Neonicotinoid Insecticides: Use and Effects in African Agriculture

A Review and Recommendations to Policymakers

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ACADEMY OF SCIENCE OF SOUTH AFRICA

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The **Network of African Science Academies** (NASAC) was established on 13 December 2001 in Nairobi, Kenya, under the auspices of the InterAcademy Panel (IAP), now known as the InterAcademy Partnership. NASAC is a consortium of merit-based science academies in Africa and aspires to make the "voice of science" heard by policymakers and decision-makers within Africa and worldwide. NASAC is dedicated to enhancing the capacity of existing national science academies and champions the cause for creation of new academies where none exist.

The **Academy of Science of South Africa** (ASSAf) is one of the founding members of NASAC. ASSAf was inaugurated in May 1996 by the former President of South Africa and patron of the Academy, Nelson Mandela. The mandate of the Academy encompasses all fields of scientific enquiry and it includes the full diversity of South Africa's distinguished scientists. ASSAf is the official national Academy of Science of South Africa and represents the country in the international community of science academies.

The **Leopoldina** is a classical scholarly society founded in 1652 and has 1,600 members from almost all branches of science. In 2008, the Leopoldina was appointed as the German National Academy of Sciences and, in this capacity, was invested with two major objectives: representing the German scientific community internationally, and providing policymakers and the public with science-based advice.

The **European Academies' Science Advisory Council** (EASAC) is formed by the national science academies of the EU Member States, Norway and Switzerland to enable them to collaborate with each other in providing independent science advice to European policymakers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

The **InterAcademy Partnership** (IAP) is the successor of three earlier global academies' networks which had been founded in the 1990s. It was formally launched in South Africa in March 2016. Under the new InterAcademy Partnership, more than 140 national and regional member academies work together to support the special role of science and its efforts to seek solutions to address the world's most challenging problems. In particular, IAP harnesses the expertise of the world's scientific, medical and engineering leaders to advance sound policies, improve public health, promote excellence in science education, and achieve other critical development goals.

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Foreword

African agriculture is in a state of rapid change, with the need to provide food security for a growing population against pressures such as climate change while seeking to protect biodiversity. Much of the continent's agriculture continues to rely on smallholdings by individuals, families, or small villages, where traditional methods of crop management include making full use of the natural pollinators and pest control functions of the surrounding natural ecosystems. However, increasing areas (particularly those involving substantial purchases of land by countries outside Africa) are applying intensive agriculture typical of Europe and the Americas, which is dependent on high inputs of fertilisers and chemicals, strongly encouraged by agrochemical companies. While Africa needs eco-friendly means to increase its productivity and to ensure its food security, experience in Europe and America has demonstrated that some agrochemicals – in particular the systemic insecticides typified by neonicotinoids – have serious negative effects on ecosystem services such as pollination and natural pest control, which has led to their restriction in several countries.

Taking advantage of the knowledge and experience outside Africa to try to avoid repeating those negative impacts on Africa's rich and diverse ecosystems appears to be urgent in view of the rapid growth of intensive agriculture here. It was with that objective in mind that the InterAcademy Partnership (IAP) has collaborated with the Network of African Science Academies (NASAC) to draw on work on systemic insecticides already completed in Europe by the European Academies' Science Advisory Council (EASAC). This project to assess the implications of systemic insecticides on African agriculture looks at whether the negative effects (particularly on bees but also on other pollinators and natural pest control species) can be expected to occur when applied in African agriculture, and how best to avoid such effects.

With the kind financial support of the German Federal Ministry of Education and Research (BMBF), we were able to use the work by EASAC on neonicotinoids and their effects on agriculture and ecosystem services as the starting point for this project. With the support of the Academy of Science of South Africa, ASSAf, a first workshop was held in Pretoria in November 2018 bringing together European experts and experts from 12 African countries. Following this successful meeting, an exhaustive review of the published literature related to neonicotinoid use in Africa was done, followed by a second workshop in Nairobi in May 2019. The latter included additional African experts nominated by their academies of science, thus covering the expertise of all African regions. This workshop discussed evidence on the use and effects of neonicotinoids, issues of regulation, enforcement, extension services, information provision and research priorities and compiled the 'Key messages' for policymakers which can be found in this report.

From the perspective of the African Science Academies, this project has shown the value of harnessing scientific knowledge to the key social and environmental objective of developing a sustainable agriculture on which future food security depends. We recognise that a synergistic relationship between agriculture and the beneficial services offered by nature (such as pollination and natural pest control) is a foundation of sustainable agriculture, and is under threat by the increased use of non-selective and systemic insecticides typified by the neonicotinoid class. It is not too late to learn from the negative experiences elsewhere and apply this to Africa to develop a more sustainable agriculture that fully exploits the benefits from the surrounding natural ecosystems rather than damaging them. But the time remaining is short given the rapid growth anticipated in the reliance on chemical pest control in African agriculture. NASAC thus encourages policymakers to consider very carefully the conclusions and recommendations in this report.

This review has shown that while Africa has some world-class scientific resources, those that may be relevant to this study's subject are distributed throughout the continent, bringing with it challenges to effective coordination at national, linguistic, cultural and geographical levels. Science continues to offer solutions to agricultural development and innovation; making full use of this potential, and strengthening synergy between available resources, are thus very important, along with collaboration on common research priorities. A critical role for Science Academies, wherever they are, is to apply scientific knowledge to society's benefit; NASAC will play its role in supporting Africa's Academies to realise this potential and to strengthen synergies between the available resources.

Prof. Bousmina Mosto Mostapha
Board Chair, NASAC

Prof. Volker ter Meulen
President, IAP

Glossary

ADAPPT	African Dryland Alliance for Pesticidal Plant Technology
AMEPH-CI	L'Association des entreprises nationales phytosanitaires de Côte d'Ivoire
AMU	Arab Maghreb Union
ASSAf	Academy of Science of South Africa
ASARECA	Association for Strengthening Agricultural Research in East and Central Africa
APC	Agricultural Pesticides Committee (Egypt)
BMBF	German Federal Ministry of Education and Research
CARBAP	African Research Centre on Bananas and Plantains (Cameroon)
CCD	Colony Collapse Disorder
CEMAC	Central African Economic and Monetary Community
CENSAD	Community of Sahel-Saharan States
CERES-Locustox	Centre Régional de Recherche en Écotoxicologie et de Sécurité Environnementale
CILSS	The Permanent Interstate Committee for Drought Control in the Sahel (Comité permanent inter-État de lutte contre la Sécheresse au Sahel)
COCOBOD	Ghana Cocoa Board
CODAPEC	Cocoa Disease and Pest Control Program
CODEX	Codex Alimentaire
COLOSS	Prevention of honey bee COLony LOSSes
COMESA	Common Market for East and Southern Africa
CNRA	Centre National de Recherche Agronomique de Côte d'Ivoire
CPAC	Interstate Committee of Pesticides in Central Africa
CRIG	Cocoa Research Institute of Ghana
CRIN	Cocoa Research Institute of Nigeria
CSP	Sahelian Committee of Pesticides (Comité Sahélien des Pesticides)
EAC	East African Community
EASAC	European Academies' Science Advisory Council
EC	European Community
ECCAS	Economic Community of Central African States
ECOWAS	Economic Community of West African States
EFSA	European Food Safety Authority
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
IAP	InterAcademy Partnership
IAPSC	Inter-African Phytosanitary Council
ICIPE	International Centre of Insect Physiology and Ecology
IGAD	Intergovernmental Authority on Development
IKS	Indigenous knowledge systems

IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPM	Integrated pest management
IPPM	Integrated pest and pollinator management
ITK	Indigenous technical knowledge
IUCN	International Union for Conservation of Nature
LANADA	Laboratory for Analysis and Support to Agricultural Development
LAPPAB	Laboratory of Bees Pathology, Parasitology and Plant Protection
LOQ	Limit of quantification
LUANAR	Lilongwe University of Agriculture and Natural Resources
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries (Uganda)
MAWF	Ministry of Agriculture, Water and Forestry (Namibia)
MEA	Millennium Ecosystem Assessment
NAADS	National Agricultural Advisory Services
NAFDAC	National Food and Drug Agency (Nigeria)
NASAC	Network of African Science Academies
NEPAD	New Partnership for Africa's Development
NPAS	Northern Presbyterian Agricultural Services
OIE	World Organisation for Animal Health
PCPB	Pest Control Products Board (Kenya)
PERSUAP	Pesticide Evaluation Report and Safer Use Action Plan
REC	Regional Economic Communities
SABS	South African Bureau of Standards
SADC	Southern African Development Community
SIRG	Social Insect Research Group (University of Pretoria)
SSP	Spray Service Provider
TFSP	Task Force on Systemic Pesticides
TPRI	Tropical Pesticide Research Institute
USEPA	United States Environmental Protection Agency
USAID	United States Agency for International Development
WHO	World Health Organization
WIA	Worldwide Integrated Assessment
ZEMA	Zambian Environmental Management Agency

Executive Summary

Why this study?

Agriculture is critically important for African societies and economies, but ensuring food security for Africa's growing population is a major challenge due to climate change, structural changes in land use and management, and intensification of agriculture, including the use of pesticides. A synergistic relationship between agriculture and the beneficial services offered by nature (such as pollination and natural pest control) is a foundation of sustainable agriculture on which future food security depends. Such 'ecosystem services' are provided mainly (although not exclusively) by invertebrates, and the rapid decline in biodiversity in general and insects in particular globally has implications for productivity and future food security. Beneficial insects increase agricultural productivity and the quality of crops, and are as (if not more) important in the African context than the rest of the world.

One factor that has been shown to contribute to loss of ecosystem services in Europe and elsewhere is the increased use of a class of systemic insecticides called neonicotinoids, which act as insect neurotoxins. They are taken up by all parts of the plant, are water soluble and can thus spread in the environment, exposing not only the target pests but also beneficial insects ranging from honey bees and other pollinating insects to natural predators of the targeted pests. As a result, the use of some of these insecticides has been restricted in the European Union (EU) and some other countries.

The debate preceding the EU restrictions was informed by a study on the impact of neonicotinoids on agriculture and ecosystem services by the European Academies' Science Advisory Council (EASAC). Building on this foundation, the InterAcademy Partnership (IAP) and the Network of African Science Academies (NASAC) collaborated in a study to examine the implications of neonicotinoid insecticide use for ecosystem services and sustainable agriculture in Africa. The study was conducted between October 2018 and October 2019 and involved two workshops with scientists from 17 African countries as well as an extensive review of relevant African research. This project has collated an unprecedented amount of information, allowing the current situation relating to neonicotinoids in Africa to be assessed for the first time. The findings have been subjected to peer review and endorsed by NASAC member academies.

Current Situation

This study looked first at the extent of neonicotinoid usage in Africa. On the basis of available evidence, overall pesticide consumption appears to be between 2.1% and 6.8% of global pesticide use. Such estimates are consistent with market penetration being at an earlier stage than in more mature markets such as Europe and North America, and Africa has been flagged as the fastest growing market for insecticides in recent market surveys. All countries appeared to be using neonicotinoids (mostly imidacloprid, acetamiprid, thiamethoxam and thiacloprid). With the 2018 ban on the use of three neonicotinoids in the EU, neonicotinoid manufacturers may seek new markets in African countries either to replace older pesticides or to increase rates of use. It is thus timely to consider the extent to which concerns over the effects of neonicotinoids on wider ecosystem services should apply to Africa.

There is already evidence of widespread environmental contamination from neonicotinoids in Africa. Residues are found in honey from several countries, with some levels similar to or higher than levels found in Europe before the restrictions imposed by the EU. A limited number of studies have also confirmed contamination in soils, again with examples where levels are very high compared with the highest levels found in European studies. Neonicotinoids have also been found in water, snails and sediment near agricultural areas.

With Africa's huge biodiversity and fewer scientific resources than Europe or the USA, it is not possible to quantify trends in pollinating insects (as done in Europe). However, there is a consistency in the qualitative findings from the participating countries that honey bee populations are in decline, as shown in decreases in wild population, fewer migratory swarms, disappearance and loss of hives, some mass bee mortalities and reduced honey production. Declines observed in other species include edible insects such as crickets, as well as insectivorous birds. Regarding use in cocoa crops, the control of mirid bugs using neonicotinoids had led to the proliferation of some pests considered as secondary owing to the destruction of their natural enemies. Pollination of cocoa flowers by the natural pollinator (a midge) had also been affected and expensive manual alternatives had to be introduced.

Regulations on agricultural pesticides exist in almost all countries, but compliance and enforcement are often weak. Moreover, regulatory procedures tend to rely on data from outside Africa, with the EU, USA and the Food and Agriculture Organization of the United Nations (FAO) being authorised sources. The EU restrictions on neonicotinoids had been followed, or were under consideration, in only a few countries, leading to significant differences in the insecticides approved. The diversity of African countries suggests that regulations should remain country-specific, but there is a need for jointly agreed-upon, science-based and binding criteria underpinned by the precautionary principle. Regulatory systems have often made no specific provision for protecting pollinators such as honey bees, so that approved pesticides are sometimes more toxic to honey bees than the pesticides approved in Europe. Including pollination protection in regulatory criteria and placement of honey bees especially, in the correct legislative framework is essential.

The study also looked at the availability of extension services. All countries represented at the workshops reported that the role of extension services was poor, particularly for small-holder farmers. Farmers are typically unaware of the environmental or health hazards associated with pesticide use. Extension services need to focus on disseminating good agricultural practice; education about ecosystem services and ability to see insects not only as pests but also as providing many beneficial services; education of farmers and pesticide operators about the effectiveness of insecticides; avoiding preventive or prophylactic application and encouraging the principle of integrated pest management (IPM).

Research resources relevant to assessing the impact of neonicotinoids on African ecosystem services are distributed throughout the continent, bringing with it challenges to effective coordination at national, linguistic, cultural and geographical levels. There is a need to identify mechanisms to strengthen synergies between available resources, and to focus on the research priorities that will most assist policy development. Such priorities are offered in the report.

Key Messages

As a conclusion to this study, the following key messages are provided.

1. The sustainability of African agriculture is critical to food security and for maintaining its contribution to African economies and supporting rural communities. Maintaining the biodiversity that supports the ecosystem services is critical to maintaining resilience against climate change and other environmental pressures. The negative effects of neonicotinoid insecticides on ecosystem services shown in research and field studies globally are cause for concern for Africa.

