

— Review —

INSECT POLLINATION AND SUSTAINABLE AGRICULTURE IN SUB-SAHARAN AFRICA

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Abstract—We are currently seeing an expansion of pollinator-dependent crops in many parts of the world, but also growing evidence for pollinator population declines and loss of pollinator habitat. Climate change and population growth will place additional demands on crop production, especially in Sub-Saharan Africa (SSA). Despite the wealth of evidence that improved management of insect pollinators can lead to substantial gains in crop yield, agricultural improvement strategies in SSA still emphasize the manipulation of abiotic factors and do not fully exploit the value of pollinators. In this article we review the importance of pollination services in sustainable agriculture, how global perspectives can inform our understanding of the situation in SSA, discuss successful pollination management, highlight where research and development are required, and suggest possible solutions to enhance the contribution of pollination services to sustainable agriculture in the region.

Keywords: Sustainable agriculture, pollination, pollinator conservation, Sub-Saharan Africa

INTRODUCTION

Agricultural land accounts for approximately 50% of the terrestrial land surface (Kearns et al. 1998; Foley et al. 2005), providing humans with food, forage, bioenergy and medicinal plants (Power 2010). Agricultural landscapes can have a dual role, not only providing food in the short-term, but also enhancing long-term ecosystem integrity for more sustainable food production (Asbjornsen et al. 2014; Godfray & Garnett 2014; Burkle et al. 2017). The global food demand is expected to increase to 60% by 2050 (Alexandratos & Bruinsma 2012; Jayne et al. 2014), much of the world's current cropland has yields below its potential, and the ongoing agricultural expansion has serious long-term impacts on biodiversity and ecosystem services (Pradhan et al. 2015). With the human population growing in Africa (Jayne et al. 2014), and a burgeoning middle class in many parts of the world, achieving efficient and productive agricultural land use while conserving ecosystem integrity is a huge challenge (Tschamtkke et al. 2012; Tanentzap et al. 2015).

The human population is expected to increase by over one billion in SSA between 2019 and 2050 and demand for cereal food will approximately triple (van Ittersum et al. 2016; United Nations, 2019). High intensity farming of wind pollinated cereals impacts on ecosystem service providers such as pollinators, which has a subsequent negative impact on pollinator-dependent crops (Ramos et al. 2018; Geeraert et

al. 2020). This is due to the destruction of floral and nesting resources for bees, and increased use of soil tillage, pesticides and herbicides (Holzschuh et al. 2011; Pfister et al. 2018; Ramos et al. 2018). To meet the higher demand for food in SSA, current agricultural strategies emphasize maximizing crop yields at the expense of ecosystem services (Knapp et al. 2016; van Ittersum et al. 2016; Tadele 2017; Rampa et al. 2019). The resulting land degradation, together with increasing climate variability, is expected to constrain future food production growth in SSA (Egoh et al. 2012; Adhikari et al. 2015; Weiner 2017; Gassner et al. 2019). It has been argued that unless more sustainable agricultural systems are adopted, agricultural yield will decrease as biodiversity declines (Burkle et al. 2017; Bjornlund et al. 2020).

Sustainable agriculture involves maximizing the productivity of the land and improving the well-being of people, under the constraint of minimal damage to natural resources (Pretty 2008; Pretty & Bharucha 2014). It relies on ecosystem services (Gemmill-Herren et al. 2014; Lázaro & Alomar 2019), that can replace, complement, or interact synergistically with external agricultural inputs (Martins 2013; Garibaldi et al. 2016). Ideally, sustainable agriculture should involve making the best use of agricultural technologies for crops, animals and management of agricultural ecosystems (Godfray & Garnett 2014; Struik & Kuyper 2017; Weiner 2017). On the contrary, intensive agriculture will result in either decreasing agricultural yield over time (Phalan et al. 2013; Gaffney et al. 2019), or ever increasing agricultural inputs, usually accompanied with a decrease in ecosystem services (Kovacs-Hostyanszki et al. 2017).

