up (Flint, 2007). Low levels of whiteflies do not cause much damage hence do not warrant control interventions (Abate and Ampofo, 1996). However, management of whitefly is very difficult in case of heavy infestations.

This is because whiteflies are not well controlled with any available insecticides. Studies by Gorman *et al.* (2007); Nderitu *et al.* (2010; Cardona, (2012); Naveen *et al.* (2017) reported resistance by whitefly species to synthetic insecticides which make it difficult to manage the pest. Therefore, alternative affordable and safe methods to deal with the insect are crucial. PPs such as neem oil has been reported to reduce but not eliminate whitefly populations. Thus, studies can be conducted on the same concept as of neem to evaluate how different live PPs would work in control whiteflies when manipulated in common bean farming.

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

Common control measures for insect pests in common bean

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

Use of Synthetic pesticides

It is estimated that about 1.8 billion people in the globe engage in agriculture and most of them use pesticides to protect food and commercial products they produce (Williamson *et al.*, 2008). Synthetic pesticides are reported to be fast acting and can kill a wide range of insect pests but have a number of limitations attributed to killing of both beneficial and non-beneficial insects. They are also limited in rural areas, are too expensive or unavailable and are often adulterated or applied at inappropriate application rate due to lack of knowledge, and are often poorly labeled or even used after expiry date. All these lead to the evolution of pesticide resistance and resurgence (Stuart, 2003).

Producers and consumers health and safety are highly threatened by the use of synthetic pesticides with no mechanism in place to ensure safeness of the produce and concern for the prolonged effects of exposure (Hart and Pimentel, 2002; Pimentel, 2005). Sola *et al.* (2014) and Agrow, (2006) reported that a very low quantity (2-3%) of the global pesticide market is used in Africa. Still, the continent bears the highest human mortality risks related to misapplication of pesticides. Stoddard *et al.* (2010) reported the reduction of leaf miner, *Liriomyza huidobrensis* by using imidacloprid pesticide which at the same time suppressed its parasitoid. From this descriptions, synthetic pesticides kills a wide range of organisms in place including beneficial ones. Therefore, adoption of alternative low-cost control measure that is less harmful to natural enemies and parasitoids and with health benefits to the applicators, producers and consumers are inevitable. In that case, pests' management through manipulation of live PPs in common bean cropping system can be critical.

Botanical pesticides (hereinafter pesticidal plants)

Pesticidal plants (PPs) are naturally occurring chemical compounds extracted or derived from plants to manage pests in the field and pests damaging stored produces (Sola *et al.*, 2014). Rosenthal and Berenbaum, (1991) and Weinzierl, (2000) reported the use empirical knowledge on the use of PPs for managing pest in different parts of the world before the development of synthetic insecticide. Some examples of PPs used to control different insect pests are; rotenone compounds from several plant species in East Asia and South America (Kennedy, 2011), neem (*Azadirachta indica*) in India, (Hedge, 1995; Singh and Raheja, 1996; Anonymous, 2006), sabadilla (*Schoenocaulon officinale*) in Central and South America (Isman, 2006; Guzman-Pantoja, 2009; Singh and Saratchandra, 2005) and pyrethrin from Pyrethrum (*Chrysanthemum cineraniifolium*) in Persia (Iran) (Parr, 1975; Weinzierl, 2000).

Studies have shown that plants are very good source of crop protectants against pests (Isman, 2008). They can easily degrade in the environment, and they are easily available, less toxic to human and non-targeted organisms and are compatible with different human cultures (Weinzierl, 2000; Oruonye and Okrikata, 2010; Mpumi *et al.*, 2016).

In countries like Benin and Uganda, PPs such as pyrethrins and neem and African marigold extracts are used to control cotton bollworm and storage pest of cowpeas respectively (Kawuki *et al.*, 2005). In other parts of Africa, PPs such as bushmints (*Hyptis suaveolens*) have been used for the control of pink stalk borer (*Sesamia calamistis*) on maize (Adda *et al.*, 2011). Ogunsina, *et al.* (2011) reported *Lantana camara*, (Verbenaceae), African nutmeg and *Euphorbia lateriflora*, Schum and Thonner to be effective against bean weevil and maize weevil. Recently, Stevenson *et al.* (2017) have reported selected pesticidal plants being used by small scale farmers in Africa to manage different field and storage pests. This includes *Ageratum conyzoides, Biden pilosa*, *Dysphania ambrosioides*, *Tagetes minuta*, *Tephrosia vogelii*, *Tithonia diversifolia* and *Vernonia amygdalina* among others.