2. Neonicotinoid insecticides are now registered and used in most, if not all, African countries. Therefore it is essential to apply the knowledge that has already led to restrictions on the use of neonicotinoids in several countries and regions outside Africa.
3. Evidence of negative effects of neonicotinoids includes loss of honey bee colonies and contamination of agricultural products, soils and freshwater systems with neonicotinoid residues. Neonicotinoid usage in Africa is currently less than historical usage in intensively farmed areas of Europe, so that there is an opportunity to learn from experiences elsewhere and promote pest-control strategies that are more compatible with a sustainable and resilient agriculture for Africa's future.
4. African agro-ecosystems and agricultural methods (and their social and cultural contexts) are wide-ranging. While there is a need for better knowledge about pollination and other ecosystem services in the different agro-ecosystems, any comprehensive and quantified review across such a diverse continent would be extremely time-consuming and expensive. This review therefore concludes that a precautionary approach needs to be taken on the basis of the existing scientific evidence on the negative effects of neonicotinoids.
5. This review stresses the urgency of reducing tensions between agricultural intensification and Africa's rich and abundant biodiversity and ecosystem services. Overall, this review concludes that stricter regulation of insecticides is required across Africa and that good agricultural practices in plant protection should be promoted to ensure sustainable agriculture that protects the environment, human health and biodiversity. Central to this should be maximising the use of natural controls to balance pest pressures and reduce the need for pesticides. This review recommends that African regulatory systems should pay close attention to the results of the regulatory reviews already conducted in Europe. Given the advent of trans-frontier conservation areas, as far as possible this should be done within the ambit of the Regional Economic Communities and the African Union.
6. Ensuring food security within a sustainable agricultural system requires farmers to be provided with the expertise to minimise pesticide use and ensure that, when used, they are applied in as safe a manner as possible (ecological intensification). Countries should strengthen expertise (e.g. in universities) and extension services to disseminate methods of integrated pest management. Such methods should maximise non-chemical methods of pest control and promote best practice in the minimal use of all pesticides. Such services should provide expert advice independently of pesticide manufacturers and suppliers/traders.
7. International funding agencies and national governments should substantially strengthen the provision of research, advice and training on sustainable agriculture in national agricultural research institutes and extension services, supported by regional centres of expertise.
8. The scientific resources available within the African continent are limited and are dispersed across large distances and different languages and cultures. At the same time, science continues to offer solutions to agricultural development and innovation; making full use of this potential and strengthening synergy between available resources are thus important, along with collaboration on common research priorities.

Final Comments

This study concludes that it is urgent to act now to prevent further deterioration in the sustainability of African agriculture. While the focus is on the neonicotinoid insecticides, alternatives that deploy the same non-selective neurotoxic effects are already entering the market (e.g. sulfoxaflor and flupyradifurone) and should be subject to the same level of scrutiny for potential side effects on non-target organisms and the ecosystem services they provide.

There are significant opportunities now to act on existing knowledge about the harmful effects of neonicotinoids, to protect ecosystem services and thus African biodiversity and agricultural sustainability. In addition, this review lays a foundation for further scientific and political engagement with the issues raised, and for development of solutions at national regional, and continental levels. Here, the African science academies can play important roles through the academic excellence of their membership and networks, their convening power and their established collaborations with policymakers.

Background 1

The use of neonicotinoid insecticides has grown rapidly worldwide since their introduction in the 1990s. They are registered in more than 120 countries and comprise a substantial proportion of the global market for insecticides (estimated at US$16.05 billion in 2018)[1]. Neonicotinoids are nicotinic acetylcholine receptor agonists; they kill insects by causing hyper-excitation of the nervous system. Their systemic mode of action renders plant tissue toxic to insects that consume parts of the plant, but their systemic nature means that the insecticide gets into pollen and nectar so that non-target species such as pollinators are exposed and at risk owing to the non-selective nature of neonicotinoids' toxic effects on all insects. Moreover, particularly when applied as dressings on plant seeds or in soil drenching, their water solubility leads to most of the neonicotinoid leaching into the soil and aquatic systems, broadening the potential exposure to natural predators and other non-target species (Goulson 2013; Sanchez-Bayo 2014).

Specific concerns about the impacts of neonicotinoid use on honey bee colonies grew during the 2000s; in Europe, the European Commission requested the European Food Safety Authority (EFSA) to review the available scientific evidence on the effects of this group of insecticides. EFSA identified potential risks of harm to honey bees (Auteri *et al*. 2017), which led to partial restrictions on the three main neonicotinoids (imidacloprid, clothianidin and thiamethoxam) in 2013 (European Commission 2013). However, this was opposed by pesticide manufacturers while uncertainties remained over the extent and nature of effects in the field. Reflecting on this, the European Academies' Science Advisory Council (EASAC) launched a review of the evidence on the effects of neonicotinoids on ecosystem services[2] of importance to agriculture (including pollination and natural pest control as well as biodiversity in general). This policy report (summarised in Box 1) was endorsed by all European national academies of science and published in April 2015 (EASAC 2015).

Since the EASAC report was released, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2016) reviewed the evidence on declines in honey bees and other pollinators (e.g. bumblebees, solitary bees, flies, beetles and butterflies). This decline had led to concerns over a global threat to pollination and other ecosystem services. Both EASAC and IPBES pointed to the significance of cumulative negative effects from lengthy exposure to low concentrations of neonicotinoids. Even though field-realistic doses were very different from the direct topical application used in LD_{50}[3] tests, sub-lethal effects were detectable on, *inter alia*, adult longevity, mobility, learning and navigation ability of adult honey bees, on defence against predators, on foraging activity at the colony level, and on colony growth rate, queen production and swarming propensity. In addition, experiments suggested synergistic effects with other agrochemicals (e.g. fungicides) by reducing the immune system's ability to suppress viruses. Such effects impact not only individual functions but also overall colony function and performance.

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[1] *www.MordorIntelligence.com*

[2] Ecosystem services were classified and evaluated comprehensively in the 2005 Millennium Ecosystem Assessment (MEA 2005) and refer to the benefits that natural systems can deliver to humankind. Alternative terminology includes 'Nature's contributions to people' and 'Nature's benefits to people' (IPBES 2016).

[3] The dose that would be lethal to 50% of a test sample.

BOX 1

THE EASAC REPORT ON NEONICOTINOIDS AND ECOSYSTEM SERVICES

EASAC (2015) reviews the relations between agriculture and ecosystem services and their economic value, evidence of acute, chronic and sub-lethal effects on insects from neonicotinoid use, and effects on ecosystem context. Some of its conclusions included the following.

- *Worldwide, 75% of the crops traded on the global market depend to some degree on pollinators estimated to be worth €153 billion (approximately US$170) per annum. With trends to grow more crops that require or benefit from pollination, there is also an emerging pollination deficit. Honey bees are the most widely used managed pollinators, but a diversity of pollinators is necessary to improve crop yield or fruit quality.*
- *Natural pest control (parasitic wasps, lacewing and hoverfly larvae, ladybirds and other beetles, etc. as well as birds) reduces the need for chemical measures and provides an ecosystem service estimated to be worth US$100 billion annually globally. Loss of natural pest control weakens agriculture's resilience and renders it less sustainable and more vulnerable to pests and diseases.*
- *Underpinning ecosystem services is biodiversity, which is an objective in its own right under both European and global agreements, including Sustainable Development Goal 15 ('Life on Land').*
- *The colony structure of honey bees provides a resilient buffer against losses of foragers and other workers, but such a buffer is lacking in bumblebees, solitary bees and other pollinators. Thus protecting honey bees is insufficient to protect pollination or other ecosystem services.*
- *Critical to assessing the effects of neonicotinoids on ecosystem services is their impact on non-target organisms (both invertebrates and vertebrates), whether located in the field or field margins, in soils, or the aquatic environment.*

Overall, EASAC (2015) concluded that the widespread prophylactic use of neonicotinoids has severe negative effects on non-target organisms that provide ecosystem services including pollination and natural pest control. The report also questioned whether recent trends to use neonicotinoids as a prophylactic treatment (e.g. as a seed dressing) are consistent with the basic principles of integrated pest management.

In parallel with the work just described, the International Union for the Conservation of Nature (IUCN) set up the "Worldwide Integrated Assessment of the Impact of Systemic Pesticides on Biodiversity and Ecosystems" (WIA) project, led by a Task Force on Systemic Pesticides (TFSP). The WIA conducted meta-analyses of the literature on neonicotinoids (and on fipronil, a non-neonicotinoid systemic insecticide), focusing on the following aspects: (1) trends, uses, mode of action and metabolites; (2) environmental fate and exposure; (3) impacts on invertebrates; (4) impacts on vertebrates; (5) impact on ecosystems and their services; (6) case studies on alternatives to neonicotinoids; and (7) conclusions (for a list of publications and updates see *www.tfsp.info/worldwide-integrated-assessment/*). In response to this mounting evidence, the European Commission completely banned all outdoor uses of the neonicotinoids imidacloprid (European Commission 2018a), clothianidin (European Commission 2018b) and thiamethoxam (European Commission 2018c) in 2018.

In the light of these detailed scientific reviews and the regulatory actions taken in Europe, the InterAcademy Partnership (IAP) decided to expand work on the impact of neonicotinoids on ecosystem services and biodiversity beyond Europe, and to support additional regional assessments through its regional members. For Africa, agriculture constitutes the largest economic sector, representing over 15% of the continent's total gross domestic product, or more than US$100 billion annually[4]. Moreover, developing countries are more reliant on

[4] Egypt and Nigeria account for one-third of total agricultural output and the top 10 countries generate 75%; see *https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS*

pollination-dependent crops than developed countries (Aizen *et al.* 2008), while subsistence farmers and rural communities may rely directly and indirectly on the services provided by pollinators (either as hive products such as honey or as crop pollination). In view of the dependence of African economies and societies on agriculture, IAP concluded that there is an urgent need to identify and collate data that would allow the potential risks of neonicotinoid use in Africa to be better evaluated, and that Africa should be the first priority in IAP's regional assessments. This initiative is funded by the German Government through the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) and is jointly managed by the Academy of Science of South Africa (ASSAf) and the German National Academy of Sciences Leopoldina, with the full engagement of the Network of African Science Academies (NASAC) and IAP.

The methodology of this review comprised the following:

- An initial scoping study to synthesise the main themes of the extensive literature reviewed by EASAC, IPBES and WIA (described above).
- The first workshop (Pretoria, 15–16 November 2018), bringing together authors of the original EASAC and WIA studies and experts from 12 African countries. This supplemented the extensive scientific evidence from Europe and North America with knowledge of the extent of use of neonicotinoids in African agriculture and their impacts (ASSAf 2019a).
- A review of the published literature related to neonicotinoid use in Africa.
- The second workshop (Nairobi, 13–15 May 2019) included additional experts nominated by their academies of science, bringing the total number of African countries involved to 17. This workshop discussed evidence on use and effects of neonicotinoids, and issues of regulation, enforcement, extension services, information provision and research priorities (ASSAf 2019b).
- The second workshop endorsed several 'key messages' for policymakers.
- This review was compiled from the above sources and from additional literature, has been reviewed by workshop participants (Annex 1), submitted to external peer review and finally endorsed by member academies of NASAC.

We trust this analysis and its messages will be helpful to Africa's farming community, its pesticide regulatory authorities and other agricultural and environmental stakeholders. We hope it will contribute to a sustainable and productive agricultural system for the continent and towards improved food security and public health.

2 Extent of Neonicotinoids' Use in Africa

Pesticide use in many developing countries remains weakly regulated and poorly documented, in parallel with an ever-increasing need for better agricultural yield coupled with widespread illiteracy and limited safety training (Kaaya 1994; Ecobichon 2001; Naidoo *et al.* 2010). The agricultural landscape in Africa also consists of far more small scale and subsistence farmers than in the EU. Combined with the reluctance of manufacturers and suppliers to provide information on sales and trends which they regard as commercial-in confidence, the extent of use of neonicotinoid insecticides on the African continent is less well documented than in the EU (van der Valk *et al.* 2013). As a result, the available market-related sales data are most often used as an indication of country-based pesticide use (Dabrowski 2015). Notably, market gardening (e.g. in parts of West Africa) relies heavily on the use of pesticides (Agboyi *et al.* 2015; Kouame *et al.* 2013). Identifying what is being used on the continent is further complicated by evidence that in some countries, restricted or banned products can still be accessed and used. Nevertheless, some information related to neonicotinoids is available in published literature from African countries, and is summarised in Box 2.

BOX 2

INFORMATION RELATED TO NEONICOTINOIDS IN AFRICAN COUNTRIES FROM AVAILABLE LITERATURE

Algeria

- *Actara (25 WG) containing thiamethoxam is widely used in northeastern Algeria on cereals, tree fruit and vegetable crops (Berghiche et al. 2017).*

Benin

- *Several neonicotinoids containing the active ingredient acetamiprid are routinely sprayed to control Tetranychus evansi (invasive red spider mite) on tomatoes and eggplants in southern Benin (Azandémè-Hounmalon et al. 2015; 2016).*
- *The addition of the active ingredient clothianidin to the products SumiShield 50 WG (Agossa et al. 2018a) and Fludora Fusion (Agossa et al. 2018b) was to ascertain its efficacy in combating the potentially pyrethroid resistant Anopheles gambiae mosquito and the spread of malaria.*
- *Imidacloprid is among the active ingredients used in the cotton industry in Benin (Zoclanclounon et al. 2016).*

Burkina Faso

- *Neonicotinoids were utilised almost exclusively against whiteflies on cotton and eventually led to the subsequent development of widespread neonicotinoid resistance within that pest (Houndété et al. 2010; Gnankiné et al. 2013a, 2013b; Legg et al. 2014). Residues of several pesticides, including the neonicotinoids imidacloprid and acetamiprid, were detected in water samples and a wide range of vegetable samples from the areas surrounding Loumbila Lake (Lehmann et al. 2017, 2018).*

Cameroon

- *Gardening activities in urban, peri-urban and rural areas around Bamenda were found to make use of many classes of pesticides to improve vegetable yields, including neonicotinoid-based insecticides such as imidacloprid (Kouame et al. 2013). Aboubakary and Mathieu (2008) indicated the use or potential registration for use of chemicals*

Continued on next page

- *with neonicotinoid active ingredients (imidacloprid (Confidor), acetamiprid (Matador 80 EG) and thiamethoxam (Actara 25 WG)) for use in the protection of cotton crops in northern Cameroon.*
- *Management of several banana and plantain pests such as borer weevils (Cosmopolites sordidus) relies largely on imidacloprid, fipronil and thiamethoxam (Okolle et al. 2009). Acetamiprid is used against aphids and whiteflies and, in contrast to policy in Mali and Senegal, there are no threshold counts done to determine when treatment is to be implemented. Instead, it is left to the farmer and the extension agent to make a treatment decision (Silvie et al. 2013).*

Côte d'Ivoire

- *In the south of the country, around 10% of insecticides used in rice cultivation include the neonicotinoid acetamiprid in conjunction with a pyrethroid (Chouaïbou et al. 2016). Similarly, vegetable cultivation makes use of mainly pyrethroids with around 30% of these insecticides being used in conjunction with acetamiprid in the south of the country (Chouaïbou et al. 2016). Tests on the resistance of mosquitoes to neonicotinoids in agricultural settings found resistance to both acetamiprid and imidacloprid, but continued susceptibility to clothianidin (Mouhamadou et al. 2019).*

