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Potentials and challenges of natural pest control for sustainable legume production in Africa

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Abstract

Insect pest is among major challenges facing leguminous crop production in small scale farming systems in Africa. Control using chemicals is both expensive and uncommon among farmers in the region. Need for cost effective and ecofriendly methods such as natural pest control are highly appropriate and recommended for sustainable leguminous crop production in Africa. Natural pest control is an innovative, sustainable and environmentally benign pest management service delivered to agriculture through natural enemies (NEs). Most of the NEs belong to several arthropod orders and they are in three major categories; predators, parasitoids and pathogens. These beneficial organisms can be found in large numbers in natural and semi-natural habitats where there is less environmental disturbance. However, there is insufficient knowledge among most African farmers about natural pest control and differentiating the beneficial insects from the insect pests has been a challenge among them. Poor management of agriculture ecosystems like indiscriminate use of chemical pesticides, herbicides, fungicides, fire settings and simplification of agricultural ecosystems such as clearing of non-cropped habitats and decreased farm heterogeneity are among the factors affecting the NEs leading to weakened natural pest control. This review explores the science of the NEs, their potentials and challenges in pest management in legumes and proposes the recommendations for research on the use of NEs for sustainable agricultural production in small scale farming systems in Africa.

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Introduction

Natural enemies (NEs) in agriculture refer to organisms that attack and feed on other organisms, particularly on insect pests of plants leading to a type of pest regulation referred to as natural pest control or sometimes biological control (Aquilino *et al.*, 2005; Martin *et al.*, 2013). They play a significant role of limiting the potential pest populations. Biological control of pests has the advantage of being self-perpetuating once established with no harmful effects to non-target organisms found in the environment. The practice of using NEs in pest control is environmentally friendly since it does not pollute or disrupt the environment and other associated components as do chemical pesticides (Eilers and Klein 2009; Souobou *et al.*, 2015).

The use of NEs in pest management is also considered safe, permanent once established and cost effective to small scale farming worldwide. Permanence, safety, and economy are the three major factors to consider in pest management strategy (Chaplin-Kramer *et al.*, 2011; Eilers and Klein 2009). The NEs contribute to about 33% of the natural pest control in agricultural systems worldwide (Getanjaly *et al.*, 2015). In nature, the number of NEs is greater compared with insect pests (Van Lenteren, 2000; van Lenteren *et al.*, 1995, van Lenteren and Martin, 1999). For instance, Van Lenteren, (2000) reported that there are about 25 species of parasitoids in the family Aphelinidae that attack whitefly and about 50 other NEs are still under investigation for the same pest species, this being the subset of about 200 NE species known to attack whitefly worldwide.

The NEs have been grouped into two major categories; macro-biological control (Predators, Parasitoids) and micro-biological control (disease causing organisms or pathogens) such as virus, protozoans and some bacteria (Belmain *et al.*, 2013). In this review, macro-biological control have been discussed to show potentials and challenges so that a proper understanding of these factors can enhance conservation and utilization of the NEs in agricultural fields for sustainable crop production among small scale farming in Africa.

Major groups of NEs used to control insect pests in leguminous crops

Predators

This group of NEs is composed of several insect orders which are generally characterized as free-living, mobile, larger body size than their insect prey, and capable of consuming several preys throughout their life cycle (Jones, 2005). Arthropods (Table 1) are the most important predators in pest management and they include lady beetles, lacewings, syrphid flies, assassin bugs, ground beetles, rove beetles, spiders, predatory mites, flower bugs, hover flies, long legged flies and robber flies (Brun, 2014; Charlet *et al.*, 2002; Getanjaly *et al.*, 2015; James, 2014). Some of the predators deposit their eggs near their prey so that when they hatch the immatures can immediately find their host and begin feeding (Macfadyen *et al.*, 2015). They prey on different stages of pest life cycle including insect eggs, young caterpillars and adults.

Parasitoids

Parasitoids are usually members of the order Hymenoptera (wasps) and a few are members of the order Diptera (Table 1). Sampaio *et al.* (2009) reported that about 80% of 600,000 known Hymenoptera species are parasitoids. They are considered important bio-control agents for a range of pest species around the world (Costamagna and Landis, 2004; De Conti *et al.*, 2008; Lee *et al.*, 2001; Schmidt *et al.*, 2003; Sigsgaard 2002).