With these few examples, it is undeniable that the PPs are used intensively in a number of crop systems, particularly in Africa. Most studies described the use of PPs in different form e.g. powder, crude oil, aqueous extract, ethanol extract, (Asogwa *et al.*, 2010; Amoabeng *et al.*, 2013; Karani *et al.*, 2017).

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

In Tanzania, several studies have shown that the PPs are effective in controlling field and storage insect pest of common bean. For instance, Paul, (2007) reported insecticidal properties of neem (*Azadirachta Indica* L.), worm seed (*Chenopodium ambrosioides* L.), cypress (*Cupressus lucitanica*) and marigold

(*Tagetes minuta* L.) in management of important field insect pest of beans. Studies by Mkenda and Ndakidemi (2014); Mkindi *et al.* (2015), Mwanauta *et al.* (2015), Mpumi *et al.* (2016) reported effectiveness and toxicity of PPs particularly *Tephrosia vogelii*, *Venonia amygdalina*, *Tithonia diversifolia* and *Lantana camara* in managing field insect pests of major economic importance (Aphids, Bean stem maggot and *Ootheca)* in common bean production. Other PPs reported having a strong ant-insecticidal properties include *Tagetes minuta, Grewia similis* K. Schum and Echnops, *Hispidus fresen* (Machocho, 2012).

All these studies described the use of PPs in other forms (such as powder, oil, aqueous & commercial) to control insect pest of common bean.

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

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

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

Biological control

This can be defined as the use of an organism to reduce the population density of another organism (Bale *et al.*, 2008). When we focus on the biological control of insect pest, it can be defined as the study and uses of predators, parasites and pathogens for regulation of pest densities (De Bach, 1964).

Biological control is divided into three techniques which are: classical (sometimes termed as inoculative biological control), augmentative (where a distinction can be made between 'inundation' and 'seasonal inoculation') and conservation control (van Lenteren 1993a, 2006b).

Classical control

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

Augmentation

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

Conservation control

Conservation control refers to the usage of native predators and parasitoids against native pests. Various measures are implemented to enhance the abundance and activity of the natural enemies, including manipulation of the crop microclimate, increasing the availability of prey, and providing essential food resources such as nectar and pollen for adult parasitoids and aphidophagous hoverflies (Gurr *et al*. 2000; Wackers 2003; Winkler *et al*. 2005). Biological control is more advantageous in comparison with synthetic pesticides and therefore its practicability is highly encouraged to lower cost of production, ensure environmental safety and health of the consumers and farmers.

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

Cultural control

This method aims at altering hosts' environment or behavior of the pests and the host makes the pests less likely to survive, grow or reproduce.

It involves the use of crop rotation, planting and harvesting time, irrigation management; trap crops, intercropping (Herzfeld *et al*., 2011).

Intercrops as a cultural control of insect pest

Intercropping is the practice of rising different crops in the same field at the same season. It can reduce the insect pest populations, increasing beneficial insects (natural enemies, parasitoids and pollinators), and weed suppression (Gurr *et al*., 2004; Gianol *et al*., 2006; Smith and Liburd, 2012; Bellon and Penvern, 2014). In addition, non-crop plants such as pesticidal plants (PPs) can be intercropped with crop plants to influence numbers of pest and beneficial arthropods (Frank and Liburd 2005; Smith and Liburd, 2012). Gurr *et al*. (2016) reported improvement of natural enemies and detritivore abundance by different plants grown in the same field and at the same season. Kasina *et al*. (2006) reported insect pests to be repelled by volatiles produced from intercropped crops and promote the population of natural enemies. There are limited studies on the role(s) played by important pesticidal plants in bean fields for crop protection. Therefore, more research is needed to investigate the role played by the plants particularly pesticidal ones for effective biological control.

