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Potential of pesticidal plants in harnessing ecosystem services and crop production

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Abstract

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

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Introduction

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

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

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

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

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

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

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

Ecosystem Services accrued from pesticidal plants

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

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

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

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

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

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

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

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

Table 1. Pesticidal plants in supporting ecosystem services.

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

The potential of pesticidal plants in crop production

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

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

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

The role of pesticidal plants in diseases and pests management

In order to improve yield in crop production, it is important to make sure that plant diseases and pests that affect the crop yield are controlled.

The pesticidal plants can be used to offer these ecosystem services in two ways, namely, i) directly as the extract from the pesticidal plants which serve as botanical pesticide or ii) the biological control facilitated by the live plant in the crop field.

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

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

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

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

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

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

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

ii) Biological Pest Control

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

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

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

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

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

Water quantity, quality and Erosion control

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

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

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

Windbreaks

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

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

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

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

Nutrient cycling

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

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

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

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

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

Crop Pollination

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

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

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

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

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

Organic matter for improved soil fertility

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

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

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

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

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

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

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

Ecosystem Services Tradeoff in Crop Production

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

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

Conclusion and recommendation

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

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

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