Egypt

- *Concentrations and frequency of detection indicate that use is similar to that found in US and European farms (Codling et al. 2018). Toxicity evaluations of acetamiprid, imidacloprid and thiamethoxam were conducted to investigate their potential as a treatment for the wood-destroying pest, the sand termite (Psammotermes hypostoma) (Ahmed et al. 2015).*
- *The efficacy of a few neonicotinoids was tested as a treatment against an emerging pest of cotton crops, the cotton mealybug (Phenacoccus solenopsis) (El-Zahi et al. 2016) as well as the cotton leafworm (Spodoptera littoralis) (Ahmed 2014). Abdu-Allah and Mohamed (2017) evaluated the potential of the three neonicotinoid insecticide products imidacloprid (Gaucho 70 WS), acetamiprid (Mospilan 20% SP) and thiamethoxam (Actara 25% WG) as seed treatments to protect against aphid damage to faba bean and its simultaneous possible side effects on associated beneficial mutualists; specifically the yeast Saccharomyces cerecisiae and the mycorrhizal fungus Glomus mosseae, which play a part in faba bean growth. These products were found to greatly reduce aphid damage but negatively impacted the beneficial organisms surrounding the faba bean roots (Abdu-Allah and Mohamed 2017).*
- *Research at the Sakha Agricultural Research Station recommended the use of flonicamid, thiamethoxam and imidacloprid as an alternative for treatment against the whitefly, Bemisia tabaci, which has acquired resistance to many other commonly used pesticides including organophosphates and pyrethroids (El-Zahi et al. 2017).*

Eritrea

- *Imidacloprid was among several treatments evaluated for use against citrus pests (woolly whitefly and cottony cushion scale) in Keren, and was found to be an effective chemical means of controlling these pests (Hussain et al. 2017).*

Ethiopia

- *A comparative study surrounding chemical pesticide use in Ethiopia indicated that thiamethoxam and imidacloprid were the neonicotinoids used by the farmers surveyed in the central eastern part of Ethiopia (Negatu et al. 2016).*

Ghana

- *The Ghana Cocoa Board (COCOBOD) instituted a mass spraying programme including the use of imidacloprid (Confidor) and thiamethoxam (Actara) against cocoa mirids in 2001 (Adu-Acheampong et al. (2015); Ninsin and Adu-Acheampong 2017). Neonicotinoids are widely used in Ghana's cocoa industry and the main neonicotinoids utilised were found to have high persistence in soil (Dankyi et al. 2018).*

Kenya

- *Part of the International Centre of Insect Physiology and Ecology (ICIPE)'s pesticide residue analysis research involved testing 261 honey samples and 322 pollen samples from 45 sites in Kenya. Over 30 pesticides were detected with approximately 22% of these being neonicotinoids (Irungu et al. 2016).*

Continued on next page

- *Imidacloprid, dinetofuran, clothianidin, acetamiprid, thiacloprid and thiamethoxam were among approved pesticides for use in Kenya for use in controlling pests on coffee, French beans, maize, cotton, wheat, forestry nurseries, roses, tobacco and vegetables (PCPB 1998). Residues in honey and pollen samples collected in the Kiambu and Nairobi Counties indicated that of the pesticides used on cultivated crops around apiaries, 14.4% were neonicotinoids (Mulati et al. 2018). Acetamiprid was found in honey samples, and thiamethoxam and imidacloprid in both counties (Mulati 2018).*
- *The neonicotinoids imidacloprid (Gaucho 350 FS; Monceren GTF 390; Confidor WG 70) and thiamethoxam (Apron Star 42 WS; Cruiser 350 FS; Actara 25 WG) were tested for use as soil drenching and seed coating treatment against snap pea pests in Mwea and were found to be effective against bean fly but not thrips (Otim et al. 2016), contrary to results for imidacloprid and thrips found by Nyasani et al. (2015).*

Libya

- *The neonicotinoid imidacloprid was tested alongside a carbamate and pyrethroid pesticide to evaluate its toxicity potential for use against the land snail Theba pisana, which causes serious damage to economically important crops (Mohamed and Radwan 2013).*

Madagascar

- *Ratnadass et al. (2012) reported on the use of imidacloprid (Gaucho T 45 WS, 5 g/kg) on protection of upland rice from black beetle damage through use of dressed seeds.*

Mali

- *Anecdotal evidence of use of the neonicotinoid acetamiprid was reported in Sikasso (Hamadoun et al. 2014). Several neonicotinoid-based pesticides (acetamiprid Gazelle C 88 EC and Emir 88 EC; imidacloprid Attakan C 344 SC) are among those used in the cotton cultivation areas of the Korokoro watershed and Bafinkabougou in Koulikoro (Maiga et al. 2018).*

Morocco

- *The control of aphids in Moroccan citrus groves relies mainly on insecticides of the carbamate and neonicotinoid family, with imidacloprid being the most prominent neonicotinoid used (Smaili et al. 2014).*

Mozambique

- *Evaluation of the optimal dosage and type of pesticide for use in the control of leaf miner (Stomphastis thraustica) and the leaf beetle (Aphthona dilutipes), a major pest of Jatropha in Mozambique, indicated that the neonicotinoid imidacloprid was by far the most efficient pesticide and was recommended for use (Cassimo et al. 2011).*

Nigeria

- *Toxicity and efficacy of the neonicotinoid thiamethoxam, the active ingredient in Actara25 WG, was evaluated for use against the cocoa mirid (Sahlbergella singularis) (Anikwe et al. 2009; Asogwa et al. 2011). Nnadi et al. (2018) examined the use of Termex, a neonicotinoid product registered for treatment of termites in Nigeria, and its effect on fish. Nwozo et al. (2015) note that one of the most commonly used neonicotinoids in Nigeria is imidacloprid. Omoyajowo et al. (2018) found residues of acetamiprid and thiacloprid in apples and imidacloprid residues in watermelons from areas in Lagos state, Nigeria.*

South Africa

- *Neonicotinoids are used on several crops in South Africa, including apples, barley, canola, citrus, cotton seed, cucurbits, grapes, maize, oats, peaches, sorghum, sunflower seed, tomatoes and wheat (Quinn et al. 2011). Seed dressing of maize using imidacloprid and thiamethoxam is used to control black maize beetle, Heteronychus arator (Drinkwater 2001).*
- *The website Agri-Intel acts as an agrochemical database comprising all crop-protection products registered for use in South Africa and is owned and managed by CropLife SA, a non-profit organisation representing manufacturers, suppliers and distributors of crop-protection products. Although*

Continued on next page

not all registration holders for pesticides submit their products to the Agri-Intel website, and registrations fluctuate constantly, the current information for South Africa on registered neonicotinoids includes five active ingredients under several trade names (Agri-Intel 2019):

- Clothianidin: six registered trade names in South Africa; also registered in Namibia, Zambia and Zimbabwe (Nhachi and Kasilo 1996).
- Imidacloprid: 48 registered trade names in South Africa; also registered in Angola, Botswana, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Zambia and Zimbabwe.
- Thiamethoxam: 16 trade names registered in South Africa; also registered in Botswana, Namibia and Mozambique.
- Thiacloprid: seven trade names in South Africa; one product also registered for use in Madagascar, Malawi, Zambia and Zimbabwe.
- Acetamiprid: 13 trade names registered for use in South Africa; other products also registered for use in Angola, Malawi, Mozambique and Namibia.

Sudan

- *Neonicotinoids are among the most commonly used pesticide classes (Hammad et al. 2017), with Actara 25 WG (thiamethoxam) widely used on potato crops against the aphid Aphis gossypii (Mohamed et al. 2014) and on tomatoes against the whitefly Bemisia tabaci (Mohamed 2004). Imidacloprid (Confidor 200 SL; Rinfidor 20% SL; Comodor 20% SL) were found to be extremely successful as a trunk injection treatment in date palm trees against the infestation of green pit scale insect (Palmapsis phoenicis). Residue analyses showed no residues present in the dates, soil or intercropped plants even at high doses (Ahmed et al. 2010). Imidacloprid residues were detected in exported cantaloupe fruit originating from both Khartoum and Gezira states (El Kheir 2004).*

Togo

- *It was found that farmers in market gardening utilised at least one synthetic pesticide to combat vegetable pests, with neonicotinoids being one of several classes of pesticides used and imidacloprid being the most common active ingredient (Agboyi et al. 2015; Ahoudi et al. 2018).*

Tunisia

- *Aphids collected between 2014 and 2016 exhibited resistance alleles to neonicotinoids, especially in northern Tunisia at a frequency of 32–55% in insects from peach, potato, pepper, tomato and melon crops, presenting a threat to aphid control (Charaabi et al. 2018). Of the six vegetable-producing regions in Tunisia, neonicotinoids are utilised for pest control on cucumber and potato crops in Korba; melon in Bizerte; tomato, melon and cucumber in Monastir; pepper, melon and cucumber in Kairouan; tomato in Gabes; and melon and pepper in Kebili (Charaabi et al. 2015). Acetamiprid and thiacloprid are among the most popular insecticides used in the citrus industry mainly targeting the tephritid fruit fly Ceratitis capitata (Harbi et al. 2017).*

Uganda

- *Pesticide use in Uganda was considered relatively unregulated with product identification made complicated by the prevalence of mislabelled/counterfeit products (Nalwanga and Ssempebwa 2011). The tobacco and citrus industries rely heavily on the use of neonicotinoids (Srigiriraju et al. 2010). Traces of several neonicotinoids were found in honey bees and hive products in three of ten agro-ecological zones in Uganda (Mid-Nile, Northern, Eastern) (Srigiriraju et al. 2010; Amulen et al. 2017). Acetamiprid, imidacloprid and thiamethoxam were all detected in beeswax, honey bee and honey samples from apiaries in close proximity to citrus and tobacco farms, although pesticide residues were detected at levels below the EU maximum residue limits and known lethal dose thresholds for honey bees (Amulen et al. 2017). Although imidacloprid and thiamethoxam are banned for use in melliferous crop seed coating in the EU, this ban does not extend to the USA or Asia, from where Uganda acquires much of its plant protection products (Amulen et al. 2017).*

Zimbabwe

- *Resistance of peach potato aphid (Mycus persicae) to imidacloprid indicates widespread use of this neonicotinoid in the country (Foster et al. 2003).*

The results of the published literature in Box 2 can be combined with the findings of the workshops. The latter included one estimate based on FAO statistics which suggested that African countries consumed 84,936 tonnes of the worldwide consumption of 4,093,340 tonnes of pesticides in 2015[5], equivalent to 2.1%. Flaubert (2016) estimates that 4% of global pesticide production is used in Africa. A further means of estimation is to extrapolate published figures of total pesticide use available for 20 countries to the rest of Africa, which provides an estimate of 137,000–170,000 tonnes of pesticide use (5.5–6.8% of global pesticide use). On the basis of available evidence, Nigeria and South Africa appear to be the biggest consumers of pesticides, followed by Algeria, Côte d'Ivoire, Egypt, Ghana, Kenya and Morocco (Quinn *et al.* 2011; Erhunmwunse *et al.* 2012; Donkor *et al.* 2016; Flaubert 2016).

Whichever figures are more accurate, they are consistent with market penetration being at an earlier stage than in more mature markets such as Europe and North America, and Africa has been flagged as the fastest growing market for insecticides in recent market surveys (see footnote 1 on page 5). Also, in some countries many of the pesticides preceding the introduction of neonicotinoids (carbamates, organophosphates, etc.) are still in widespread use. With the 2018 ban on the use of neonicotinoids in the EU, it is plausible that neonicotinoid manufacturers are seeking new markets in African countries to either replace older pesticides or increase rates of use. It is thus timely to consider the extent to which concerns over the effects of neonicotinoids on ecosystem services should apply to Africa.

In Africa, the main target pests include aphids (Bass *et al*. 2015; Charaabi *et al*. 2018), stem borers (Prasad *et al*. 2009; Anuradha 2012; Haq *et al.* 2018) and spider mites (Smith *et al.* 2013) on crops, fruit flies on mangoes, oranges, etc. (Gogi *et al.* 2007; Yee 2010) and cover the main crops of cereals, maize, rice, tobacco, cotton and vegetables (Capella *et al*. 2004; Houndété *et al.* 2010; Prabhaker *et al.* 2011; Mtetwa 2015; Chouaïbou *et al*. 2016; Mutengwe *et al*. 2016; Del Pozo-Valdivia *et al.* 2018; Lanka *et al.* 2017; Milosavljević *et al.* 2019). In addition, non-agricultural uses include treatment of livestock, use in forestry, indoor residual spraying of dwellings against disease vectors (cockroaches, mosquitoes, tsetse flies, etc.), as well as use against termites in and around buildings, and for combating fleas on pets (see, for example, Corbel *et al.* 2004; Rust and Saran 2008; Benzidane *et al.* 2010; Vo *et al.* 2010; Darriet and Fabrice 2013; Naqqash *et al.* 2016; Wiggins *et al.* 2018).

Imidacloprid appears to be the most commonly used of the neonicotinoid insecticides and the same registered products are available in many countries. However, the range of available active ingredients and formulations varies significantly between countries. Some countries have approved most available neonicotinoids (imidacloprid, acetamiprid, thiamethoxam and thiacloprid) while others have authorised only a single active ingredient. For instance, imidacloprid, acetamiprid, and thiamethoxam are among the pesticides registered in Cameroon, Kenya, Sudan, Tanzania, Uganda and elsewhere, while in Botswana imidacloprid is the main neonicotinoid authorised. The neonicotinoids acetamiprid and imidacloprid are among the pesticides most recently authorised for use in Benin, Burkina Faso, Cape Verde, Chad, Côte d'Ivoire, Gambia, Guinea, Guinea Bissau, Mali, Mauritania, Niger, Senegal and Togo by the Sahelian Committee of Pesticides (Sahelian Committee of Pesticides 2018). However, the limited controls and enforcement on imports or mislabelling mean that unregistered neonicotinoids may still be in use, even if not registered or approved in a particular country.

[5] See *http://www.fao.org/faostat/en/#data*. Database search: Inputs – Pesticides Use; Regions: World (Total) and Africa (Total); Items: Pesticides (Total); Years: 2015.

Participants in the two project workshops provided additional details of the use of neonicotinoids in their respective countries. In **Botswana**, neonicotinoids are used mainly on maize and sorghum; also in horticulture (tomatoes, etc.), while in West Africa – including **Benin**, **Cameroon**, **Côte d'Ivoire** and **Ghana** – treated crops include fruits (mangoes, citrus, etc.) and cocoa. Furthermore, the main active ingredients may appear in many different products and applications ranging from domestic garden use, seed treatments and foliar sprays, to formulations targeting specific African pests such as fall armyworm and tsetse flies. For instance, in Cameroon, 35 formulations of imidacloprid are registered, for acetamiprid, 20 formulations, and a further 3 and 8 formulations for thiacloprid and thiamethoxam, respectively. Trials are also continuing for the registration of 'Fortenza Duo' (thiamethoxam and imidacloprid) to treat maize seeds, with plans to use from 2019 in Cameroon.

In **Egypt**, data on consumption of neonicotinoids were provided in the Nairobi workshop, suggesting that the dominant neonicotinoid had been imidacloprid until 2017, since when acetamiprid and thiamethoxam had become the most used neonicotinoid, as well as the start of the use of the recently approved substitute for neonicotinoids (sulfoxaflor).