Effect of synthetic pesticides use on natural enemies

Natural enemies (NEs) are adversely affected by and usually perish through synthetic pesticides. Synthetic pesticides kill natural enemies including those in resistant stages at the time of application and those which will migrate into the sprayed area (Bacci *et al*., 2007). The same author further reported that if natural enemies exposed to pesticides were not killed at the time of application, there is a possibility of the pesticides to accumulate to a lethal level. The mortality rate of 61% of parasitoids *Encarsia* sp has been reported to be caused by cartap, imidacloprid, malathion, methamidophos, abamectin, acephate and acetamiprid insecticides (Thomson, *et al*., 2001). Martinous *et al*. (2014) reported 100% mortality rate of *Macrolophus pygmaeus* nymphs predator caused by thiacloprid pesticides.

Another insecticide cypermethrin has been reported to reduce the number of spiders (generalist predator) and increase the number of white-backed plant hoppers. An increase in this insect pest can be due to resurgence (Vorley, 1985; Caroline, 1996). Hassan *et al*. (1988) reported over 80 percent mortality of the tested parasitoid and predators to be caused by the same synthetic pesticide.

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

The effect of intercrops on natural enemies

Intercropping is a form of polyculture commonly used in tropical parts of the world and by indigenous peoples throughout the world (Altieri, 2000; Cai *et al*., 2010). Elmore and Jackobs (1984); Altieri (1994); You and Xu (2000); Blaser *et al*., (2007), described intercropping as a means of enhancing botanical diversity and abundance of natural enemies, (such as predators and parasitoids) which prey on insect pest thus increased crop yield and quality. In view of this, many ecologists and entomologists advocate intercrops in cropping system for suppression of insect pests (Andow, 1991; Landis *et al*., 2000). For example, it has been reported that increased botanical diversity generally enhances abundance of ground predators, such as carabids, staphylinidae and lycosid spiders (Hummel *et al.*, 2002). Andow, (1991); Altieri, (1994) reported an increase of natural enemies specifically predators in cotton & maize and peanut & corn intercropping systems. This is an important practice to be incorporated in the cropping system for pests' suppression, control of soil erosion, conservation of soil moisture, build-up of organic matter and more important the health of the growers and consumers as it is an alternative to synthetic pesticides which pose high health risk to producers and consumers. However, little information is known about intercropping some native live pesticidal plants in attracting the agents of biological control and repel pests. Thus, there is a need for further study to determine effects of intercropping the plants in bean fields.

The effect of intercropping pesticidal plants with other crops

Pesticidal plants (PPs), especially of weed species can be intercropped with crops for different purposes with insect pest suppression being the major one. In a study by Penagos *et al.* (2003), it was observed that, there was a decrease in insect pest and increase in natural enemies' numbers in a maize plot with weeds compared with maize plots under rigorous manual weed control. In the same study infestation of maize by fall armyworm larvae, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) was heavy in non-weedy plot compared with a weedy plot. Under the same condition, the number of aphid infestation were reported to be lower (Altieri 1980; Penagos *et al.*, 2003). It is possible some weedy species had volatile organic compounds which repelled aphids and at the same time created diverse environment for NEs such as predator which feeds on aphids and parasitoid which parasitized *S. frugiperda*. Another study by Ngatimin *et al.* (2013) reported the effect of weed management level on the abundance of insect natural enemies in cabbage fields where the number of natural enemies in the field without herbicide application was reported to be higher compared with the field with herbicide application. The same has been reported in the study by Penagos *et al.* (2003).

From those examples, it seems that weeds have something to do with insect pest suppression. Therefore, weeds with pesticidal effect can be mixed/intercropped in cropping system to attract NEs and repel some insect pests. Examples of weeds reported to have positive outcome in insect pest suppression in cabbage field are; *Nasturtium indicum* (Brassicaceae), *Galinsoga parviflora* (Asteraceae), *Ageratum conyzoides* (Asteraceae) and *Cleome rutidospema* (Capparidaceae). It is further reported that weeds have been used to increase the vegetation diversity which in turn helps to enhance the natural enemy population (Altieri and Whitcomb, 1979). The hypothesis here would be greater diversity of habitat for NEs so provision of greater abundance and varierty of prey and hosts of predatots and parasitoids. With this description, weed population in a cropping system can be manipulated (e.g intercropped, strip cropping, planting at the edge of the field) in such a way that non-crop vegetation can effectively function as a source of natural enemies but without causing adverse effects on the main crop production. For example, weeds are kept as strip plant between crop rows or allowed to grow on the boundaries of the field (Andow, 1991; Landis *et al*,. 2005; Ngatimin *et al.*, 2013;).