The free-living adult parasitoids seek out a host and parasitize different life stages of their host depending on the parasitoid species. Parasitoids can either lay single egg or several eggs on or within their host (Lee *et al.*, 2001). The immature parasitoid(s) depend on their host for growth and development through feeding and later the host is killed, where it emerge as free-living adult parasitoid (Getanjaly *et al.*, 2015). They include Chalcid wasps, Encyrtid wasps, Ichneumonid, Braconid wasps and Trachinid flies (Getanjaly *et al.*, 2015; Inclan *et al.*, 2015; Landis *et al.*, 2000). The adult parasitoids are free living and sometimes may be predators. Many parasitoids are limited to one of few closely related host species because they must be adapted to the life cycle, physiology and defenses of their host plant (Lajeunesse and Forbes, 2002). In comparison to predators, parasitoids are considered more effective due to the fact that they are host specific, increase with increasing density of the host, can complete their life cycle within a single host and able to synchronize with the host (Murdoch *et al.*, 1985). Their impact is easier to quantify since they can be reared on a host in the laboratory to record how the species emerges, hence direct estimates of parasitism rates in the field are not difficult to obtain (Macfadyen *et al.*, 2015).

Table 1. Predatory and parasitic arthropod groups commonly used in biological control of agricultural crop pests.

Natural enemies	Prey or pest targeted									References
	Aphids	Mites	Leaf hopper	Mealy bugs	Thrips	Caterpillars	Whitefly	Scale insect	Insect eggs	
i) Beetles Lady beetles, rove beetles, soldier beetles and carabid beetles	✓	✓	✓	✓	✓	X	X	✓	✓	Evans, 2009 Getanjaly, *et al.*, 2015; James, 2014
ii) Bugs True bugs, including assassin bugs, damsel bugs, minute pirate bugs, mirid bugs, stink bugs, ambush bugs and big-eyed bugs,	✓	✓	✓	✓	✓	✓	X	✓	✓	Charlet *et al.*, 2002; Getanjaly, *et al.*, 2015; James, 2014; Sampaio *et al.*, 2009
iii) Flies Hover flies, robber flies, long-legged flies, bee flies, predatory midges, dance flies	✓	✓	✓	X	✓	✓	✓	X	X	Cannings, 2014; Charlet *et al.*, 2002; James, 2014
Lacewings	✓	✓	✓	✓	✓	✓	✓	✓	✓	James, 2014; Knutson *et al.*, 1993;
Earwigs	✓	✓	✓	X	✓	✓	✓	X	✓	Nicholas *et al.*, 2005; Suckling *et al.*, 2006
Ants	✓	✓	✓	X	✓	✓	✓	X	✓	James, 2014
Spiders (orb-weaver, crab, jumping)	✓	✓	✓	X	✓	✓	✓	X	X	James, 2014; Jeyaparvathi *et al.*, 2013
Predatory mites	X	✓	X	X	X	X	X	✓	✓	James, 2014
Parasitic wasps Chalcids, encyrtids, braconids, ichneumonids,	✓	X	✓	✓	X	✓	✓	X	✓	Getanjaly *et al.*, 2015; James, 2014, Sampaio *et al.*, 2009
Parasitic flies Tachinids, bee flies	✓	X	✓	✓	X	✓	✓	X	✓	James, 2014

Natural enemy manipulation for biological control

Natural enemies can be manipulated as part of integrated pest management through several approaches as follows;

Augmentative biological control

Augmentative biological control is an attempt to reduce pests' population to non-economic levels by temporarily increasing number of the NEs in an area through periodic releases (Collier & van Steenwyk, 2004; Crowder, 2007). It is a direct manipulation of insects which involves rearing predators/parasitoids at a commercial scale and releasing them to the crop where the host pest insects are present, particularly in glasshouse environments, where it can be more effective (Belmain *et al.*, 2013). In some countries, the NEs are reared artificially and then released into the field in a more effective way and economical (Lee *et al.*, 2001; Levie *et al.*, 2000). However, in most developing countries including those in Africa, it is less practical in outdoor field crops and unlikely affordable in small holder farming systems.

There are two types of augmentative biological control; the inundative and the seasonal inoculative release method (Orr, 2009; Van Lanteren, 2000).

Inundative release method is where the NEs are collected and reared into large number, then released for immediate control of the pest by the released NEs and not their offspring (Van Lenteren, 2000). This is mostly applicable in situations where viable breeding population of the NEs is not possible or where rapid control is required and in situations where only single pest generation occurs. On the other hand, seasonal inoculative biological control involves collection and rearing of the NEs and releasing them periodically in situations where several pest generations occur for immediate pest control and throughout the season especially in greenhouses (Bale *et al.,* 2008; Cock *et al.*, 2010). Augmentative biological control has been very successful in many places (Van Lanteren, 2000, Van Lanteren and Bueno, 2003), though in some areas it has been a challenge due to the movement of the released natural enemies away from the target area as a result of low pest densities or high level of competition (Wajnberg *et al.,* 2008). It is usually a commercial activity which involves mass production and large area release of the natural enemies (Van Lanteren, 2012), thus rarely applied among the small scale farming systems in Africa.