In **Ghana**, neonicotinoid insecticides comprise a significant proportion of insecticides applied. They are approved for use on cocoa, cotton, various fruits, vegetables, pulses, sweet potatoes and for seed treatment. Currently imidacloprid, thiamethoxam, and acetamiprid are fully registered for various applications and are mainly applied as foliar sprays, in which the insecticides are applied to the leaves and branches of trees using backpack manual sprayers or motorised mist blowers. Most neonicotinoids are applied in cocoa farming for the control of mirid bugs. The Government of Ghana set up the Cocoa Disease and Pest Control Program (CODAPEC) in 2001 whereby pesticides are applied on cocoa farms or given to farmers for application at no financial cost. Neonicotinoids (e.g. Confidor, containing imidacloprid) are widely applied in cocoa farms multiple times each year.

In **Malawi**, neonicotinoids are widely used and applied to crops via blanket sprays. Indoor residual spraying to coat the walls and other surfaces of a house with a residual pesticide is very common to control disease vectors such as mosquitoes, with clothianidin now in use for indoor residual spraying. Neonicotinoids registered in **Namibia** are imidacloprid, thiamethoxam, clothianidin, acetamiprid, thiacloprid, dinotefuran and nitenpyram. **Senegal** participates in a regional system of neonicotinoids regulation operated by the Sahelian Committee of Pesticides (Comité Sahélien des Pesticides) under the supervision of CILSS[6]. In November 2018, the Sahelian Committee of Pesticides authorised 59 pesticide formulations, among which are three formulations containing imidacloprid or acetamiprid for use against sucking insects, and pests of cotton.

In **South Africa**, over 130 imidacloprid insecticides and over 105 other neonicotinoid pesticides are registered and available for use. Such insecticides are used on all major crops; for example maize, sunflower, grapes, citrus, macadamia, etc. While foliar spraying and soil drenching is widespread and common throughout Africa, seed treatment is expanding – for instance the

[6] The Permanent Interstate Committee for Drought Control in the Sahel (Comité permanent inter-État de lutte contre la sécheresse au Sahel, CILSS) is an international organization consisting of countries in the Sahel region of Africa. The organization's mandate is to invest in research for food security and the fight against the effects of drought and desertification for a new ecological balance in the Sahel. CILSS member states are Benin, Burkina Faso, Cape Verde, Chad, Gambia, Guinea, Guinea-Bissau, Ivory Coast, Mali, Mauritania, Niger, Senegal and Togo.

geographical distributions of imidacloprid and thiamethoxam in South Africa are associated with grain production where pre-treatment is used (Figure 1). Surveys have shown that producers often spray crops with a variety of pesticides at inappropriate doses.

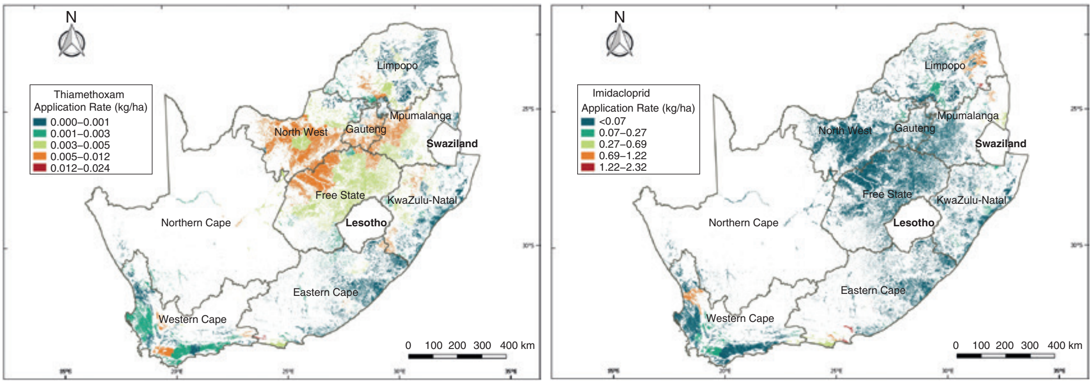

Figure 1. Distribution of the use of thiamethoxam and imidacloprid in South Africa (Dabrowski 2015).

In **Sudan**, neonicotinoids are used mainly on cotton and wheat in the irrigated areas, with up to 13 sprays per season at peak times, and widely used to control horticultural insect pests. Neonicotinoids are used under approximately 20 registered trade names. Thiamethoxam is used for seed treatment and imidacloprid for foliar sprays. In **Tanzania**, seven neonicotinoids are registered in 133 formulations.

Neonicotinoids have become the most widely used class of insecticides in **Tunisia**, with large-scale applications ranging from plant protection (crops, vegetables, fruits), veterinary products and biocides, to invertebrate pest control in fish farming. The citrus and olive agro-industries both use neonicotinoids extensively. Neonicotinoids are also used on vegetable crops and rapeseed. Foliar application has become routine for controlling aphids, whiteflies, leaf miners and mites, and resistance is appearing in some insects, particularly in the economically important species of aphid *Myzus persicae* (Charaabi *et al.* 2018), whitefly and plant hoppers. This loss of efficacy of neonicotinoids presents a serious threat to the continued success of aphid control and, by implication, the virus diseases they transmit.

Registered neonicotinoids in **Zimbabwe** are imidacloprid, clothianidin, acetamiprid, thiacloprid and thiamethoxam. They are used for grain protection, to combat cotton aphids, in horticulture and in indoor residual spraying. As in other African countries, the agricultural sector forms the backbone of the **Zambian** economy and 70% of the farming communities in Zambia are small-scale farmers. Major pests are armyworms, stalk and stem borers, weevils and termites, and the registered neonicotinoids are imidacloprid, clothianidin and thiamethoxam. Imidacloprid has been widely used to control termites in maize fields in most parts of Zambia. Most recently, in January 2018, Fortenza Duo received registration by the Zambia Environmental Management Agency (ZEMA). The traditional knowledge and experience of non-pesticide control methods ('indigenous technical knowledge'[7], ITK) of farmers has also worked well in controlling insect pests in most parts of Zambia (see also Section 6).

[7] ITK is equivalent to the 'indigenous and local knowledge' being pursued within IPBES (see SRC 2019).

Contamination

There is evidence of widespread environmental contamination from neonicotinoids from a global survey of neonicotinoid residues in honey by Mitchell *et al.* (2017); see Figure 2.

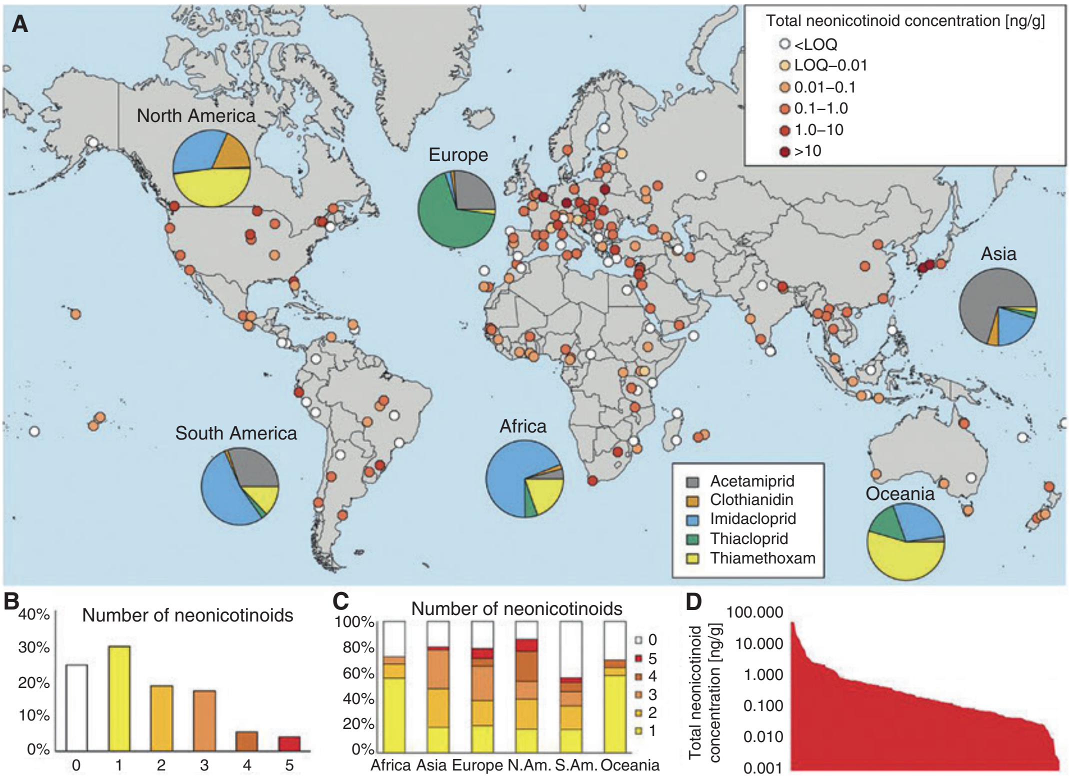

Figure 2. Concentrations of neonicotinoids in honey samples around the world (Mitchell et al. 2017). (A) White symbols indicate concentration below the limit of quantification (<LOQ) for all tested neonicotinoids; coloured symbols indicate concentrations above the limit of quantification for at least one neonicotinoid; shading indicates the total neonicotinoid concentration (in nanograms per gram, ng/g). (B) Overall percentage of samples with quantifiable amounts of 0, 1, or a cocktail of 2, 3, 4 or 5 individual neonicotinoids. (C) Proportion of samples with 0, 1, 2, 3, 4 and 5 individual neonicotinoids in each continent. (D) Ranking of the total neonicotinoid concentrations found in all of the 149 samples in which quantifiable amounts of neonicotinoids were measured, showing that most samples had concentrations of 0.001 and 0.1 ng/g and only a few samples had concentrations as high as 10 to 100 ng/g. From Mitchell et al. (2017). Reprinted with permission from AAAS.

The concentrations found in African samples support the conclusions from the project workshops and published literature that neonicotinoid use is widespread and that the dominant active ingredient in use is imidacloprid. Overall, most samples (21 out of 30) contained at least one neonicotinoid residue. Countries where samples showed no detectable levels included Madagascar and the Central African Republic but around half of African countries were not sampled. This study also indicates that concentrations of imidacloprid in African honey were higher (mean 0.181 ng/g; maximum 2.445 ng/g) than in Europe (mean 0.076 ng/g; maximum 1.199 ng/g) but lower than in Asia and North America. Concentrations of thiamethoxam were higher in African samples than in those from Asia (Mitchell *et al.* 2017).

Honey analyses were also conducted by Codling *et al*. (2018) in Egypt, where residue levels were well above the highest levels reported by Mitchell *et al.* (2017) (see Table 1). The residue levels found were similar to, or higher (especially in the case of thiamethoxam), than levels found in European studies before the restrictions imposed by the EU (Table 1; Mitchell *et al.* 2017; also see additional data on Europe in Botías *et al*. 2015; EASAC 2015).

Table 1. Neonicotinoid concentrations (nanograms per gram) in honey and pollen from surveys of Egypt (Codling *et al.* 2018), and in Africa and Europe (Mitchell *et al*. 2017; collected 2012–2016).

Sample type	Sample provenance	Acetamiprid	Clothianidin	Thiamethoxam	Imidacloprid
Honey	Egypt	av. 4.5 max. 9.4	n.d.	av. 18.84	av. 0.87 max. 1.68
Pollen	Egypt	av. 13.63 max. 22.46	av. 4.53	av. 12.35	av. 6.15 max. 7.03
Honey	Africa	av. 0.01 max. 0.139	av. 0.01 max. 0.10	av. 0.05 max. 0.60	av. 0.18 max. 2.45
Honey	Europe	av. 0.82 max. 29.31	av. 0.05 max. 0.95	av. 0.07 max. 1.42	av. 0.08 max. 1.20

Abbreviations: av., average; n.d., not detected; max., maximum.

In the studies of Codling *et al*. (2018), pollen samples were taken in the hives and therefore reflected a mixture of sources, but recent work by Jiang *et al*. (2018) in China showed that pollen from cotton treated with imidacloprid and thiamethoxam contained from 1.61 to 64.58 ng/g imidacloprid and from not detectable to 14.521 ng/g thiamethoxam. Major cotton growing areas treated with neonicotinoids in Africa are also likely to contribute to bee and other pollinator exposure.

Studies from other countries include that of pesticide residues in bee products from Uganda (Amulen *et al.* 2017), where acetamiprid, thiacloprid, imidacloprid and thiamethoxam were detected in beeswax but not in honey. Irungu *et al.* (2016a,b) and Mulati *et al*. (2018) analysed Kenyan honey and pollen samples from sites around the country and found considerable variability in residues of acetamiprid, imidacloprid and thiamethoxam – ranging from below the limit of detection to levels (of thiamethoxam) well above EU maximum residues levels for pollen. These reflected the heterogeneous nature of pesticide use at the landscape level, with the highest levels encountered in one area where small scale and large scale intensive farming of French beans, coffee and other horticulture were practiced with high local dependence on thiamethoxam.

With regard to soil contamination, neonicotinoid residues in different soil types have been found in a multitude of studies from Europe (Rexrode *et al.* 2003; Fernandez-Bayo *et al.* 2009), USA (Rexrode *et al.* 2003), Canada (De Cant and Barrett 2010), India (Sarkar *et al.* 2001) and Australia (Baskaran *et al.* 1999), with residues persisting from approximately 30 days to over 1,000 days within the soil (Goulson 2013). In Africa, the products imidacloprid (Gaucho 70 WS), acetamiprid (Mospilan 20% SP) and thiamethoxam (Actara 25% WG) were found to negatively affect soil microbial activity (Abdu-Allah and Mohamed 2017), leading these authors to recommend alternative methods to seed coating in the battle against aphid infestation of faba beans. Other studies have found accumulation in soils; in Ghana (Dankyi *et al*. 2014), imidacloprid concentrations were found in soils at concentrations of 4.3–251.4 ng/g, which is very high compared with the highest levels found in European studies (see Botías *et al.* 2015; EASAC 2015). In a study of rivers and lakes in Kenya in an area characterised by commercial agricultural plantations (mainly tea, rice and sugarcane), imidacloprid and acetamiprid were found in water, snails and sediment; the degradation product imidacloprid-guanidine (resulting from photolysis in water and with higher mammalian toxicity than the parent (Sharma and Singh 2014)) was found in water; and thiacloprid was detected in sediments. All examined snails contained imidacloprid and acetamiprid (B. Torto, ICIPE, personal communication). Other studies (see, for example, Douglas *et al.* 2014) have shown that slugs and snails are more resistant to neonicotinoids than their natural predators, and Hamlet *et al*. (2012) found that snails could be used as an indicator of neonicotinoid exposure because they undergo dose-dependent histological changes up to levels of exposure likely to be higher than those exhibited in the field. The iatrogenic effects found by Douglas *et al.* (2014) may increase risk of human schistosomiasis by supporting higher densities of snails, which are intermediate hosts of *Schistosoma* flatworms (see Halstead *et al.* 2018).

In addition, there is further evidence of widespread contamination by neonicotinoids in higher trophic levels (e.g. in Europe in sparrow feathers (Humann-Guilleminot *et al.* 2018) and honey buzzard blood samples (Byholm *et al.* 2019); in Canada in hummingbirds (Bishop *et al.* 2018)), while neonicotinoids and their metabolites have also been detected in various human biological samples (Han *et al.* 2018).