Concerns about the long-term impacts of intensive agriculture on ecosystems, have prompted the search for

Received 13 May 2020, accepted 3 December 2020

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alternative methods of sustainable production that are more ecologically and economically sustainable (Tschamtko et al. 2012; Bommarco et al. 2013). Pollination services are an essential element of maximizing production in sustainable agriculture (Kevan et al. 1990; Knapp et al. 2016; Kovacs-Hostyanszki et al. 2017). They are critical for food production and human livelihoods, and directly link wild ecosystems with agricultural production systems (Bommarco et al. 2013; Sharma & Abrol 2014; Lázaro & Alomar 2019).

Insect pollination improves the yield of most crop species and contributes to one-third of global crop production (Klatt et al. 2014). Research from 200 countries found that agricultural productivity from 87 out of 115 of the leading global food crops is dependent upon animal pollination (Klein et al. 2007). The value of the worldwide contribution by pollinators to human food crops is estimated at €153 billion, and the crops most vulnerable to pollinator scarcity appear to be more sensitive to price variation (Gallai et al. 2009). The volume of production by pollinator-dependent crops has increased by 300% over the last five decades, making livelihoods increasingly dependent on the provision of pollination (Potts et al. 2016a). As this cultivation of pollinator-dependent crops expands, so does the concern for the sustainability of pollination services (Aizen & Harder 2009; Knapp et al. 2016), and the decline of many pollinator populations (Breeze et al. 2014; Ollerton 2017; Sawe et al. 2020).

Managed honeybees provide a wide range of benefits to society in terms of contributions to food security, social and cultural values, and ecosystem stability (Calderone 2012; Rogers et al. 2014; AU-IBAR 2019). The increase in the global population of managed honeybee colonies could represent a compensatory response to an agricultural pollination crisis caused by declining of wild pollinators (Aizen & Harder 2009; Veldtman 2018). However, there is growing concern over the negative impacts that managed honeybees may have on native wild bees. This may occur through competition over floral resources and nesting habitat, through changes in plant communities due to the honeybee-mediated spread of exotic plants and resulting decline of native plants, and through transmission of pathogens (Mallinger et al. 2017; Ropars et al. 2019; Valido et al. 2019). The extent of these negative effects is likely to be reduced in the native range of honeybees (Geslin et al. 2017; Ropars et al. 2019), but more evidence is still needed.

Wild pollinators are important in both agricultural and natural ecosystems and are threatened by land-use changes (Potts et al. 2016b, Guzman et al. 2019), intensive agricultural management, pesticide use (Vanbergen & The Insect Pollinators Initiative 2013, Gaffney et al. 2019), pathogens (VanEngelsdorp et al. 2009; Graystock et al. 2016), and climatic change. These threats pose added risks to societies and ecosystems (Vanbergen & The Insect Pollinators Initiative 2013; Hall & Steiner 2019). For example, people living in SSA depend on the supply of ecosystem services (Egoh et al. 2012; Tibesigwa 2018), but only over recent decades has it been realized that failing pollinator health is a dire threat to ecosystem services and agricultural productivity (Misganaw et al. 2017; Sawe et al. 2020). In this review we

will cover the following topics from the overlooked perspective of sustainable agriculture in SSA: (1) importance of sustainable agriculture in SSA, (2) importance of pollination services and pollinator conservation in SSA, (3) current policies and initiatives for pollinator services and pollinator conservation, (4) pollinator management with agricultural practices in SSA, and (5) finally, we will propose key steps to be taken to promote sustainable pollination services in SSA through pollinator management.

1. IMPORTANCE OF SUSTAINABLE AGRICULTURE IN SSA

While there is widespread support from governments and international organizations for a more sustainable intensification of agriculture in SSA, there are huge challenges in translating this support into policies that actually have positive ecological and social impacts on the way food is produced (Munthali et al. 2014; Adenle et al. 2019). Soil degradation, climate instability and low-yielding food production based upon shifting cultivations, often make it difficult to improve per hectare crop production in SSA (Vlek 1990; Egoh et al. 2012; Perrings & Halkos 2015; Bommarco et al. 2018). Moreover, smallholders in SSA have rarely benefited from farm input subsidies, and instead have been encouraged to expand croplands at the expense of agrobiodiversity (Agula et al. 2018; Zabel et al. 2019).