Classical biological control

This is a process where new NEs are introduced to an area for establishing a permanent population (Charlet *et al.*, 2002). It involves an extensive research into the biology of the pest and the potential NE as well as the possible unintended consequences before introducing the NE to the area (Cock *et al.*, 2009). The NEs are released after carefully study of the pests' life cycle in a site where they are abundant so as to allow complete establishment of the NEs. This process is very complex and time consuming, but once it is established it is long lasting. The need for importing the NE occurs when a pest is accidentally introduced into an area and its NEs are left behind.

Therefore, an attempt is made to locate these enemies and introduce them to reestablish the control that often existed in the native range of the pest. In Africa, classical biological control has been useful in the control of mites in cassava (Herren *et al.*, 1987; Herren and Neuenschwander, 1991; Korang-Amoakoh *et al.*, 1987; Megev and *et al.,* 1987; Onzo *et al.*, 2005; Zannou *et al.*, 2005; Zeddies *et al.*, 2001), with very limited application in other crops including leguminous crops.

Conservation biological control

Conservation biology is an attempt to protect the NEs that are already present in an area by manipulating the environment or the farming practices so as to provide the required resources for them to survive and build up populations to levels where they can manage the pest and prevent them from causing economic damage to crops (Gurr *et al.*, 2000; Gurr and Wratten 1999; Wyckhuys *et al.*, 2013). Agricultural intensification and broad-spectrum use of pesticides have resulted to a decrease in the diversity of NE populations and an increase in the likelihood of pest outbreaks (Heitala-Koivu *et al.*, 2004; Landis *et al.*, 2000). Apart from direct toxicity effect of the synthetic pesticides, they may also pose subtle effects on the physiology of the NEs (Cullen *et al.*, 2008; Jonsson *et al.*, 2008). To conserve the NEs simple strategies such as reducing frequency of synthetic pesticides and carefully targeting pesticide use are recommended (Belmain *et. al.*, 2013; Wyckhuys *et. al.*, 2013).

According to Gurr and Wratten (1999), Landis *et al.* (2000) and Van Driesche *et al.* (2008), effective conservation of NEs depend on: 1) understanding the agro-ecosystem, 2) use of selective pesticides, 3) use of the least disruptive formulation of the chemical, 4) application of the insecticide only when necessary and based on reasonable economic injury levels of the pest and 5) pesticide application at the time or place that is the least injurious to NEs. Conservation biological control can also be achieved by manipulating the landscape through the provision of flowering resources for NEs and establishing source habitats for NEs (Gurr *et al.*, 2016; Landis *et al.*, 2000; Sigsgaard *et al.*, 2013).

In Africa, the manipulation of NEs through conservation biological control is a more promising due to favourable climatic conditions with diverse biodiversity (Sampaio *et al.,* 2009).

It is also less expensive as it just involves the manipulation of the environment and the farming practices to attract the NEs and it is self-perpetuating, unless it is disturbed by introduction of some chemicals or any other environmental disturbance like fire. Conservation biological control can be economically worthwhile, although, unfortunately, only few studies have been conducted with the specific goal of assessing its economic benefit in crop protection (Cullen *et al.*, 2008). Despite the high tropical diversity of Africa, application of conservation biological control is very limited especially for leguminous crops (Wyckhuys *et al.*, 2013). There is therefore a need to assess how conservation biological control can be employed in African agricultural systems due to its richness in terms of biodiversity.

Fig. 1 below illustrates the three major ways of natural enemy manipulations for biological control. In this model biological control will be possible if the imported NEs (Classical) or released NEs (Augmentative) are able to adopt or the environment supports the existence of the NEs (Conservation).