Ecosystem Effects

Assessing effects of neonicotinoids on ecosystem services in Africa is complicated by the great differences in ecosystems, ecosystem services, the traditional approaches to farming and land management, and biodiversity within Africa itself. Although a wide range of ecosystem effects from neonicotinoids have been documented in Europe, these findings cannot be simply extrapolated to Africa owing to the great differences between the two regions' ecosystems. For example, honey bee populations in Europe are primarily privately owned, intensively managed colonies, whereas in Africa wild colonies are an important source in addition to the managed colonies seen in countries such as South Africa. Moreover, the colony density of wild honey bees can be higher in Africa than in Europe, even in the harsh conditions of the African dry highland savannah areas in South Africa (Moritz *et al*. 2007). Some differences in factors relevant to pollination services are highlighted in Box 3.

BOX 3

DIFFERENCES IN POLLINATION BETWEEN EUROPE AND AFRICA

Pollination dependence of crop production and crop quality continues to grow worldwide, particularly in the developing world, which depends more heavily on pollination-dependent crops than developed countries (Aizen et al. 2008; IPBES 2016). The value of pollination of cash crops differs worldwide, with peak areas, for example in West Africa, India, eastern China and Asia (Gallai et al. 2009; IPBES 2016), as does the proportion of agricultural production that is dependent on pollination for vitamin A, iron and folate. Most areas of sub-Saharan Africa are to some extent dependent on pollination for supplying these micronutrients (Ellis et al. 2015; IPBES 2016), and demonstrate that food security concerns extend to supplying enough micronutrients.

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Archer et al. (2014) identified the regions with high economic vulnerability to pollinator loss and estimated that North and West Africa have similar vulnerability to the EU (see Table 2).

Table 2. ***Economic vulnerability of different geographical regions to pollinator loss (from Archer et al. 2014)***

Geographical region	Economic vulnerability*
Central Africa	*7*
East Africa	*5*
North Africa	*6*
South Africa	*11*
West Africa	*10*
Other regions	
EU-25 Member States	*10*
Bermuda, Canada, USA	*11*
East Asia	*12*

**The economic vulnerability to pollinator loss is the percentage of the economic value of insect pollinators in the 100 most important commodity crops for human consumption.*

Factors relevant to pollination in Africa include that they involve many species other than honey bees, such as solitary bees, wasps, a wide range of flies, butterflies, moths, beetles, birds and bats. Honey bees introduced to provide pollination services can even displace more efficient native pollinators (see Badano and Vergara 2011). Genetic diversity of honey bees and other pollinators is high (see, for example, Jones et al. 2004; Oldroyd and Fewell 2007; Harpur et al. 2012) and there is considerable local adaptation between pollinators and their food plants, so that (local) extinction of one partner in this mutualism (e.g. the pollinator) can result in subsequent extinction of the other partner (e.g. one or several plant species). Melin et al. (2014) reviewed the role of different pollinators on South African crops, particularly those involved in the fruit industry. Despite the latter being heavily reliant on pollination from managed honey bees, these are not the most efficient pollinators for many types of fruit, particularly mango, lucerne and rooibos seed production, where larger pollinators are more effective. As noted in other studies in Europe (EASAC 2015), protecting honey bees is not sufficient to protect pollinator services in Africa. Specific challenges in understanding the threat of insecticides thus include the high diversity of flora and fauna, high levels of endemism, increasing pressure for food production against the background of population growth and climate change, and high diversity of insects whose role in pollination services and other ecosystem functions and/or services is not well understood.

The number of honey bee colonies in Africa is estimated at 310 million (Kajobe and Roubik 2006; Dietemann et al. 2009) compared with approximately 11.5 million in Europe (De La Rúa et al. 2009). Even allowing for the area outside of the Sahara being twice that of Europe, African colony density is substantially higher (South Africa has an estimated 10 million colonies (Dietemann et al. 2009)). There are also differences in management: as in Europe, managed colonies are moved around for pollination or foraging in some countries (especially South Africa where the managed honey bee industry is extensively used for pollination-dependent crops). On the other hand, many African honey bees are not owned or transportable; instead they are mostly wild, and beekeepers rely on capture or harvest of wild colonies for restocking. Many colonies cannot thus be moved to avoid specific applications of insecticides and therefore may be more vulnerable to local treatments.

Continued on next page

There are over 3000 species of bees in Africa, but data on wild bee populations and their density are very limited. Moreover, the importance of honey bees varies between crops (Garibaldi et al. 2013; Melin et al. 2014). For instance, they are dominant pollinators in the deciduous fruit industry in South Africa's Western Cape (Carvalheiro et al. 2010, 2011), but a diverse array of insects contributes to increased productivity for sunflowers and mangoes. Overall, Garibaldi et al. (2013) found that in 41 crop systems worldwide, honey bees were the most effective pollinator (relative to wild insects) in only 14% of the systems surveyed. More recently, Kleijn et al. (2015) calculated that, globally, the economic value of pollination services from the more common wild bee species is on a par with that from managed honey bees. Farmers thus need to be more aware that there are more pollinator species than just honey bees if they are to recognise other insects as beneficial rather than as pests.

Some indication of the relative sensitivities to toxins can be obtained from a comparison of the LD_{50} levels of dimethoate (an organophosphate) and deltamethrin (a pyrethroid) in European, South American and African bees, which showed considerable differences among bee species. The African honey bee and the small African stingless bee Melliponula ferruginea respond most sensitively to dimethoate. Both African and Brazilian solitary bees are highly sensitive to deltamethrin, to which African honey bees are less sensitive. Bumblebees are least sensitive to both pesticides, suggesting that body size matters and that smaller bees are more susceptible than larger ones (Blacquière et al. 2012). However, the sub-lethal effects of neonicotinoids on other African pollinators, especially stingless bees (an important source of pollination and honey), are unknown.

Neonicotinoids are systemic and accumulate in the entire plant (Hopwood *et al.* 2012), but their application methods and water solubility are such that they can permeate the surrounding environment, thus affecting the soil (Goulson 2013), water (Van Dijk *et al*. 2013), air (Raina-Fulton 2016) and organic matter (Hopwood *et al.* 2012). The literature records a wide range of lethal and sub-lethal effects on terrestrial and aquatic organisms, on beneficial soil microorganisms and on invertebrates and vertebrates (see the EASAC 2015 report and the WIA overviews of the many hundreds of papers).

Declines in butterflies and moths have been well studied (EASAC 2015; IPBES 2016) but longitudinal studies of protected areas in Germany show that this is not localised to agricultural fields but symptomatic of a widespread decline in insects. Hallmann *et al.* (2017) reported a seasonal decline of 76% in insect biomass over a period of 27 years in a German study, and declines in the entomofauna are being observed globally (see, for example, Sanchez-Bayo and Wyckhuys 2019), with agricultural intensification and pesticide use as primary drivers.

Most recently, a UK survey of 353 species of wild bees and hoverflies showed losses or reduction in ranges of most species with the exception of some bee species involved in pollinating crops that had benefited from farmers' agri-environment measures (such as providing wild flower strips around fields). In contrast, rarer species of pollinating insects encountered "severe" declines from 2007 (Powney *et al*. 2019).

Research on global pollinator loss has tended to focus mostly on Europe and North America (Ghazoul 2005; Kluser and Peduzzi 2007; Potts *et al.* 2010; Woodcock *et al.* 2017), with information on pollinator populations in Africa, especially honey bees, far less prevalent (Muli *et al*. 2014). Throughout much of Africa there are still wide-ranging wild honey-producing bee populations but, because they are largely unmanaged, accurately quantifying them remains challenging. Recording losses to beekeepers in managed honey bee populations is complicated by the fact that beekeeping practices differ greatly from country to country and across vegetation type. Therefore, the EU model for determining honey bee declines (e.g. winter colony loss rates or incidents of colony collapse disorder) cannot necessarily be applied in an African context. The global prevention of honey bee colony losses (COLOSS) network (which collects and publishes information on honey bee colony losses from 40 countries) includes only 2 African countries – South Africa and Egypt (Neumann and Carreck 2010) – while the review by Sanchez-Bayo and Wyckhuys (2019) of global insect decline included only one record from South Africa.

Nevertheless, several countries have noted declines in honey bee populations. Benin beekeepers have seen a decline in both managed and wild populations, including mass mortalities and colony disappearances; South Africa shows signs of decreasing managed populations, with a nationwide survey showing losses of 29.6% from 2009-2010 and 46.2% decline from 2010-2011 (Pirk *et al.* 2014). In Kenya, data collected by the National Beekeeping Station (2007) and anecdotal and observational evidence (Muli *et al.* 2014) indicate wild population declines, fewer migratory swarms and reduced honey production over the preceding 5 to 7 years. In South African mango plantations, the distance from natural habitat negatively affects pollinator diversity, and pesticide use increases this negative relationship (Carvalheiro *et al.* 2012).

Anecdotal evidence provided at the workshops included reduced numbers of honey bees, reduced yields of honey and wax, disappearance and losses of hives and some mass bee mortalities from Benin, Kenya, South Africa, Tanzania and Uganda. The size of honey bee colonies appeared to be getting smaller and colonies becoming fewer; in the past, baits would be likely to attract swarms but nowadays success rates are nearer 20%. Contamination by pesticides, which had caused severe losses of both foraging bees and hive bees, could be persistent, with toxic effects remaining in a hive for months, thus preventing recovery. Such deleterious effects emanating from the widespread use of pesticides in Africa has led some beekeepers to feel ignored by scientists and the users of pesticides, and to give up beekeeping. Decline observed in other species included edible insects such as crickets (see Miantsia *et al.* 2018), as well as insectivorous birds. Such observations are not associated with quantitative studies of local pesticide use and trends, so cannot differentiate between different pesticides, nor separate them from other potential causative factors.

Regarding use in cocoa crops, the chemical control of mirid bugs by using neonicotinoids in Côte d'Ivoire had led to the breakdown of biological balances in plantations. Consequently, some pests considered as secondary have proliferated because of the destruction of their natural enemies by chemical control aimed at mirids. Moreover, since cocoa flowers are pollinated by ceratopogonid midges, the application of insecticides at the time of flowering can decrease the pollination rate. In Ghana, where the free distribution of neonicotinoids (e.g. Confidor) by the Ghana Cocoa Authority has encouraged overuse, contamination can be measured in food (Dankyi *et al.* 2015) and in soils where neonicotinoids persist with dissipation half-lives of over 150 days for imidacloprid and thiamethoxam (Dankyi *et al.* 2014, 2018). Concentrations of imidacloprid of 11.5–35.6 ng/g in cocoa beans and 11.8–214 ng/g in cocoa shells were also recorded. Studies comparing the effects of imidacloprid (Confidor) and aqueous neem seed extract insecticides showed significantly fewer midges on the imidacloprid-treated areas, which affected fruit set even though midge populations recovered after 30 days (Kwapong and Frimpong-Anin 2013).

Reliance on frequent sprays with insecticide contributed to reduced numbers of pollinators and led the Ghana Cocoa Board to launch a national hand pollination programme in 2017, which employed around 30,000 youths to hand-pollinate cocoa trees. This programme aims to increase cocoa yields in Ghana from a current average of 12 pods per tree to 100 pods, and to elevate overall yields from the current 0.45 tonnes per hectare to the 2 tonnes per hectare harvested in Malaysia, Indonesia and Ecuador. When launching this programme, the Chief Executive of the Ghana Cocoa Board stated that "*hand pollination had become necessary because the natural agents for pollination – insects – had reduced in numbers through the spraying of chemicals on farms to ward off diseases that affected the trees and the pods*"[8].

Preliminary results from this programme show considerable variability, with some farms recording yield increases of up to 100% while others show no change. Yields were also constrained in subsequent years by a lack of flower production. This experience suggests that hand pollination cannot replace pollination ecosystem services in the long term, possibly because of the frailty of the flowers which are easily fatally damaged by hand. Economic costs of the loss of pollination services can be estimated by assuming a payment of US$100 per month per person for 6 months each year, giving a total budget of US$18 million for just the salaries of the 30,000 youths employed.

The economic consequences of both pest infestation and pest control in exports are also potentially wide-ranging. They can include complete restrictions on trade (e.g. US bans on some horticultural produce from Africa owing to their infestation with *Bactrocera* fruit flies), or restriction/rejection due to rules on maximum residue levels (cf. the high variability in residues in honey described earlier). Pest control in produce destined for export therefore must strike a careful balance between reducing pest infestation and not exceeding maximum residue levels. However, for both environmental and human health protection, it is desirable that crops destined for domestic consumption also not exceed the (usually stricter) export maximum residue levels.

[8] *https://www.graphic.com.gh/news/general-news/cocobod-introduces-hand-pollination-to-increase-yield.html*

4 Research in Africa

There are research groups, both governmental and institutional, that undertake a wide range of research related to neonicotinoids, some of which are listed in Box 4 (this should not be taken as an exhaustive list).