Overexploitation of resources, coupled with large scale agriculture, threatens both ecosystem services and sustainable agricultural production in SSA (Egoh et al. 2012; Fagan et al. 2017; Kehoe et al. 2017). This is especially concerning, as the livelihood of the majority of rural poor in SSA heavily depends on natural resources (Fisher 2004; Mbiba et al. 2018). To satisfy the higher demand for food, SSA mainly focuses on production of cereal crops, such as maize, sorghum, wheat, millet and rice to achieve food self-sufficiency (Perrings & Halkos 2015; van Ittersum et al. 2016). Increased demand for these crops has led to expansion of cultivated areas and increased use of external agricultural inputs (e.g. fertilizers, herbicides and pesticides) (Gowing & Palmer 2008; Deguines et al. 2014; Reynolds et al. 2015). This extensive farming system creates challenges for smallholder agriculture of SSA, as it increases short-term yields, but has long-term negative impacts on biodiversity and ecosystem services (Martins 2013, Holden & Otsuka 2014; Asiama et al. 2017). Many of these problems can be seen in Ethiopia and Tanzania, where increased crop yield has come at the price of deforestation and conversion of marginal grazing land to agriculture (van Ittersum et al. 2016). Instead, we need to increase agricultural productivity in these systems but also mitigate the negative effects of agricultural transformation on the provision of environmental goods and services in SSA (Gowing & Palmer 2008).

Intensive agriculture threatens a number of cultural practices based on indigenous and local knowledge that facilitate sustainable agriculture in SSA (Sawe et al. 2020). A large proportion of smallholders in SSA practice sustainable agriculture, with different varieties of food crops, often out of an inability to afford chemical agricultural inputs (Adenle et al. 2019). It involves management procedures that maintain

or improve farm productivity, such as crop rotation, fallow land periods, and intercropping, while limiting damage to the local ecosystem (Munthali et al. 2014). This sustainable agricultural system takes advantage of existing soil nutrients, water cycles, beneficial soil organisms, natural pest control and pollination (Munthali et al. 2014; Reynolds et al. 2015), to enhance sustainable production of major food crops in SSA (Agula et al. 2018). The challenge is to expand such sustainable agriculture, without adverse impacts on environmental goods and services, while also improving the long-term prospects of the smallholders themselves (Kleemann 2012; Fijen et al. 2018).

Insect pollination is a vital contributor to the expansion of sustainable agriculture, often matching or exceeding the importance of other external agricultural inputs for pollinator dependent crops (van der Sluijs & Nora 2016; Catarino et al. 2019). Better management of insect pollinators is one of the most cost-effective but infrequently considered ways to improve yields in small scale sustainable farming in SSA (Samnegård et al. 2016; Elisante et al. 2017; Tibesigwa et al. 2019). Indeed, the underestimation by smallholders and government of the role played by insect pollinators is a key constraint to the sustainability of agricultural productivity in SSA (Tibesigwa et al. 2019; Sawe et al. 2020). There is need for policies that build and sustain robust agricultural systems in SSA that focus on ecosystem resilience and sustainability.

2. IMPORTANCE OF POLLINATION SERVICES AND POLLINATOR CONSERVATION IN SSA

Promotion of pollination services significantly benefits agricultural productivity, food security, and the achievement of the UN's sustainable development goals (Boruff et al. 2020; Sawe et al. 2020). Three-quarters of leading global food crops rely on animal pollination from managed and wild pollinators (Winfree 2003). With cultivated crop areas increasing in SSA (Fuglie & Rada 2013), the supply of pollinators is becoming increasingly threatened and it is predicted that countries will encounter pollination-driven declines in food production (Winfree 2003; Ghazoul 2005; Ollerton 2017). This has become a serious concern and a topic debated heavily in both the academic community and wider public (Goulson & Nicholls 2016; Sánchez-Bayo & Wyckhuys 2019; Wagner 2020). While the risk of falling crop yields due to inadequate pollination services is a key research topic and policy focus in Europe and US (Klein et al. 2007; Axel et al. 2011; Kleijn et al. 2015), comparatively little research and policy focus has concentrated on developing countries, where reliance on insect-pollinated or pollinator-dependent crops is increasing at higher rates (Aizen et al. 2019; Fijen et al. 2020).