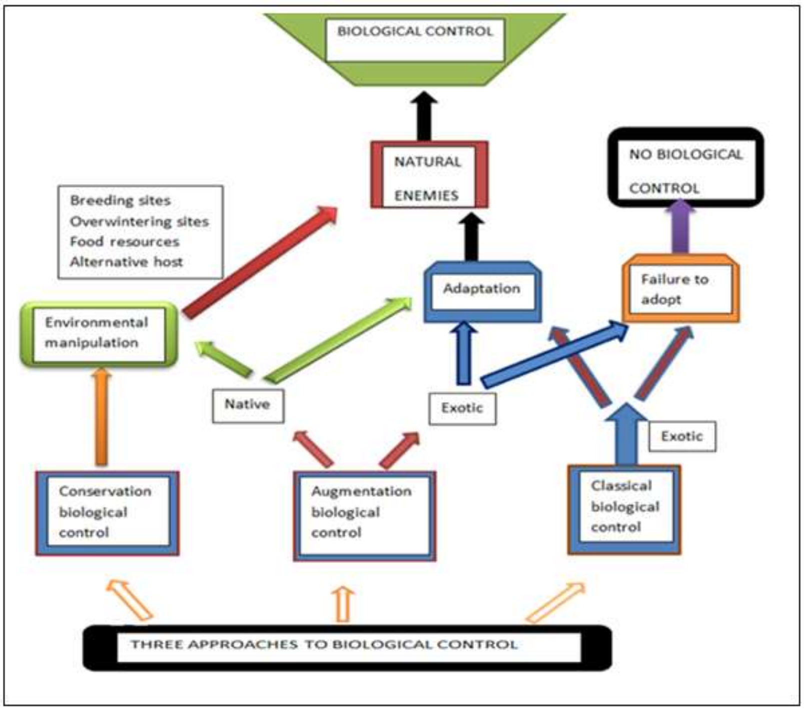

Fig. 1. Natural enemy manipulations for biological control

Effect of landscape ecology and farm management practices to the NEs population

Landscape ecology and local management of agricultural lands are major determinants of biodiversity patterns in agricultural landscapes, especially those related with biological pest control (Landis *et al.*, 2000; Martin *et al.*, 2013). Landscape in terms of the amount of natural or non-crop habitat in the field margin surrounding the farm and land use intensity, are known to be the driving force of natural enemy dynamics in agricultural ecosystems (Landis *et al.*, 2000; Landis and Marino, 1999; Martin *et al.*, 2013; Woltz *et al.*, 2012).

Mono-cropping vs inter-cropping system

Increasing vegetation diversity within crops is predicted to enhance the survival of NEs in agricultural systems; consequently pest outbreaks tend to be less common in polycultures (many crops) than in monocultures (Bianchi *et al.*, 2006). Polyculture promote the activities of NEs through provision of various resources such as alternative food resource, breeding sites, shelters and overwintering sites within the field (Kremen and Miles, 2012). Therefore, intercropping can be a good method to increase beneficial insect diversity within agro ecosystems compared with mono cropping.

De la Fuente *et al*. (2014) reported that total insect assemblages were higher in intercrops of sunflower and soybean than in sole crops. This shows a significant effect of vegetation diversity to the diversity of invertebrates in the field. Depending on the size of the NEs, increasing vegetation diversity can be the best way to enhance the NEs (Gurr *et al*., 2016). This is because not all entomophagous species are sufficiently mobile to travel outside the field to search for food resources. For example, most larval stages of many NEs are relatively immobile, thus food resources should be within the field so as to promote their activity. The best way of conserving NEs and stabilizing their populations is to meet their ecological requirements within or near the cropping environment (Landis *et al*., 2000). Diverse flowering plants within the crop land provides alternative hosts, food resources, breeding sites and overwintering sites to NEs, thereby enhancing biological control services (Gurr *et al*., 2016). On the other hand, monoculture may lead to increased pest problems as the pests can accumulate in the area each season as long as their host plants are available (Benton *et al*., 2003). This is because continuous growing of a single crop in a certain area provides a narrower range of habitat to beneficial insects while harbouring more pests, leading to an increased need for chemical pesticides. According to (Kremen and Miles, 2012) monoculture systems have been found to be more susceptible to insect pest infestation and plant viruses than polycultures. Thus vegetation diversity which may involve legume component in the mixture together with crop rotation should be emphasized among the smallholder farmers in order to reduce the extent of pest infestation.

Organic vs conventional farming

Organic farming involves the augmentation of ecological processes that aim at increasing agricultural production sustainably, with no harmful effect to the environment and human health (Kremen *et al*. 2012; Pimentel *et al*., 2005). Organic agriculture is important in promoting and maintaining the ecosystem services for sustainable agriculture. The use of synthetic chemicals for pest control is neither economically feasible nor ecologically acceptable. They are highly toxic to the environment, non-target organisms and to the consumer health since they can persist over a long period of time in the environment, thus disturbing some ecological processes like natural pest control (Moyo *et al*., 2006; Prakash *et al*., 2008). According to Mkenda *et al*., (2015), the synthetic pesticides greatly affected the NEs of bean pests being studied which were ladybird beetles and spiders whereas botanical pesticides had no effect. Therefore, the use of synthetic chemicals is highly discouraged as it affects the ecosystem services including pest control services by the NEs. Therefore, some organic technologies such as crop rotation, increasing the level of soil organic matter and employing natural biodiversity to reduce or eliminate the use of synthetic chemicals should be adopted in the current conventional production systems in order to rescue the current biodiversity loss.