BOX 4

RESEARCH GROUPS IN AFRICA THAT ARE RELEVANT TO THE USE OF NEONICOTINOIDS

- *Several university institutions in* ***Algeria*** *conduct a variety of toxicity testing on non-target organisms, among those the shrimp Palaemon adspersus (Berghiche et al. 2017) and mosquitofish Gambusia affinis (Chouahda et al. 2017).*
- *Work in* ***Benin*** *(University of Parakou and the Laboratory of Bees Pathology, Parasitology and Plant Protection (LAPPAB)) has researched the effects of different pesticides on the West African honey bee Apis mellifera adansonii, including imidacloprid and acetamiprid as widely used neonicotinoids in cotton, market gardening and arboriculture protection, and found similar toxicity to earlier studies on the European honey bee Apis mellifera mellifera and A. m. caucasica (Suchail et al. 2001).*
- *The African Research Centre on Bananas and Plantains (CARBAP) based in* ***Cameroon*** *conducts research on a wide range of insect pests and pest management for bananas and plantains (Okolle et al. 2009) and has conducted studies on the relative effectiveness of chemical insecticides, biocontrol and IPM. In the case of borer weevils, limited success of single approaches suggested that IPM approaches (clean planting materials, use of botanicals, entomopathogens, proper field sanitation, wise use of synthetic chemicals as well as use of resistant or tolerant varieties) should be evaluated.*
- ***Côte d'Ivoire*** *has the Laboratoire National d'Appui au Développement Agricole (LANADA)[9], which works, among other things, in quality control of agrochemicals and feeds, conducts research on pesticide and mycotoxin residues in agri-food products, and provides development research and consulting. There has been considerable work on mosquitoes and their resistance to pesticides, studies of neonicotinoid effects in freshwater fish, and a study evaluating cocoa farmers' phytosanitary practices (Martin et al. 2018). Also in Côte d'Ivoire, research evaluating the efficiency of neonicotinoids for pest control is conducted by the group of Professor Akpesse at Félix Houphouët-Boigny University. Research is also conducted at the National Centre for Agronomic Research (Centre National de Recherche Agronomique de Côte d'Ivoire, CNRA). Doctoral research is underway to evaluate neonicotinoid effects on animal populations colonising rivers neighbouring cocoa fields, as well as on pollinators of this crop.*
- *The Association for Strengthening Agricultural Research in* ***East and Central Africa*** *(ASARECA) funds agriculturally relevant research, including that involving neonicotinoids in Uganda, Kenya, Tanzania and Rwanda to expand and improve knowledge and implementation (Otim et al. 2016).*
- *The University of* ***Ghana*** *conducts the studies cited earlier on neonicotinoid use in cocoa crops and resultant soil contamination (Dankyi et al. 2014, 2015, 2018). The Cocoa Research Institute of Ghana (CRIG) conducts studies on pesticides used in cocoa farming including neonicotinoids. Research on the effects of insecticide use on pollination of cocoa flowers is also performed at the University of Cape Coast (Kwapong and Frimpong-Anin 2013).*

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[9] *http://www.lanada.ci/index.html*

- *The International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi, **Kenya**, is an international centre of excellence in Africa, with a focus on capacity-building in general and applied entomology, and a staff of over 500 from 39 nationalities. ICIPE works on human, environmental, and plant and animal health. ICIPE research includes pollinators other than honey bees, databasing plant–pollinator interactions, studying pollinator diversity and ecological networks in natural and agricultural habitats, and seeking natural mechanisms ('bioprospecting') that can be applied to reduce pest insects. The African Reference Laboratory for Bee Health is developing a world-class research portfolio with the purpose of improving honey bee health in Africa and beyond, focusing on honey bee health, endosymbionts, nutrition and pollination. In 2017 the laboratory was accredited as a World Organisation for Animal Health (OIE) Collaborating Centre for Bee Health in Africa. A project focusing on stingless bees as potential crop pollinators has developed rearing techniques and species identification tools, and has studied the diversity, foraging communication and pollination efficiency of stingless bees. A study on IPPM (integrated pest and pollinator management) in avocado and cucurbit cropping systems was launched in 2018. The Mpala Research Centre also performs work on the risk to pollinators of pesticide use, while the National Sericulture Research Centre conducts research on pest and pollination management as well as on promoting agroecology in Kenya.*
- *Lilongwe University of Agriculture and Natural Resources in **Malawi** is conducting research involving insect physiology, sodium channel targets and mutations and olfactory receptors to find eco-friendly pest management solutions. Current research focuses on Tephrosia vogelii (Fabaceae) and neem (Azadirachta indica, Meliaceae), in particular on toxicity testing for topical application, identification of mode of action, selectivity of toxic action and safety to bees. Pyrethroids can scare away insects even in minute amounts, so olfactory repellents can be an efficient means of pest control that requires minimal use of chemicals. Current research also includes control of agricultural pests with garlic extracts, combining botanical extracts with pyrethroids, and ensuring bee safety of products.*
- *The Cocoa Research Institute of **Nigeria** (CRIN) has a national mandate to evaluate, test and recommend new insecticides, including neonicotinoids, for use on cocoa in Nigeria (Anikwe et al. 2009). Toxicity and efficacy of the neonicotinoid thiamethoxam, the active ingredient in Actara 25 WG, was evaluated for use against the cocoa mirid (Sahlbergella singularis) (Anikwe et al. 2009). Research on pesticides including neonicotinoids is also performed at the Forestry Research Institute at Ibadan and at several universities including the University of Agriculture in Benue State, the Department of Biology, Federal University of Technology Akure, the Environmental Biology Laboratory at the University of Lagos, the Institute of Agricultural Research at Amadu Bello University and in the Nutrition and Health Related Environmental Research Laboratory of Obafemi Awolowo University, Osun State.*
- ***Senegal** has the Centre Régional de Recherche en Écotoxicologie et de Sécurité Environnementale (CERES-Locustox)[10], which does ecotoxicological work but lacks permanent funding. Dakar University has several groups working on ecotoxicology in biology and chemistry.*
- *The Social Insect Research Group (SIRG) based at the University of Pretoria in **South Africa** is investigating the way neonicotinoid pesticides have the potential to influence various aspects of honey bee physiology and behaviour (Démares et al. 2016; Tosi et al. 2016; C.L. Bester et al., unpublished data). Also in South Africa, the Agriculture Research Council Onderstepoort Veterinary Institute coordinates the national residue analysis programme supporting institutes dealing with crop investigations. In addition, the Water Research Group of North-Western University has collaborated with Japanese researchers on neonicotinoid levels in urine samples of low-weight infants (Ichikawa et al. 2019).*
- *Work at the University of Sfax in **Tunisia** examined the cardiotoxicity of thiamethoxam in vertebrates and suggested that a polysaccharide derived from fenugreek seeds could provide protection from the toxic effects of thiamethoxam (Feki et al. 2019).*

[10] http://cereslocustox.sn/

Specific projects mentioned in the workshops included research on the sensitivity of African bees to sucrose (one of the main sugars in floral nectar) in thiamethoxam-laced artificial bee foods; this showed reduced sucrose responses and reducing foraging efficiency in bees (Démares *et al.* 2016). In another study, thiamethoxam affected the ability of bees to regulate their body temperature (Tosi *et al.* 2016).

As seen in Box 4, research resources that may be relevant to assessing the impact of neonicotinoids on African ecosystem services are distributed throughout the continent, bringing with it challenges to effective coordination at national, linguistic, cultural and geographical levels. Since there are very few entomologists and taxonomists in African countries and even fewer study pollination (Gemmill-Herren *et al.* 2014), trends in pollinators remain unclear. Expertise in related disciplines and the necessary resources (e.g. chemical analysis, chemical ecology) are also scattered throughout the continent. The need to identify mechanisms to strengthen synergies between available resources is one of the key issues that emerge from this analysis (see also Section 8).

Regulations and Enforcement 5

Regulations provide the legal framework within which the use of neonicotinoid pesticides can be controlled, but even the most rigorous regulations are of no use when effective enforcement is lacking. Workshop participants provided several examples of regulations and enforcement in their countries. Regulatory authorities for pesticides reside in different ministries in different African countries and follow different procedures, and this report does not attempt to conduct an inventory of these across the continent. However, the information provided by workshop participants does allow the range of regulatory approaches to be better understood and is summarised here.

In **Benin**, a National Pesticide Management Committee was created in 2018[11], which is responsible for accreditation and certification of pesticides.

In **Botswana**, the National Chemicals Committee is responsible for registration of chemicals including fertilisers and pesticides. If a pesticide is imported from a country where it is not registered, then it will not be registered in Botswana (a Prior Informed Consent procedure under the Rotterdam Convention). If necessary, additional trials are conducted. Currently, most registered neonicotinoid formulations contain imidacloprid.

Cameroon's Phytosanitary Law of 2003 established a National Phytosanitary Council (with representatives of at least five ministries including agriculture, environment and trade) as a consultative body on phytosanitary protection policy. This Council meets annually, although extraordinary meetings (e.g. in case of fall armyworm) can be convened to discuss additional registrations. The list of pesticides authorised by the Comité Sahélien des Pesticides (last updated May 2018) is available online[12]. The Cameroonian Minister of Agriculture can authorise removal of pesticides from this list. Cameroon is also a member of the Central African Inter-State Pesticides Committee (CPAC) of the Central African Economic and Monetary Community (CEMAC), which includes Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, Equatorial Guinea and Gabon. Products approved within Cameroon can move easily within the CEMAC. Cameroon is also a member of the Inter-African Phytosanitary Council (IAPSC) and applies the FAO International Plant Protection Convention.

In **Côte d'Ivoire**, chemical control of pests involves over 800 formulations approved by a Pesticides Committee which consists of representatives of several ministries (research, health, environment, trade, industry, interior, economy, finance), other public organisations (Directorate of Plant Protection, Control and Quality; Permanent Secretariat of the Pesticides Committee; National Centre for Agronomic Research; Laboratory for Analysis and Support to Agricultural Development; Ivorian Anti-Pollution Centre) as well as professional organisations (such as the national phytosanitary organisation CropLife and AMEPH-CI). The Pesticide Committee issues approvals for phytosanitary products and for pesticide applicators, distributors and retailers.

In **Egypt**, pesticide registration is under the auspices of the Ministry of Agriculture and Land Reclamation through the Agricultural Pesticides Committee (APC), with input from the

[11] *https://juriafrique.com/eng/2018/10/17/benin-equips-itself-with-a-national-pesticide-management-committee/*

[12] *http://www.reca-niger.org/IMG/pdf/-4.pdf*

Ministry of Health and Veterinary Services. Registration of pesticides follows guidance from the EU or the US Environmental Protection Agency (USEPA), as well as information from the World Health Organization (WHO) and FAO. Testing on the toxicity of pesticides to honey bees in Egypt is done at the Agricultural Research Centre (El-Ghareeb *et al*. 1983; Sharaf-El-Din and Girgis 1997). Egypt has established certification for applicators (farmers) on the basis of training courses[13], with mandatory recertification every 3 years. The Ministry of Agriculture and Land Reclamation selects the institutions that conduct training.

The APC responded to actions taken in the EU and the USEPA by first (in 2015) applying warnings to avoid spraying neonicotinoid insecticides onto flowering crops, and secondly (15 May 2018) applying the EU restriction on outside use of products containing clothianidin, imidacloprid and thiamethoxam. The APC set a secondary objective of reducing the authorised quantities of these pesticides by 20% annually, and continuously follows up on decisions taken by the EU.

The **Ghanaian** Environmental Protection Agency undertakes registration of chemicals, usually taking 90 days from application to decision, and ensures that labelling and formulation are correct. Pesticides for use in cocoa cultivation are registered by the Ghana Cocoa Board, which conducts field trials focused on efficacy but not necessarily on environmental effects.

In **Kenya** the Pest Control and Products Board (PCPB) is responsible for the regulation of manufacturing, exportation, importation, distribution and use of all pest control products (Mulati 2016).

In **Malawi**, the Poisons Board registers pesticides but has no additional mandate for monitoring use or enforcement.

In **Namibia**, pesticides are regulated by the Ministry of Agriculture, Water, and Forestry (MAWF). MAWF is now reviewing the Pesticides Act to make provision for the registration of pesticides and pest-control operators. MAWF uses international guidance from FAO, the South African Bureau of Standards (SABS), WHO, Codex Alimentaire (CODEX), etc. to recommend or reject pesticide registration. Registration requirements include a dossier containing (1) plant/pest-specific research findings, (2) human and animal health findings, (3) environmental effects in the semi-arid conditions of Namibia, and (4) toxicology profiles. MAWF is already in the process of deregistering pesticides found to have negative effects on the environment and biodiversity.

In **Nigeria**, the National Food and Drug Agency (NAFDAC) is the primary government institution responsible for pesticide regulations.

Regulation of certain aspects of the manufacture, marketing, distribution, labelling, packaging, use and disposal of pesticides in **South Africa** is outlined in the Department of Agriculture, Forestry and Fisheries' Pesticide Management Policy for South Africa (Department of Agriculture, Forestry and Fisheries 2019). South African legislation on pesticides relies mostly on European models.

In **Sudan**, the Pesticides Act was established in 1969. Today, over 350 active ingredients under 1,100 trade names are registered, although not all of them are in use. Pesticide registration is based on data from Sudanese national research centres. New chemicals are first tested on a small scale for 2 years, then on a larger scale, before a registration application is submitted to the Pesticides Committee. The Pesticides Committee assesses the data underpinning the

[13] *http://www.egypttoday.com/Article/1/70310/Egypt-introduces-pesticide-applicator-training-program*

registration application. Any bans are based on data, either from Sudanese laboratories or from the WHO. Sudanese standards are being put into place for each active ingredient and formulation. On arrival in Sudan, imported chemicals are analysed in Sudanese laboratories and, if they conform to Sudanese standards, they are allowed to enter the country. Sudan imports pesticides to the value of about US$100 million per year.

In **Tanzania**, pesticide use is regulated by the Plant Protection Acts of 1997 and the plant protection regulations of 1998[14], which set out the documentation required to register a plant protection product. Pesticide documentation must show efficacy and not have harmful effects (under recommended conditions of use) on human or animal health, ground water and the natural environment. In addition, pesticides submitted for registration are submitted for analysis to the Tropical Pesticide Research Institute (TPRI) which performs field tests within three cropping seasons and any laboratory analysis necessary to determine the product's suitability for Tanzania. The TPRI also performs research on pesticide efficacy, application and safety, and supervises the manufacture, importation, distribution, sale and use of pesticides and administers the regulations. A pesticide is disqualified from registration if it is subject to a Prior Informed Consent procedure[15]; if it is highly toxic, persistent and biologically cumulative; or if it causes poisoning effects to human and animals for which no effective antidote is available. Pesticides restricted or banned in the country of origin cannot be registered in Tanzania.

In **Tunisia**, the Ministry of Agriculture, Water Resources and Fisheries regulates the use of pesticides through its National Committee of Pesticides. Among the registered pesticides is imidacloprid, which currently continues to be approved while debate takes place on the implications of the EU ban of imidacloprid (the EU is a major market for Tunisian agricultural products).

The **Ugandan** Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) has four directorates and six agencies, of which the National Agricultural Advisory Services (NAADS) provide advice on pesticide usage. Pesticide handling and management is dealt with at several levels, namely the MAAIF's Directorates of Crop Protection and Animal Resources, the Vector Control Division of the Ministry of Health, the National Environment Management Authority, the National Drug Authority (regulation of human and veterinary drug use), the Agriculture police unit (control of counterfeit pesticides and monitoring of correct use of pesticides) and the Uganda National Bureau of Standards (involved in registration). The National Agricultural Research Organisation issues advice to farmers on pesticides, particularly in emergency situations such as outbreaks of fall armyworm and conducts research on, for example, reductions of bee drone sperm counts following exposure to neonicotinoids (Williams *et al.* 2015; Straub *et al.* 2016). Uganda Police staff are trained in following up on agro-chemical suppliers and traders and in looking for fake and counterfeit agrochemicals.

All pesticides used in **Zimbabwe** are regulated under the Fertilizers, Farm Feeds, and Remedies Act. Pesticide governance in Zimbabwe is in the hands of the Ministry of Lands, Agriculture,

[14] *http://extwprlegs1.fao.org/docs/pdf/tan19459.pdf*

[15] The Prior Informed Consent Regulation (PIC, Regulation (EU) 649/2012) administers the import and export of certain hazardous chemicals and places obligations on companies that wish to export these chemicals to non-EU countries. It aims to promote shared responsibility and cooperation in the international trade of hazardous chemicals, and to protect human health and the environment by providing developing countries with information on how to store, transport, use and dispose of hazardous chemicals safely. *https://echa.europa.eu/regulations/prior-informed-consent/understanding-pic*

Water, Climate and Rural Resettlement and in the Specialized Services Division for Fertilizer, Farm Feeds and Remedies, which conducts research on pesticides and acts as a Pesticides Registration Office, and follows up on pesticide regulation.