In many parts of Africa, the most important cash crops including coffee, cocoa, sesame, cotton and many pulse and oil crops are pollinator-dependent (Mushambanyi & Munyuli 2014). These crops constitute leading export products, providing employment and income for millions of people (OECD/FAO 2016; Potts et al. 2016b). Research carried out in Burkina Faso, indicated that the negative consequence of any pollinator decline can cause an average yield gap of 37% for cotton production, and 59% in sesame production

(Stein et al. 2017). These yield gaps in pollination services can be calculated for each crop by comparing the fruit yields in the presence of different pollinator communities (Garibaldi et al. 2016) or by comparisons between open natural pollination (mixed self- and cross-pollination), outcrossing hand pollination and pollinator exclusion (Hudewenz et al. 2013; Martin et al. 2021). Yield gaps effectively estimate the potential to improve crop yields by optimizing the pollination environment. In Ivory Coast, yield loss in cocoa production was often attributed to disease, pests, and low soil fertility, but there is increasing evidence that inadequate pollination provision of cocoa has also played a significant role (Claus et al. 2018). Despite the availability of effective agronomic management practices to increase cocoa production, the benefits gained from pollination services are not commonly considered at the local level (Toledo-Hernández et al. 2017).

For the many pollinator-dependent crops in SSA (African Pollinator Initiative 2007a), pollinators provide a free and potentially diverse ecosystem service to farmers (Klein et al. 2008; Tibesigwa 2018). For example, smallholder farmers in SSA grow a variety of grains, vegetables, fruits, oil crops, root and tubers, and most of these crops rely on pollinators to different extents (Tibesigwa 2018; Sawe et al. 2020). From a total of 137 food crops grown in Tanzania, Malawi, Uganda, Nigeria and Ethiopia, 77 are pollinator-dependent, 19 are pollinator-independent and 49 are pollinator-unknown crops (Tibesigwa 2018). This converts to an average of 1193 kg of pollinator-dependent crops produced per household per year, 829 kg of pollinator-independent crops per household per year, and 195 kg of pollinator-unknown crops per household per year (Tibesigwa 2018). Of these countries, Uganda presently produces the greatest proportional yields of pollinator-dependent crops per household per year (77%), followed by Nigeria (64%) and Tanzania (55%), while Ethiopia and Malawi each produce 36% (Tibesigwa 2018). There are fears that the agricultural resource of the rich pollinator diversity found in SSA is under threat from potentially damaging practices, such as a growing reliance on fertilizers and pesticides in the region (Eardley et al. 2006; Raina et al. 2011; Elisante et al. 2017). However, there has been little research on yield gaps in SSA and it is often unclear how pollen limited crops in SSA actually are and whether farmers are benefitting fully from pollination mutualisms.

Some evidence does suggest that landscape degradation is already reducing coffee yields. In Uganda, the relationship between coffee production, landscape degradation and pollinator community structure was assessed in different habitats. It was found that proximity to natural habitat improves pollinators diversity and abundance, and enhanced both the yield and stability of coffee production (Mushambanyi & Munyuli 2014). However, a great deal of work is still required to translate knowledge of pollination services into a set of practical guidelines that can be implemented to enhance sustainable crop production in SSA. Basic information on the pollination of crops in SSA is often hindered by the high diversity of native pollinator fauna, which can be difficult to distinguish and may frequently be undescribed (Kuhlmann 2009).