Crop cover vs bare fields

Crop cover are significant in conserving soil quality thereby reducing too much dependence to external inputs such as pesticides, chemical fertilizers, herbicides and fungicides leading to favourable environment to beneficial insects including the NEs (Arbuckle & Roesch-McNally, 2015; Chatterjee, 2013; Kaspar *et al*. 2001; Pimentel *et al*., 2005; Singer *et al*., 2007). They are purposely grown between the periods of regular crop cultivation as a soil conservation strategy since bare soils are prone to soil erosion and weed invasion leading to loss of soil quality. It has been reported that beneficial insects may be attracted to particular crop backgrounds. For example, the number of *B. brassicae* was higher in the field dominated by Brussel plants compared with the field dominated with 'carpet' of weeds (Verkerk *et al*., 1998). When crops are absent in the field, cover crops may promote the availability of NEs in the filed in two ways; one is by providing prey species (host) to maintain their local population at an effective level, and two is by providing nectar and pollen to the beneficial insects that require such resource if the cover crop is a flowering plant (Dunn *et al*., 2016; Landis *et al*., 2000). Therefore, flowering plant species have been promoted as cover crops to provide flowering resources for insects when the crop is not in bloom in order to meet their ecological requirement (Gurr *et al*., 2016; Walton & Isaacs, 2011). Generally, cover crops can provide both economic and ecological benefits in agricultural production systems.

Non crop habitats surrounding agricultural lands

Non crop habitats include natural and semi-natural habitats, such as forests, hedgerows, field margins, meadows and fallows, which usually harbour numerous species of beneficial insects. Studies by (Belmain *et al*., 2013; Lamarque *et al*., 2011; Landis *et al*., 2000; Letourneau *et al.,* 2012; Tscharntke *et al*., 2005) reported that NEs decreased with increasing conversion of natural habitats to arable lands as a result of agricultural intensification. The non-crop habitats may have different resources that are useful to beneficial insects thereby promoting their growth and development which later migrates into the field crops around and provide the ecosystem services such as natural pest control and pollination (Gardiner *et al.,* 2009; Marshall and Moonen 2002; Thies *et al.,* 2005; Tscharntke *et al.,* 2007). For example, studies by (Bianchi *et al*., 2006; Inclan *et al*., 2015; Gillespie *et al*., 2016) reported that field margin plant species provide habitat to a range of insect species which are of agricultural importance. A study by (Tscharntke *et al.,* 2007) revealed that spiders' diversity in agricultural ecosystems were the result of immigration from the surrounding non crop habitats. The non-crop habitats surrounding the agricultural land may provide alternate hosts or prey species to NEs of pests, including carabid beetles (Ranjha and Irmler, 2013), staphylinids, spiders (Schmidt *et al*., 2005), coccinellids and syrphids (Nicholls *et al*., 2001), predatory mites (Norton *et.al.,* 2001), parasitoids (Landis *et al*., 2000), predacious Heteroptera and insectivorous birds (Bianchi *et al*., 2006; Nicholls *et al*., 2001). Field margin vegetation may act as sources of pollen and nectar, which are essential prerequisites for many NEs such as parasitoids in which their longevity and fecundity have been reported to increase substantially when nectar sources are available (Costamagna & Landis 2004; Lee *et al*., 2001; Siekmann *et al*., 2001).

Therefore, non-crop habitats may be good source of NEs and other beneficial insects for providing ecosystem services to the cultivated fields around.

Potentials of natural pest control in pest management in Africa

Natural pest control is among the Integrated Pest Management (IPM) practices and an important ecosystem service provided in agriculture worldwide (Cardinale *et al*., 2012; Holland *et al*., 2012; Macfadyen *et al*., 2015). Due to continuing concerns regarding unsustainable trends in pest management, IPM is being promoted as a priority of many governmental and non-governmental organizations (NGOs) and the World Bank (Gurr *et al*., 2003; Holland *et al*., 2012; Parrella *et al*. 1999; van Lenteren and Woets, 1988). Increased adoption of IPM has led to aggregate changes in pesticide use to as low as 37% in some non-African countries like Vietnam and Denmark where emphasis has been put on biological pest control (Pretty and Bharucha, 2015).