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

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

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

It is further reported that Coccinellids predator demonstrate affinities for certain plants regardless of prey availability but, such preference has not been effectively exploited in biological control (Michaud, 2012). For example, in German, Schmid (1992) it was observed that coccinellids had consistent patterns of occurrence on particular non-crop plant species, mostly common weeds, and avoided others. The reported affinities were independent of the presence of prey as fully 40% of the coccinellids were observed on plants without aphids, it seems that, non-crop plants can attract beneficial insects regardless of its prey availability. Lixa *et al.* (2010) reported six species of Coccinellidae to be attracted to aromatic species of Apiaceae (dill, coriander and sweet fennel) particularly in their blooming seasons; Silva *et al.* (2010) found the increased abundance of coccinellids and other beneficial insects in lemon orchards in response to ground cover vegetation.

In Africa PPs like *Biden pilosa*, *Tagetes minuta* and *Ageratum conyzoides* have shown the same effect of attracting Cocinnelids (unpublished data). However, with the described effect of live PPs on insect pests and natural enemies, information on the use of PPs as an intercrop with common bean is very limited. This call for diverse research of PPs especially of weed species to be intercropped with common bean to come up with findings on how they control insect pests without negatively affecting the main crop yield.

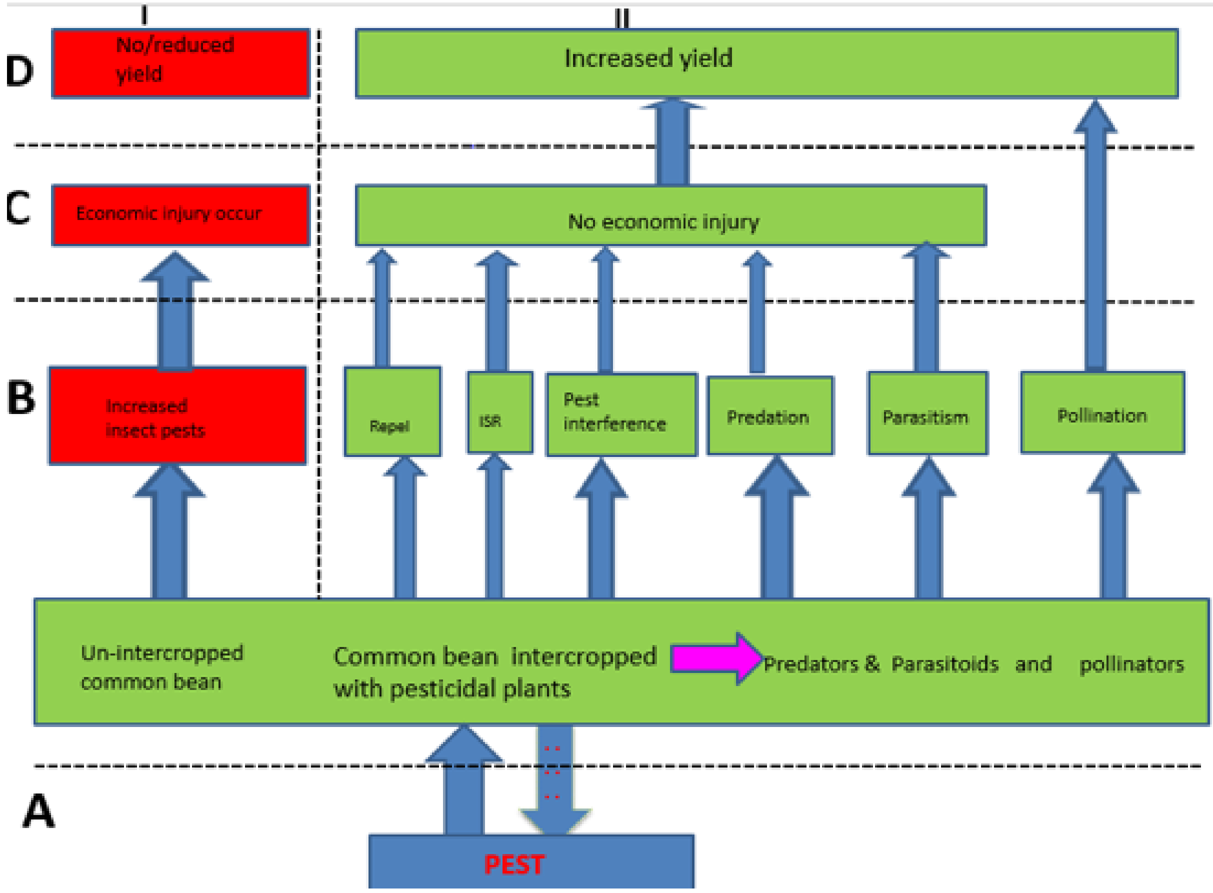

Fig. 1. A model describes how common bean, pesticidal plants (PPs), and natural enemies (NEs) interact with the pests in the field.

In stage A, the pest receives signals (essential oil/chemical communication) released by a host plant (common bean) and moves towards the host plant.

In stage B (II), the pest reaches the surface of the host plant intercropped with PPs and there a combination or either of the following can happen, volatiles produced by PPs can repel the pest or elicit the plant to develop induced systemic resistance (ISR), the intercropped plants produce volatiles which can confuse the pest and therefore difficult for it to locate the host, when two or more plants are grown in the same field concurrently, food resources are scattered compared with monoculture therefore condition will not fully favor the pests. Furthermore, intercropped plants create vegetative diversity which is an essential condition for attracting beneficial insects i.e. NEs (predators & parasitoids) and pollinators. NEs prey or parasitize the pests and if combination or either of these happens, the plant will not be colonized by the pest thus no economic injury (part II C) as a result bean quality and productivity will be enhanced D (II).