Honeybees are an important pollinator of the African flora and part of the pollinator networks of natural ecosystems (Eardley et al. 2009). While there has been some debate around the need for conservation of this native *Apis mellifera* in Africa (Dietemann et al. 2009), honeybees in SSA deserve conservation effort in order to ensure that colony losses experienced in other parts of the world are not repeated in Africa (Pirk et al. 2016; Nganso et al. 2017). In the USA and in Europe, losses of managed honeybee colonies due to Colony Collapse Disorder (van Engelsdorp et al. 2009; Dainat & Neumann 2012), associated with *Varroa destructor* mites and small hive beetles, have threatened sustainable agricultural production (Martin et al. 2012; Ellis et al. 2015a). *Varroa* mites have also been detected in honeybee colonies in SSA (Fazier et al. 2009; Pirk et al. 2016; Nganso et al. 2017). However, compared to European honeybees, African honeybee subspecies seem less susceptible to various pathogens, parasites, pests and predators, as their large endemic wild populations contain higher genetic diversity, with associated improved immune responses and hygienic behaviour (Dietemann et al. 2009; Pirk et al. 2016; Nganso et al. 2017). This genetic diversity of African honeybees may deserve special conservation attention if it provides increased resistance to pathogens (Eardley et al. 2009; Pirk et al. 2016).

Ethiopia has an estimated 10 million native honeybee colonies, the largest number in Africa (Negash and Greiling 2017), but the pollination benefits of honeybees are poorly documented and even less is known about the performance of wild pollinators (Samnegård et al. 2014). From about 76 food crops recorded, 53% are identified as pollinator-dependent, and pollinator dependence is unknown for 26% (Tibesigwa 2018), indicating that most smallholder farmers in Ethiopia are reliant on pollination services. However, severe pollen limitation was reported in a commonly cultivated local variety of rapeseed, *Brassica napus*, across a heterogeneous agricultural landscape, which might be linked to the low bee abundance found in the area (Samnegård et al. 2016). With supplementary pollination, the yield of oil crops increased by 91% (Samnegård et al. 2016). Ethiopian farmers often give less attention to the importance of insect pollinators for crop production (Samnegård et al. 2016; Misganaw et al. 2017) and the majority of beekeeping use traditional hive types, kept primarily for hive products, so beekeepers are usually not trained in managing honeybee colonies for crop pollination (Enamin et al. 2017; Lowore et al. 2018). Efforts to expand beekeeping practices in SSA to modern hives with higher productivity are often hampered by inadequate follow-on funding and training (Amulen et al. 2017a).

Inadequate pollination affects not only the total volume of agricultural production, but also the nutritional value of food crops (Klatt et al. 2014; Ellis et al. 2015b; Suso et al. 2016). About 74% of all globally produced lipids are present in oils from plants and 98% of the available vitamin C comes from animal-pollinated plants (Eilers et al. 2011). As many indigenous crops in SSA are pollinator-dependent, the region is more vulnerable to pollinator loss (Smith et al. 2015; Tibesigwa 2018). This suggests that decline in pollinator diversity and abundance, could result in significant nutrient deficiencies (Chaplin-Kramer et al. 2014). Research done in Zambia, Uganda and Mozambique, across five nutrients

(Vitamin A, Calcium, Folate, Iron and Zinc), found that, up to 56% of the population would become at risk if pollinator populations declined (Ellis et al. 2015b). The effects of a pollinator crisis in SSA would be felt by smallholders due to their lower income and direct dependence on this ecosystem service for their nutrition.

Declines of managed and wild pollinators may particularly affect the SSA smallholder farms, but there is a huge gap in understanding of how pollination benefits livelihoods, agriculture and conservation sectors (Rodger et al. 2004; Steward et al. 2014; Stenchy et al. 2018). The contribution of insect pollinators to important indigenous crop yields in SSA remains largely undocumented and often depends on unmanaged pollinators, as crop pollination is usually incidental (Tibesigwa 2018; Tibesigwa et al. 2019). Poor documentation of pollinator-dependent-crops, lack of data on pollinators (pollinator species diversity, distribution and abundance) (Rodger et al. 2004; Gemmill-Herren et al. 2014; Melin et al. 2014), and poor understanding of pollination gaps of pollinator-dependent crops (Stein et al. 2017), hampers estimates of the contribution of pollinators in sustainable agriculture in SSA. Apart from limited information on pollination services, the extent to which habitat destruction may affect pollinators, and which methods are most appropriate to conserve pollinator habitats are lacking in SSA (Mushambanyi & Munyuli 2014; Elisante et al. 2017).