There exist huge potential of promoting natural pest control for sustainable agriculture and pest management in Africa, as the continent is known worldwide in terms of its biodiversity which forms the base of its natural wealth (Newmark, 2002). Africa harbours about one quarter of the worlds' 4,700 mammalian species including 40,000 - 60,000 plant species and about 100,000 known species of insects, spiders and other beneficial insects (Duruigbo *et al*., 2013). Sub Saharan Africa specifically is a home of more than 1/5 of the worlds' plant and animal diversity (Duruigbo *et al*., 2013). However, this biodiversity has not been sufficiently integrated into broader sectors, such as agriculture, fisheries and economy leading to low development in those sectors (Sunderland, 2011). Furthermore, trade-offs between food production, biodiversity conservation, ecosystem services, and human well-being in agricultural landscapes is not yet addressed (Martinet and Barraquand, 2012). As a result insect pests continues to be among major problems in crop production leading to poor quality and low crop yields in Africa (Delate *et al.,* 2008; Mwang'ombe *et al*., 2007; Shannag and Ababneh, 2007).

Thus, with proper understanding, sustainable use of the agricultural biodiversity present will particularly be beneficial to small-scale farmers who usually have poor access to external inputs due to financial and infrastructural constraints (Belmain *et al*., 2013).

Management practices that use complex, ecologically based approaches are therefore encouraged. There is need to identify innovative and acceptable ways of integrating biodiversity conservation such as use of NEs in food production systems in Africa. Fig. 2 below illustrates various ecosystem services important for increasing agricultural productivity. The model indicates that agricultural ecosystems require regulating and supporting functions from the surrounding ecosystem for it to be able to provide provisioning and cultural functions and all these functions are interconnected.

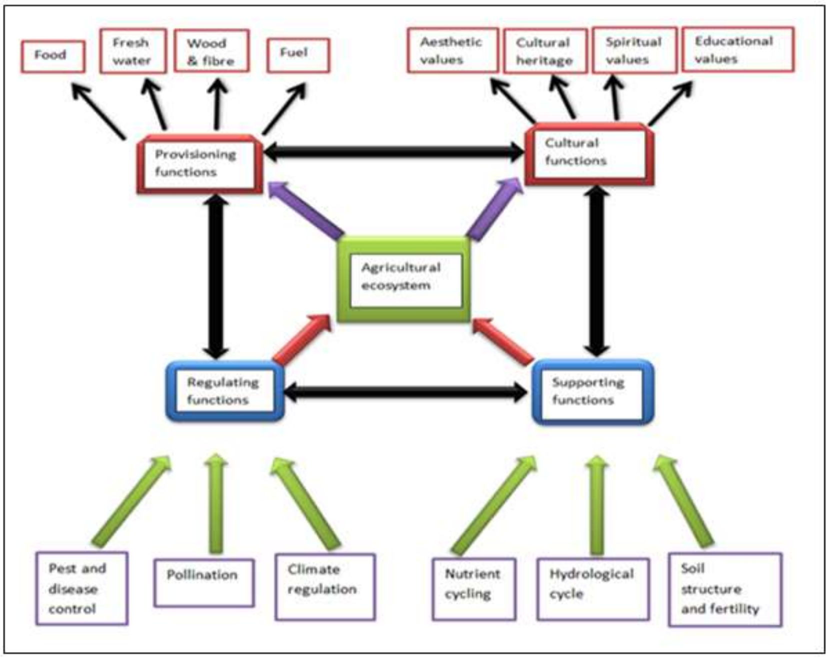

Fig. 2. Agricultural ecosystems as consumer and provider of ecosystem services.

Use of NEs in biological control has several advantages of being self-sustaining, cost effective and eco-friendly compared with most other pest management techniques such as synthetic pesticides (Chaplin-Kramer *et al*., 2011; Eilers and Klein, 2009. Due to these benefits, many countries such as UK, France, Italy, and Japan have started using pest management approaches that cut down cost of farming , one of which is application of biological control methods such as use of NEs (Brouder and Gomez-Mac Pherson, 2014; Kassam *et al*., 2014; Pretty and Bharucha, 2015). There is therefore a need to explore on the feasibility of the biological pest control methods especially the conservation biological control for sustainable crop pest management in African agricultural systems.

There are several reasons as why biological control of pests should be promoted in crop production. Development of pesticide resistance by numerous pest species have been one of the major reasons apart from increasing concern of the effects of chemicals to the environment, non-target organisms and human health (Chidawanyika *et al*., 2012).

Pesticide residue is another cross cutting issue among different consumers and generally in the market chains (Van Lenteren, 2012). There is an increased awareness of the effects of pesticides in food production among consumers. Less risk is associated with the foods produced through biological pest control compared with those which synthetic pesticides were applied (McNeil *et al*., 2010).

It is now obvious that the ecological based pest management approach is important for the environmental and human health and sustainable agriculture.