At the level of **regional communities**, the Comité permanent inter-État de lutte contre la Sécheresse au Sahel (CILSS) has the Comité Sahélien des Pesticide (CSP), which publishes lists of product preparations that can be used (each country can decide whether they use these preparations or not). As an example of such regional action, the control of the tomato leaf miner *Tuta absoluta* on tomatoes in sub-Saharan Africa differs from country to country but many of the products that prove most effective against this pest are not yet registered. In 2016, the CSP authorised 11 insecticides for use on tomatoes; among those were the neonicotinoids acetamiprid and imidacloprid (Mansour *et al.* 2018).

In **Central Africa**, within the Economic Community of Central African States (ECCAS), the Interstate Committee of Pesticides in Central Africa (CPAC) is a sub-regional inter-state body in charge of pesticide regulation for some member states. There are intentions to harmonise regulations among countries. Authorisation decisions of these committees often rely on Prior Informed Consent procedures under the Rotterdam Convention.

Enforcement of regulations appears weak or non-existent in many African countries. For instance, studies have found that, despite many products having restricted use or being banned altogether, they are still often readily available in the Kenyan market and are easily purchased by any farmer (Wandiga 2001; Lekei *et al.* 2014).

In Ghana, the Environmental Protection Agency showed in 2007 that around 30% of pesticides on sale were either unlicensed or smuggled. Officials still estimate that at least 10–15% of all imports are illegal, either brought in by unlicensed dealers or involving expired or adulterated goods. Some imports arrive in bulk and are repackaged into smaller containers, often carrying inadequate or misleading labelling. Many pesticide dealers do not have licenses to operate and are believed to be selling banned or restricted pesticides. Unregistered dealers not only sell directly to farmers by visiting villages but also set up stalls in urban markets. They are unlikely to have the requisite knowledge to inform farmers about the safe use of pesticides. Yet many farmers now rely on such traders for pest control advice rather than on extension officers (NPAS 2012).

Similar problems were found in an audit by the Tanzanian National Audit Office in 2018. This was set up to examine the extent to which the Ministry of Agriculture and its Crop Development Division and TPRI were efficiently managing the risks to human health and the environment from pesticides in order to ensure sustainability of land productivity. The audit (National Audit Office 2018) found widespread use of unregistered pesticides and illegal imports (especially in regions bordering other countries), inadequate assessment of health and environmental impacts, and weak monitoring and enforcement. Among the factors contributing to these weaknesses were the presence of few and unqualified inspectors; inadequate awareness campaigns among pesticides users, sellers and farmers; lack of inspections at points of entry; and weak implementation of sanctions to pesticides sellers.

Other aspects affecting the efficacy and independence of the registration process mentioned in the workshops included the following.

- Authorisation processes are driven and sponsored by chemical companies; for instance, emergency registrations to combat the fall armyworm.
- Staff working in the institutions registering pesticides are often unaware of the toxicity of various compounds to non-target organisms.

In conclusion, the workshop participants noted that although there are regulations in almost all countries, compliance and enforcement is often weak. The diversity of African countries suggests that regulations should remain country-specific, but continent-wide authorisation based on jointly agreed-upon, science-based and binding criteria underpinned by the precautionary principle should be considered as an effective way to harmonise authorisation of active ingredients, and to ban active ingredients that are harmful to humans or the environment.

Regarding specific legislation focused on pollination and other ecosystem services, workshop participants noted that measures to explicitly address honey bees or pollinators in general tended to be in the form of best practice guidelines, rather than provisions for pollinator protection being included in pesticide legislation. One result of this absence of legislation is that beekeepers who suffer economic damage from pesticide misuse have difficulty in seeking redress (which is particularly important where beekeeping is a significant source of income reducing poverty (Amulen *et al.* 2019)). Another consequence is that the effects on pollinators may not be considered in the regulatory process, so that approved pesticides are more toxic than in Europe. For example, in Kenya, 43% of pesticides registered or used are categorised as highly toxic to honey bees compared with 15% in the Netherlands (van der Valk *et al.* 2013).

Including pollination protection in regulatory criteria and placement of bees especially, in the correct legislative framework is essential to provide the basis for accounting and monitoring honey bees, for ensuring their protection and conservation, as well as for safeguarding bee products. One model is in Europe and the USA where honey bees are treated as an agricultural commodity, which allows accounting for beekeeper livelihoods. This is currently under consideration in South Africa, where bee products (honey, beeswax, etc.) are currently regulated under the Plant Protection and Pesticides Act. A current proposal involves moving honey bees and their products into the Agricultural Pests Act (Act 36 of 1983) through amendment of the Control Measures relating to honey bees (of 2013). This would ensure that honey bees are under the oversight of veterinary sciences, like any other domestic animal.

Although yet to be reflected in regulations, some African countries (Burundi, Ethiopia, Morocco and Nigeria as of July 2019) have joined the IPBES 'Coalition of the Willing on Pollinators' initiative[16]. This commits to taking action to protect pollinators and their habitats to stop and reverse their decline, by promoting pollinator-friendly habitats including through sustainable agricultural practices such as agroecology. The commitment includes that of avoiding or reducing the use of pesticides harmful to wild and domestic pollinators, and developing research that will help to fill knowledge gaps on the subject of pollinator conservation. This could be a useful route to increase awareness of pollination in the regulation of pesticides.

In the wider context of biodiversity, there is scattered legislation for the protection of biodiversity within regulations covering environmental protection, protection of wildlife and heritage sites, and protection of forests and natural resources such as water catchments. Such legislation, together with developments such as the good agricultural practices (GAPs) codes, standards and regulations may help to protect honey bees and other non-target insects, albeit incidentally. Given the ecological and economic importance of pollinators and other ecosystem providers, it would be desirable that the involved species and their habitats be more explicitly protected.

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[16] *https://promotepollinators.org/wp-content/uploads/sites/117/2018/11/181106-Declaration-on-the-Coalition-of-the-Willing-on-Pollinators.pdf*

6 Extension Services and Advice

All countries represented at the workshops reported that the role of extension services was poor, particularly for small-holder farmers. Farmers remain untrained or are trained by public servants responsible for providing advice on a wide range of issues, and are typically unaware of the environmental or health hazards associated with pesticide use. Many small-holders also rely on word of mouth advice from neighbours. Where advice is offered, it often comes from the pesticide manufacturers or agents (see, for example, Box 5) and focuses on promoting or managing the use of pesticides rather than on IPM with its focus on minimising pesticide use. Commercial farmers often rely on private extension services from chemical companies, which again typically promote the use of chemical pesticides rather than alternative methods of pest management.

BOX 5

AVAILABLE TRAINING ON PESTICIDE USE THE EXAMPLE OF CROPLIFE INTERNATIONAL

The safe and effective use of pesticides (especially those utilised by small-scale and subsistence farmers who may lack the education, experience or access to the same advice and extension services available to large-scale commercial farmers) is especially important in Africa. CropLife International is a non-profit industry association that represents the plant science industry, focusing on leading global manufacturers of pesticides, seeds and biotechnology products in its territories, which include several African countries. Various training courses are offered through CropLife. One example is CropLife Africa/Middle East which performs the training and capacity-building initiative Spray Service Provider (SSP) that provides special pesticide application training to farmers, who in turn hire out their services to other farmers to spray their fields. The SSP concept was developed to improve access to quality pesticides and promote correct application and use. SSP has proved successful in Cameroon, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mali, Nigeria, Sudan, Tanzania, Uganda and Zambia, with more than 12,000 trained SSPs assisting over 90,000 farmers annually. CropLife South Africa also provides online training in crop protection (including storage, application and safety training) as well as in-person courses in aerial application (CropLife South Africa 2015).

The unsafe use of pesticides may be exacerbated by the extent of fraudulent or counterfeit pesticides. There is also widespread non-compliance with labelling standards and product packaging with mislabelled products being marketed illegally. Key challenges faced include quack suppliers selling unregistered and/or counterfeit products, limited knowledge about the broader effects of pesticides, and poor handling and usage (tank mixing, rotational application, dose rates). Some studies have brought into focus the risks posed by lack of knowledge on use, storage and disposal of toxic pesticides which have led to frequent illness and mortality (see, for example, NPAS 2012; Martin *et al*. 2018). Larger insects (e.g. tree locusts) are commonly eaten as an additional protein source in some countries (FAO 2013), and thus their contamination due to spraying presents an additional risk of human transmission. In addition to adverse effects on health, other concerns are over the development of resistance by pest species, effects on non-target organisms, wash-off/over to water bodies, and residues in plant and animal products.

Studies have shown that some farmers are not even aware of the fundamental role of pollination in their crops. Despite the evidence that coffee yields and quality (taste and aroma) in Africa are greatly improved by insect pollination (Klein *et al.* 2003; Karanja *et al.* 2013), over 90% of farmers interviewed in Uganda by Munyuli (2011) were unaware of the role played by bees in increasing coffee yield. They were also unaware of the role of nearby semi-natural habitats in enhancing pollinator service and were unwilling to manage their lands to protect pollination services. Many farmers also believed that the more toxic a pesticide is the better, and routinely spray above recommended doses, with multiples of between 1.5 and 5 times the recommended dose mentioned by some of the workshop participants. The low awareness of the beneficial role of many insects (even of honey bees), associated with low levels of awareness of potential toxic effects, means that there is little awareness of any special risks associated with neonicotinoids on wider ecosystem services within the farming community (and the public at large). For instance, a survey in Botswana showed that only 56% of users of neonicotinoid insecticides were aware that ecosystem damage was possible, with even lower rates of awareness for threats to pollination and other specific ecosystem services (Leungo *et al*. 2012).

The challenges faced by extension services in providing the necessary information and advice are thus substantial, and the extent of such services and their independence are important. Specific examples of extension services and communication methods provided during the project workshops included the following.

- CropLifeSA is aligned with the Association of Veterinary and Crop Associations of South Africa[17] and has the endorsement of Registrar Act 36 (Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act[18]) with the Department of Agriculture, Forestry and Fisheries. CropLifeSA also runs the website Agri-Intel[19], which hosts information on pesticide label information, residue management, etc.
- In Senegal, the Department of Plant Protection (Direction de la Protection des Végétaux) and the Senegalese Institute for Agricultural Research (Institut Sénégalais de Recherches Agricole), both under the Ministry of Agriculture and Rural Infrastructure, provide extension services[20], with different specialisations. Information on regulatory matters is available on the internet[21].
- CropLife Cameroon is an association of 10 major pesticides companies. As part of CropLife Africa Middle East, it offers pesticide management courses[22] in partnership with the Ministry of Agriculture and Rural Development[23].
- In Sudan, the General Directorate of Extension, Technology Transfer and Pastoralists' Development[24] of the Federal Ministry of Animal Resources and Fisheries trains farmers in the correct use of pesticides, including when to spray relative to harvest times.

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[17] *https://www.avcasa.co.za/*

[18] *https://www.nda.agric.za/doaDev/sideMenu/ActNo36_1947/act36.htm*

[19] *https://www.agri-intel.com/*

[20] *https://www.g-fras.org/en/knowledge/documents/category/86-senegal.html?download=708:senegal-in-depth -assessment-of-extension-and-advisory-services*

[21] *https://www.ippc.int/en/countries/senegal/*

[22] *https://croplife.org/case-study/croplife-cameroon-offers-pesticide-management-course/*

[23] *https://allafrica.com/stories/201904030976.html*

[24] *http://mar.gov.sd/en/index.php/departments/view_dept/6*

- In Malawi, in collaboration between the Lilongwe University of Agriculture and Natural Resources (LUANAR) Bunda College, the Farm Radio Trust[25] fosters rural and agricultural development through a 'farm radio' programme where farmers can ask questions, including in their local languages. The programme also provides farmer advisory services based on expert inputs.
- Advice on agriculture is also offered by some AID programmes: for instance USAID's (United States Agency for International Development) Pesticide Evaluation Report and Safer Use Action Plan (PERSUAP), although guidance here will be exclusively based on the USEPA pesticide authorisations. In addition, advice on IPM is provided by the Pesticides Action Network and by the Africa Bureau IPM and pesticide use guidelines (*www.encapafrica.org*).

From the above, it is apparent that extension services in some countries depend very much on industry-associated services, where advice is likely to focus primarily on pesticide use and management rather than alternative strategies based on IPM or agroecology. A comprehensive range of extension services would need to focus on the following.

- Increasing awareness of the FAO International Code of Conduct on Pesticide Management[26].
- Disseminating good agricultural practice.
- Basic education about ecosystem services and ability to see insects as not just pests but also as providing many beneficial services, including pollination and natural pest control. As pointed out in FAO (2013), the number of beneficial species or species harmless to a particular crop typically greatly exceeds the number of pest species.
- Better education of farmers and pesticide operators with regard to effectiveness of insecticides. Instant death of insects should not be regarded as the only, or even relevant, measure of success.
- Understanding the potential synergies between agriculture and the local ecosystem (agroecology).
- Encouraging the principle of IPM to avoiding preventive or prophylactic application of pesticides, by carrying out surveys to assess the level of pest infestation and establishing meaningful thresholds before considering pesticide treatment.

The ratio of extension workers to farmers is also important: there need to be enough extension workers to cover the ground and reach villages. The relationship between company consultants and extension officers also needs to be regulated to ensure the independence of the latter. To improve efficiency, extension services may have to move away from face-to-face/one-on-one communication to methods with wider impact and use websites, print media, labelling of products, radio campaigns, workshops (e.g. mentorship classes, tutorials for emerging farmers, farmers' days) and other novel ways of reaching target farmers. For example, churches, mosques and social clubs could help to disseminate information, and the responsible ministries could also become involved in information dissemination. Novel approaches may include deploying smart phone applications and social media, and by taking a leaf out of the book of the pesticide companies whereby one lead farmer is asked to deploy (e.g. good agricultural practice and IPM) on an easily visible strip of land to show how the crops are performing, and help demonstrate the value of pollination and natural pest control.

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[25] *https://www.farmradiomw.org/*

[26] *http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/en/*

Studies have shown that, under normal conditions, biologically-based IPM schemes that are less reliant on external chemical inputs can significantly increase yields while reducing pesticide input. Non-chemical management options, for example for fruit flies, thrips, the moth *Tuta absoluta* and fall armyworm, include habitat management and/or sanitation, use of healthy seeds/seedlings and resistant cultivars, quarantine, the release or augmentation/encouragement of natural populations of parasitoids and other natural enemies (e.g. push-pull technologies), monitoring, biopesticides, male annihilation, bait spray, auto-dissemination of insect diseases (lure and infect) and post-harvest assessment treatment. Adoption of such measures and dissemination of the associated technologies should result in lower production costs, improved yields and incomes, employment, healthier and safer foods, and improved health. These outcomes provide the best option for sustainable agriculture in Africa but, owing to the very limited advice on IPM, their application is limited. In this context, Kasina and Kinuthia (2013) recommend that farmers should lobby their governments to develop IPM policies that would protect bees and other useful insects (e.g. biological control insects, edible insects) important to agriculture.