Farmers in SSA have been encouraged to adopt widespread and unsustainable use of insecticides, fungicides, and herbicides to increase agricultural productivity by limiting a range of pre-harvest losses (Grzywacz et al. 2014; Sheahan et al. 2017). The resulting risks to human health and ecosystem services from such poorly regulated pesticide use in SSA are still poorly understood (Bon et al. 2014; Amulen et al. 2017b). Moreover, the use of these agrochemicals can undermine food security by eliminating food resources for pollinators, reduce nesting material, and lead to the loss of managed and wild pollinators in local areas (Rodger et al. 2004; Gemmill-Herren et al. 2014; Ndayambaje et al. 2019).

Generally, land-use practices, such as conversion of semi-natural habitats to agricultural land, can negatively impact managed and wild pollinators through reduced floral resources and nesting sites (Potts et al. 2003; Stein et al. 2018; Sawe et al. 2020). Diversity of nesting resources in agricultural landscapes can play an important role in the presence and diversity of pollinator species (Melin et al. 2014; Dainese et al. 2017). Managed honeybees have become an integral component of agriculture due to rising demand for pollinator-dependent crops (Ropars et al. 2019; Hristov et al. 2020), however, the use of managed honeybees may negatively affect abundance and diversity of wild bees and subsequent pollination services (Goras et al. 2016; Valido et al. 2019). The community dynamics between endemic honeybees and other wild pollinators are still poorly understood in SSA, but we do know that similar negative interactions can occur (Hargreaves et al. 2010). If the trend towards favouring cultivation of pollinator-dependent crops continues in SSA, the need for pollination services and pollinator management will greatly increase.

3. POLICIES AND INITIATIVES FOR POLLINATOR SERVICES AND POLLINATOR CONSERVATION

The Convention on Biological Diversity (CBD) identified pollinators as a priority and promotes the conservation and sustainable use of pollinators and pollination services as a key element in the achievement of more sustainable agriculture (CBD 2018). This agreement should be central to agriculture and forestry policies, national biodiversity strategies, national climatic change adaptation plans, and address drivers of pollinator declines and reduce the crop yield gaps due to pollination deficit (Byrne & Fitzpatrick 2009; Dicks et al. 2013; van der Sluijs & Nora 2016). However, the existing policies for pollinator conservation are highly fragmented, and uncoordinated (Vasiliev & Greenwood 2020).

Regional pollinator initiatives, such as European Pollinator Initiatives (EPI), North American Pollinator Initiatives (NAPI), Oceania Pollinator Initiatives (OPI), and African Pollinator Initiatives (API) have been developed to facilitate the conservation, restoration and sustainable use of pollinator diversity into the healthy functioning of agro-ecosystems (Ghazoul 2005; Byrne & Fitzpatrick 2009; Rose et al. 2014; Burkle et al. 2017). These regional frameworks depend on strong links with global pollinator initiatives to facilitate policy integration and dissemination of information amongst the different stakeholders, including conservationists, development agents, crop growers and beekeepers.

The African Pollinator Initiative (API) was established in January 1999 at the inaugural congress of the Southern African Society for Systematic Biology. The objectives of the initiative are to facilitate African country participation in the International Pollinator Initiative and global pollination project (conservation and management of pollinator for sustainable agriculture through an ecosystem approach). Additionally, it aims to improve pollinator biodiversity conservation, and the pollination of crops through networking (Byrne & Fitzpatrick 2009). The initiative tries to promote pollination research as critical to agricultural production and human nutrition. However, it is characterized by lack of clear strategies and hampered by insufficient financial resources to implement them (Rodger et al. 2004; Mayer et al. 2011). This poses major challenges to the coordination effort that is needed to address the issue of pollination services and pollinators in SSA.