Challenges

Agricultural expansion and intensification

Land use change as a result of agricultural expansion to meet the needs of the increasing population in Africa has decreased most of the natural habitats with concomitant decline in overall biodiversity (Belmain *et al.*, 2013; Lamarque *et al.*, 2011; Tscharntke *et al.*, 2005). It has been projected that the world's population will grow to nine billion by the year 2050 (Perrings *et al.*, 2006). Providing sufficient, affordable, and safe food for the increasing world population is one of the biggest challenges. Agricultural intensification worldwide has strongly increased crop productivity through the use of improved crop varieties, chemical fertilizers and pesticides leading to a marked reduction in the diversity of insects including the NEs with its associated pest control services (Getanjaly *et al.*, 2015; Inclan *et al.*, 2015).

Modern agricultural development has been established with the goal of increasing productivity and meeting the growing need for food. This has resulted to considerable simplification of cropping systems in terms of the diversity of the species grown and cultural practices in agricultural landscapes. The expansion of agricultural land through land conversion has a continuing devastating effect of the world's remaining biodiversity (Getanjaly *et al.*, 2015). NEs have been reported to be affected directly by interfering with their biological functions and indirectly through their secondary resources (Gurr *et al.*, 2003). The effectiveness of NEs in pest management in agricultural systems is inhibited by pesticides use, lack of food or lack of intermediate hosts as results of disturbance regimes imposed to their environment (Bianchi *et al.*, 2006; Macfadyen *et al.*, 2009). The overuse of chemical pesticides inadvertently affect natural pest control as it kills beneficial insects which would normally keep pest populations below the economic threshold leading to secondary pest problems (Getanjaly *et al.*, 2015).

In Integrated Pest Management, pesticide use to control pests should be the last option when all other management tactics have failed and the pesticide to be used should also be selective, with no harm to the environment or non-target organisms (Fig. 3).

Biodiversity loss and associated ecosystem services such as pest suppression, continues to be one of the main consequences of intensive agriculture in Africa (Bianchi *et al.*, 2006). Practices such as monoculture which involves the cultivation of a single crop species in a field has been cited as a key component in agricultural intensification, leading to increased pest infestation associated with more pesticides application.

The options for IPM has been described in Fig 3. In this illustration, education and communication is considered as the first step since knowledge and information is necessary for assessing the presence or absence of the insect pests in the field.

The second step involves intervention of agricultural practices that reduce the number of pests below the economic threshold level, but those actions should have no negative impact to the environment. If such agricultural practices are still not sufficient to reduce pest abundance, it follows the third step where the pests will be controlled physically or mechanically by trapping them. When the infestation is still serious, other management options such as the use of selective pesticides may be considered as the final option.

Pesticide industries

Most of the pesticide industries are looking for the immediate solution towards pest control rather than long term solutions. They are interested with production and marketing of new pesticides and unfortunately, most of the current cultivars have been selected under the umbrella of heavy pesticide applications for high yield and best quality produce (Van Lenteren, 2012). Consequently, there will be a continuous reduction in biodiversity and specifically the NEs leading to poor natural pest control. International Organization for Biological Control (IOBC) whose aim is to promote environmentally safe methods of pest and disease control has worked hard on the demand to test the side-effects of the new pesticides towards non-target organisms including the NEs (Sterk *et al.*, 1999). This has resulted to some improvements in the attitudes of pesticide industries and some of them have engaged in the commercial production of the NEs instead of chemical pesticides (Van Lenteren, 2012). A part form the side effects of the chemical pesticides, the need for biological control is obvious due to the fact that it is no longer possible to control all pests by chemical pesticides alone.