In stage B (I), the pest will also reach the surface of un-intercropped host plant (monoculture) where population density of the pest is high (resource concentration hypothesis). If no control measure being applied here then the pests population will multiply and colonize the plant leading to reach stage C (I) and cause economic injury. As a result there will be no/low yield; Stage D-II (Karani *et al*., 2017 with modification).

Conclusion

The potential of intercropping non-crop plant particularly pesticidal ones with common bean needs to be pronounced as a means of enhancing botanical diversity for promotion of natural enemies and therefore the eco-friendly and low-cost strategy for pest management. Intercropping common bean with non-crop plants is a possible approach toward pest control since they are considered safe to the environment, growers, consumers and human health. Furthermore, farmers do not need time for extract/powder preparation, they will not bother with the knowledge on dosage and application frequency which are technical recommendations.

After crop harvest, PPs can also being harvested for making different extract against field and storage pest. More research has to be done on the use of live plants particularly pesticidal ones on the effect of insect pests, diversity and abundance of natural enemies also beneficial insects like pollinators and their effects on common bean production.

The hypothesis behind can be one or combination of the following; 1) the volatile organic compound produced from the plants as a response to damage by herbivore insects are used as cues by the natural enemies (NEs) to aid in the location of their prey, 2) volatiles produced by intercropped plant can confuse the pests and make it difficult for them to locate the host, 3) crop mixture provide a greater diversity of NEs through provision of of greater abundance and variety of prey and host of of predators and parasitoids , 4) when two or more plants are grown concurrently, 5) food resources are scattered compared with monoculture therefore condition will not fully favor the pests, 6) non-crop shadingcan affect the pestse.g aphids are highly affected by shading, 7) non-crop plant can directly masking the crop plant and therefore protect it from pest, 8) botanical diversity provide food resources and shelter for NEs (make it possible to survive even in the absence of its host) and 9) volatiles from non-main crop can directly repel the pests (Fig. 1 is a model which describe the scenerios).

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