Some countries are already implementing national pollinator conservation strategies through integrating pollinator conservation into existing policy frameworks (Vasiliev & Greenwood 2020). In the United States, for example, a national strategy has been implemented to promote the health of managed bees, wild bees (both native and introduced species), butterflies, other pollinating insects, birds and bats (Vilsack & McCarthy 2015). In Europe, general conservation policies exist that can impact on pollinator conservation indirectly through habitat protection, the creation of reserves and parks, and conservation networks that extend transnationally (Byrne & Fitzpatrick 2009).

China has a long history of applying sustainable agricultural practices that take into account plant-pollinator

interactions (Ren et al. 2018). The country officially recognizes pollination as an agricultural input, together with improved seeds, fertilizers and pesticides (African Pollinator Initiative 2007b). However, the widespread decline of native pollinators, together with the increasing demand of fruit pollination, has resulted in the need for extensive hand pollination of crops like pear fruit (Tolera et al. 2017). Hand pollination is more labour intensive, markedly less effective and economically unsustainable (Allsopp et al. 2008; Ren et al. 2014; Wu et al. 2018). Crop productivity declines have also been related to pollination limitation in India (Basu et al. 2011; Bhattacharya & Basu 2018), where more than 50% of crop types are dependent on animal pollinators but successful policy implementation to safeguard their use is still lacking (Chaudhary & Chand 2017).

Some African countries, such as South Africa, Kenya and Uganda, have drafted pollinator conservation policies (Eardley et al. 2009). However, these policies are often undermined by limited institutional capacity, insufficient infrastructure, lack of trained bee taxonomists or pollination ecologists, and lack of funding opportunities (African Pollinator Initiative 2007b; Eardley et al. 2009; AU-IBAR 2019). Extensive work remains to be done in SSA to bring our understanding of pollination in line with that in developed world. In the USA, for example, crop breeders are encouraged to develop legume breeding into the health functioning of agro-ecosystems (Palmer et al. 2009). The approach preserves pollinators and pollination services by breeding crop plants which can be integrated into natural pollination networks because they provide more suitable rewards to pollinators. Despite their importance, crop improvement and conservation strategies in SSA rarely consider pollinators (Garratt et al. 2018) and collaboration among conservationists, agronomists, farmers and beekeepers to enhance pollinator conservation is still rare (Munyuli 2011a). Data on the economic value of pollination services, may potentially persuade governments to allocate more resources towards pollinator management, however these kinds of data are lacking for much of SSA (Porto et al. 2020). Urgent efforts are required to bring pollinator conservation and pollination services into the attention of policy-makers and other stakeholders in SSA. This requires a holistic approach where sustainable crop production and habitat management are integrated.

4. POLLINATOR MANAGEMENT WITH AGRICULTURAL PRACTICES IN SSA

Farmlands can have a dual role by providing food in the short-term and enhancing long-term sustainability by acting as pollinator reserves (Burkle et al. 2017). Agriculture is mainly small-scale and heavily dependent on the natural ecosystem services to boost crop yield in SSA (Tibesigwa et al. 2019). The traditional practices of farmers in SSA often enhance agrobiodiversity around their agricultural landscape and this potentially sustains the reproductive cycle of pollinators (Nicholls & Altieri 2013; Giuseppe et al. 2018). They often cultivate diverse crops, demarcated by natural field borders and intercropping, associated with remnants of

natural forest which gain the most agricultural crop yield, when compared with farmers with lower crop diversity (Altieri 2002).

Agroforestry systems, in which large woody perennials are integrated into agricultural landscape, can increase landscape complexity (Tanentzap et al. 2015; Kovacs-Hostyanszki et al. 2017; Lázaro & Alomar 2019), providing nesting sites for bees that result in higher pollinator diversity and abundance, and increasing pollination success (Klein et al. 2008; Garibaldi et al. 2017; Imbach et al. 2017). While outcomes are likely to be crop-dependent, agroforestry systems in SSA are heterogeneous and flower-rich, favourable for beekeeping and have been suggested to hold higher abundance of managed and wild pollinator populations important for mass flowering agricultural crops pollination, such as coffee and oil crops (Eardley et al. 2009; Archer et al. 2014; Samnegård et al. 2014). Therefore, the local ecological knowledge of beekeepers is important in establishment and maintenance of agrobiodiversity, associated with income generation and ecosystem service provision (Galbraith et al. 2017). This creates an economic incentive for conservation, described as win-win solutions to support human livelihoods while protecting ecosystem services.