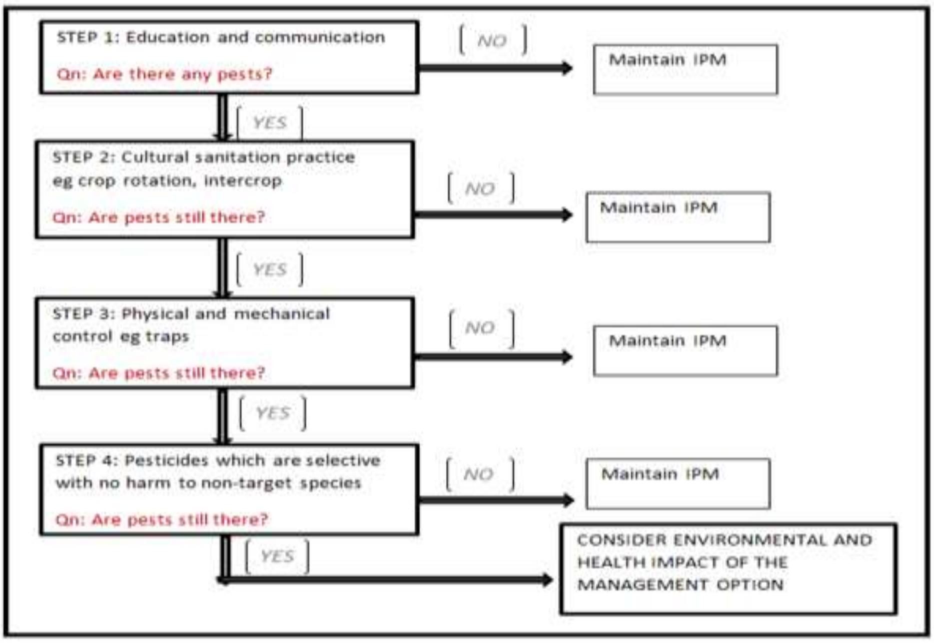

Fig. 3. Integrated pest management (IPM) options

Farmers' attitude

In many areas, farmers have developed a calendar for pesticide application in their fields regardless of the extent of pest infestation due to their inability to monitor and control the pests at the most appropriate time (Lekei *et al.*, 2014). This can be termed as misuse of pesticides which is associated with decline of natural pest control. The use of chemical pesticides in pest management has been considered as cheap due to the fact that the indirect costs associated with the use of the pesticides such as environmental pollution, death of non-target organisms, health problems and interference with ecosystem services are not taken into account (Pimentel, 2005). Farmers lack both biological and ecological knowledge towards pest control and thus they only believe in the use of pesticides and since they are registered products, they don't see the reason of why not to use them (Korir *et al.*, 2015; Schreinemachers *et al.*, 2014; Van Lenteren, 2012). Therefore, effective implementation of natural pest control requires a drastic change in the mindset of farmers who are already addicted with pesticide use and unaware of other associated side effects.

Biological control research dissemination

Though very few researches on biological control have been conducted in African countries (Annecke and Moran, 1978; Herren and Neuensch wander, 1991) compared with other countries outside Africa such as US, UK and other countries, (Benton *et al.,* 2002; Losey and Vaughan, 2006) still such information are not known to most of the agricultural stakeholders. The impressive benefits of such biological control researches have not yet reached many of the African farmers as the main stakeholders in agriculture sector, thus restricting mass adoption of natural pest control (Herren and Neuensch wander, 1991). It has been reported that many researches about pest management conducted in Africa have not been adopted by most of the farmers across the continent due to lack of knowledge together with heterogeneous conditions they are facing (Belmain *et al.*, 2013).

Therefore, pest management measures should often be site-specific and should involve farmers directly for better knowledge dissemination.

Policy regulation

There is lethargic push by national and International policy towards the implementation of biological control for sustainable pest control (Van Lenteren, 2012). One of the indicators to show this is the lack of support to researches that contribute to conservation and sustainable use of biological diversity for pest control and other ecosystem services. The adoption and implementation of natural pest control among the smallholder farmers in many African countries will not work unless it is reinforced by the government policies since agriculture has been cited as among the major contributor of biodiversity loss (Geiger *et al.* 2010). The regulations for import and release of biological control agents should also be simplified to facilitate the uptake of biological control (IPPC, 2005).

Agricultural sustainability in Africa requires the production practices that are not depending on external inputs, such as chemical fertilizers, pesticides and herbicides, otherwise food shortage will continue to increase and the damage to the environment will also increase (Kremen and Miles, 2012). Biodiversity loss and deforestation followed by land degradation has been cited as major environmental issues associated with the use of external inputs that greatly affect the agriculture sector (Geiger *et al.*, 2010). Due to this, there a need to integrate biodiversity conservation in agricultural landscapes to boosts ecosystem productivity as each single species, no matter how small it is, play an important role in the environment. Biodiversity conservation will also lead to protection of other natural resources like soil and water which have much contribution to agricultural productivity.

Conclusions and research gaps

Sustainability in agriculture requires a new approach of integrating biodiversity conservation in agricultural ecosystems. Biological control of pests through NEs is a more cost effective and a sustainable approach compared with other pest management techniques. Unfortunately, only few studies have been conducted with the specific goal of assessing the economic and ecological benefits of using NEs in crop protection in African agricultural systems. This is due to the fact that less attention has been given to the importance of biodiversity and specifically to the biological control of pests through NEs in the field. This calls for more research on the abundance and diversity of the NEs in different agro-ecologies with detailed analysis of their activities and impact in pest management in different environmental situations. Farmer's knowledge on biological control should be enhanced practically through farmer field schools or by involving them directly in the researches in their own fields. Farmers themselves should realize the importance of integrating biodiversity conservation and food production systems to enhance ecosystem services for biological control. In addition, both national and International policy regulations should focus in promoting chemical free pest management strategies by supporting conservation and biological control researches.

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