In Africa, the density of wild honeybee colonies is much higher than in Europe, especially in forests and protected areas rich in nesting sites. In these habitats, honey hunters use traditional hives mounted on trees and harvest bee products by destroying nests, but little is known about the effects of these practices on honeybee populations (Requier et al. 2019). Habitat loss due to deforestation may well be an even more influential factor affecting honeybee populations (Dietemann et al. 2009).

Abundance and diversity of weeds grown around agricultural landscapes are also positively correlated with pollinator abundance and diversity (Norfolk et al. 2016; Xavier et al. 2017), making them important as cost-effective means of maximizing crop yield (Bretagnolle & Gab 2015; Kovacs-Hostyanszki et al. 2017). Different weed species grown in fallow areas, field margins, and road sides have been demonstrated to enhance diverse pollinator assemblages that benefit crop pollination (Decourtye et al. 2010). Given the limited knowledge about pollinator ecology in most African farmlands, strategies should be incorporated into the existing national agricultural and conservation policies towards identifying key beneficial plant species of fallow ground areas, conserving pollinators, improving agricultural productivity and combating climatic change.

Urban agriculture is also important in terms of economic wellbeing and food security in many cities in SSA (Drechsel & Dongus 2010). Just as is being shown in Europe and America (Baldock et al. 2015; Harrison and Winfree 2015; Baldock 2020), initial evidence suggests cities in SSA may also support abundant and diverse bee communities (Guenat et al. 2019). A better understanding of how these communities differ from those in traditional agricultural areas across SSA will improve our understanding of how these pollinator populations may support urban agriculture and potentially act as refuges for some species. However, in both urban and rural areas, more effective land governance strategies will also often

be needed to ensure that the most deprived also benefit from pollination services in SSA (Holden & Otsuka 2014).

SUMMARY AND FUTURE DIRECTIONS

Improving our understanding of the relationship between sustainable agriculture and pollination services will help us to adapt strategies for pollinator management and sustainable use in SSA. Documenting accurate information on pollinator-dependent crops, pollinator diversity and abundance will allow us to identify pollination crises and better-target conservation measures (Mayer et al. 2011; Tibesigwa et al. 2019). Collaboration between developed countries and SSA, as well as between African countries, should aim to foster local ecological, taxonomic and agricultural expertise and resources within the region.

It is essential to develop innovative strategies for managing pollinators in ever changing agroecosystems without jeopardizing agricultural production in SSA (Mwangi et al. 2015). Crop improvement programs should develop approaches that strive to integrate food production into the healthy functioning of agro-ecosystems. Investment is needed in ongoing knowledge exchange between scientists and decision makers, and skill-sharing workshops to enhance the expertise of professionals in pollination ecology and sustainable agriculture. This will facilitate mainstreaming of pollinator management through engagement with stakeholders at all levels to successfully enforce sustainable agricultural policy and incorporate these policies into traditional habitat management practices and national conservation plans. This will involve capacity-building through provision of technical pollination knowledge for growers, agricultural extension workers and conservation agencies via data collection and improved accessibility for users.

This review has highlighted the importance of pollination services in SSA, sustainable agriculture and also key knowledge gaps related to the African context. Enhanced understanding of this ecosystem service will help to design and implement conservation strategies and prioritize policies for pollinator-dependent crops that support millions of households in SSA.

ACKNOWLEDGEMENTS

The authors would like to thank Alemayehu Gela and Céline Garnier for their help enabling this review. We would also like to thank all researchers from HOLETA Bee Research Center for their support and the very helpful comments provided by the editor, Bruce Anderson, and reviewers. This collaboration was made possible thanks to a grant from the Global Challenges Research Fund and the Scottish Funding Council.

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