IPM principles may be supplemented in Africa by indigenous knowledge systems (IKS) which continue to play a significant role in the management of crop insect pests among small-scale farmers (see Mihale *et al.* 2010; Nkunika *et al*. 2013). For example, Muswishi farmers in the central province of Zambia who employed ITK under IPM recorded a 37% maize yield increase compared with farmers who did not use ITK (Nkunika 2002). ITK may use botanical insecticides that are compatible with IPM. For example, the most widely used natural plant products were extracts of *Swartzia madagascariensis* Desv, *Tephrosia vogelli*, *Euphorbia tirucalli*, wood ash and cow dung. Alternative control options to the use of imidacloprid to control termites have also been documented in Tanzania and Zambia (Mihale *et al.* 2010; Nkunika *et al.* 2013). Such studies demonstrated the continuing need for integrating ITK into IPM technology. In this context, the African Dryland Alliance for Pesticidal Plant Technology (ADAPPT)[27] is a network for optimising and promoting the use of indigenous botanical knowledge for food security and combating poverty. Without fully applying IPM/ITK, the increasing population in most African countries and the greater demand for improved food security is likely to result in increasing pesticide usage with the associated negative effects on ecosystems and sustainability. Research on alternative control options is a priority in ensuring household food security, enhancing sustainable livelihoods of rural small-holder farmers, assuring the health of farmers and their families, and maintaining balanced ecosystems.

[27] *http://projects.nri.org/adappt/*

7 Gaps in Available Information

Although research into pesticides in general has been documented throughout Africa (Youm *et al.* 1990; Lambert 1997; Wandiga 2001; Quinn *et al.* 2011), peer-reviewed, published research about the prevalence of use, efficacy, toxicity testing, etc. of neonicotinoids is lacking for more than half of individual African countries. In this study, we found that several government and institutional websites from countries indicated as providing information on registered neonicotinoids, support services, published research, etc. were often not up to date; links to relevant supporting information had expired; listed documents or information sources were not accessible; and requests for full-text versions of research went unanswered. Although such data should be publicly available, it does mean that there will be data that have not been accessed by this study.

Although not the primary focus of this study, it would be an oversight if we did not also mention the question of neonicotinoids' toxicity to vertebrates and the potential for adverse effects on humans. Previously used pesticides (e.g. organophosphates) are very toxic to humans, and Africa has encountered many cases of deaths through exposure to pesticides in application, storage, disposal or contamination of food. One of the attractions of neonicotinoids has thus been the assumption that, since the human neurotransmitters are different from those of insects and less sensitive to the neonicotinoid group, acute toxicity is substantially less. Although this lower sensitivity is observed for the original active molecules, however, metabolites do not necessarily follow the same pattern. For example, one degradation product of imidacloprid (desnitro-imidacloprid) is more toxic to humans than to insects[28].

Moreover, the water solubility of neonicotinoids (especially when applied as a soil drench) contributes to their spread throughout the environment, contamination of soil and aqueous media, and uptake in the tissues of a broad range of living organisms. As a result, neonicotinoids have been detected in wild birds, rodents, fish, lizards, frogs and other animals. A survey of this literature is beyond the terms of this review, but this extensive contamination raises concern over the potential uptake by humans and whether there could be health implications arising from sub-lethal effects of low doses over extended periods.

Some accidental exposures to humans have shown neurological effects (see, for example, Taira 2014); moreover, other studies suggest a danger of toxic effects on birds and mammals. For instance, Eng *et al.* (2017) found that imidacloprid in white-crowned sparrows (*Zonotrichia leucophrys*) caused them to lose up to a quarter of their body mass and that they could not find true north for weeks after being exposed. Berheim *et al.* (2019) demonstrated that imidacloprid has direct effects at field-relevant doses similar to deformities in white-tailed deer (*Odocoileus virginianus*) observed in the field by Hoy *et al.* (2002): namely overbiting, enlarged right heart ventricles, and damaged or missing thymus glands and scrota.

Other effects from experimental exposures (Gibbons *et al.* 2014) have been observed in rats (*Rattus norvegicus*: reduced sperm production, reduced offspring weight, increased abortions, skeletal abnormalities, thyroid lesions, atrophy of retina, reduced weight gain of offspring, oxidative stress and neuro-behavioural deficits), mice (*Mus musculus*: suppressed

[28] Tomizawa and Casida (1999); Tomizawa *et al.* (2000, 2001).

cell-mediated immune response and prominent histopathological alterations in spleen and liver), rabbits (*Sylvilagus* sp.: increased frequency of miscarriage and premature births), red-legged partridges (*Alectoris rufa*: reduced adult and chick survival, fertilisation rate and immune response), Nile tilapia (*Oreochromis niloticus*: extensive disintegration of testicular tissue and changes to gonads), Japanese rice fish (*Oryzias latipes*: juvenile stress led to ectoparasite infestation) and black-spotted pond frogs (*Rana nigromaculata*: DNA damage at very low concentrations).

Particularly against the background of high exposures due to over-application and misuse of neonicotinoids in Africa, these uncertainties and lack of data mean that effects beyond those on pollination and other ecosystem services extending to other wildlife and human health cannot be ruled out.

8 Commentary

Trends and Overall Assessment

The general view of workshop participants was that neonicotinoids pose significant threats for vulnerable small-holder farmers. The situation is exacerbated in the African context by a lack of investment, limited access to markets and loans within a framework of weak regulatory systems, a lack of extension services, compounded in many cases by low levels of literacy. Many farmers need to make choices on managing their crops from a large variety of pesticides (both neonicotinoids and non-neonicotinoids) with inadequate advice and information, and without even the ability to trust the contents of the product purchased. Neonicotinoid use appeared to have expanded, replacing older pesticides including seed dressings on larger commercial crops, in a similar pattern to that observed in the EU before the restrictions starting in 2013.

A combination of published and anecdotal evidence provided by invited experts suggests that negative ecosystem effects are being experienced across Africa, although field studies are limited and thus impacts are not attributable to individual pesticides. However, limited laboratory work confirms the effects of neonicotinoids on African test species and provides no basis on which to question the relevance of European and North American research in assessing the risks to African ecosystem services.

Several of the research papers summarised in Box 2 refer to the evolution of resistance to neonicotinoid insecticides in a range of pest species, and in disease vectors such as mosquitoes. The current state of resistance globally to neonicotinoids was reviewed by Bass *et al.* (2015) who noted that the growth in use has applied selection pressures for resistance, and resistance in several species has reached levels that compromise insecticide efficacy. Research to understand the molecular basis of neonicotinoid resistance has revealed both target-site and metabolic mechanisms conferring resistance. Field-evolved mutations have only been definitely characterised in two aphid species, but metabolic resistance appears much more common through the enhanced expression of one or more cytochrome P450s, including those expressed in resistant aphid strains in Africa. Work on the mechanism has been performed in Africa by Liu *et al.* (2008). Pest species exhibiting resistance in African studies include aphids and whiteflies affecting fruits and vegetables, cocoa and tobacco, as well as resistance in urban insects. Whitefly resistance in African cotton has been recorded (Houndété *et al.* 2010; Gnankiné *et al.* 2013a, 2013b; Legg *et al*. 2014), but work elsewhere also shows a tendency for resistance in aphid pests of cotton (see, for example, Herron and Wilson 2011). Multiple authors thus emphasise the need for resistance management strategies to avoid resistance becoming more widespread, and the spread of resistance is seen as one of the key drivers for increased use of insecticides forecast in market surveys.

As in other regions, the rational use of chemical pesticides is necessary to protect ecosystem services and biodiversity. Current practices negatively affect honey bees and result in bee products contaminated with pesticides; thus all crop-protection strategies should specifically consider the protection of honey bees, other pollinators and other non-target organisms, and incorporate such criteria in laws and regulations. Overall, this review concludes that stricter regulation of insecticides is required across Africa and that good agricultural practices in plant protection should be promoted to ensure sustainable agriculture that protects the environment, human health and biodiversity. Central to this should be maximising the use of natural controls to balance pest pressures and reduce the need for pesticides.

Scientific Resources

This review concludes that it is important not to divert the limited resources available in Africa into repeating Europe's research on the basic properties of neonicotinoids, given that there is no scientific basis for expecting significantly different effects of neonicotinoid pesticides on insects in Africa. Rather, the priority should be to apply existing knowledge urgently to update regulatory procedures and agricultural practices to address the ecosystem threats of neonicotinoid use in the African context.

To make the maximum use of the resources available for ensuring pesticide use can deliver both food security and environmental sustainability, work on standardisation across Africa and identifying ways of sharing the necessary workload (e.g. by working in groupings such as the Regional Economic Communities (RECs)) should be considered. Where research questions specific to the African situation are identified, these should have priority. Specific research priorities for the African situation were considered in the second workshop and are summarised in Table 3.

Table 3. Some priorities for research and field studies

Category	Specific priorities
Basic research infrastructure	• Set up and permanently fund independent laboratories that follow international standards to detect residues and that carry out, *inter alia*, ecotoxicological research on neonicotinoids. The work of such centres of expertise can be integrated into regional groupings to inform regionally-relevant decisions on pesticide authorisation. Models are ICIPE, the Group on Earth Observations' Geo Biodiversity Observation Network GEO BON[29] and the Bee Informed Partnership which collects data across the USA and Europe to monitor colony collapse disorder (CCD).
Ecosystem services	• Africa has more pollinator species and differing climatic regions than Europe, and most countries have few data on presence, abundance, distribution, endemicity and ecological requirements of insects. • Studies on insect abundance, diversity and the ecosystem services they provide are needed to quantify their economic value and to assess neonicotinoids' effects on ecosystem services (not just pollination but also insects as food and in natural pest control; biodegradation/decomposition; soil aeration). • Encouraging scientists, students and/or citizen scientists to monitor insect numbers could be a start.
Research on neonicotinoids	• Evaluation of existing data from Europe, the USA and elsewhere on the fate of neonicotinoids in plants and their persistence/accumulation in soils and transfer to water under African conditions (e.g. microclimate could affect degradation rate and provide unforeseen opportunities for accumulation). • Collect baseline data on neonicotinoid residues in the environment and in food. • Determine the effects on birds, many of which are important in biological pest control. • Conduct research on effects of switching from neonicotinoids to other pesticides or alternative methods of control (including biological control).

[29] *https://www.earthobservations.org/activity.php?id=128*

Table 3. Some priorities for research and field studies—cont'd

Category	Specific priorities
Use of neonicotinoids and other farming aspects	• Conduct socioeconomic studies on the perception of neonicotinoids by farmers and other users. • Develop communication strategies to reach small-holder audiences, for example to inform them about alternative pest management strategies and beneficial insects, and to counter pesticide-related myths (e.g. not getting sick after applying pesticides does not suggest inadequate application). • Provide technical and financial support to conduct inventories of neonicotinoids available and used in the country, and to implement IPM. • Develop participatory IPM to help farmers understand that, while pesticide use is a quick fix, investment in long-term biological control would be beneficial. Biological control systems can be self-sustaining once established. • Explore how technology (e.g. mobile phones) can help with creating awareness.
Others	• Conduct research on effects on human health from prolonged low-level exposure to neonicotinoids through food or air/water. In addition, examine potential effects on pregnant mothers of indoor residual spraying involving neonicotinoids.

As noted earlier, Africa's scientific resources related to agriculture are distributed over large geographical distances and differ in terms of structure, language, culture and available resources. Identifying mechanisms to strengthen synergy between available resources is a major challenge. Workshop participants considered this briefly and developed the following suggestions.

- It is important to build on existing networks of African scientists. For example, the African Association of Insect Scientists[30] could provide a platform for networking within/between research groups on a regional basis mirrored on the RECs. Use could also be made of the network of African scientists under the Science for Africa initiative[31]. The UNDP's Biodiversity and Ecosystem Services Network (BES-Net) is already looking at the regional and national implementation options for IPBES's reports on pollination and land degradation, and held its third regional 'trialogue' in May 2019 between Anglophone countries of Ethiopia, Ghana, Kenya, Malawi, Nigeria and Zambia.[32]
- Africa's science academies could provide a common source of information on potential funding opportunities (including from EU programmes) to facilitate research collaboration within Africa. They can also provide inventories of expertise and map the location of experts.
- New networks may be needed in fields which are currently lacking, for instance a network of toxicologists.
- Consortia could be formed in key specialist areas such as IPM, bee health, toxicology, etc. and communication platforms constructed between expert communities through social media; this would make it easier to form working groups on specific issues.
- Countries with national associations in areas of scientific expertise already present could provide starting points to build international expert communities.

Agricultural Management and Pesticides

This review found that different countries relied on different sources for guidance in their regulatory decisions (USA, EU, FAO, WHO, etc.). This is leading to fragmented and differing

[30] *http://aais-africa.com/*

[31] *www.futureafrica.science*

[32] Trialogues aim to strengthen the interface between policy, science/traditional knowledge and practice. See *https://www.besnet.world/bes-net-newsletter-no-may-2019*

responses to regulatory restrictions elsewhere, especially where the response of one regulatory authority (e.g. USA) lags behind that of another (e.g. EU). There is thus a need for jointly agreed-upon, science-based and binding criteria underpinned by the precautionary principle to help develop a more consistent system for registering active ingredients and deciding when to ban active ingredients that are harmful to humans or the environment.

Overall, this review concludes that Africa needs greater efforts to protect the environment from the misuse of pesticides, to advise all stakeholders involved in pesticide use, production, trade and regulation, to regulate and monitor pesticide usage better, and to evaluate the efficiency and effects of pesticides on the environment. Africa should thus better equip itself to detect, measure and assess pest outbreaks; collect data to quantify the damage, losses and gains; engage policymakers and create awareness; develop a platform for debate and advocacy; and integrate pest-control mechanisms that are mindful of environmental health. The IPBES initiative on pollinators mentioned in Section 5 provides a platform for members to share experience and lessons in developing and implementing pollinator strategies which "*avoid or reduce the use of pesticides harmful to wild and domestic pollinators*", although currently only four African countries have joined.

Policy options (some of which are already applied in some countries) involve the following:

- registration of dealers, commercial applicators, fumigators and storage premises;
- sensitisation/training and education of dealers and users;
- import control; compliance monitoring and inspection at various points; quality assurance at point of entry, distribution systems, etc.;
- surveillance and enforcement;
- research on available pesticides, their application, and their impact on the ecosystem;
- research on alternative control systems such as biological control.

The role of IPM is insufficiently appreciated and communicated. Various IPM strategies are available for different purposes on the continent, but they need to be communicated to the farmers, particularly in terms of effective methods of technology transfer that encourage farmers to apply and experiment with various aspects of IPM or agroecology (e.g. farmer field schools involving a two-way interaction between the extension services and those applying the information provided). Extension officers would need to be assigned to villages to teach rural farmers about IPM, explaining and demonstrating IPM practices instead of just giving instructions, and helping early-adopter farmers to share their knowledge with others. The training and mindset of extension officers are important because the current perception is that pesticides are the only way to increase crop yields. Applying IPM should also incorporate indigenous knowledge systems.

A sense of urgency requires routes for effective communication of the best available science to policymakers and to that end we have drafted the key messages in Box 6. These will be communicated to the African Union policymakers by working with the New Partnership for Africa's Development (NEPAD) and at the REC level (Arab Maghreb Union (AMU), Community of Sahel-Saharan States (CENSAD), Common Market for East and Southern Africa (COMESA), East African Community (EAC), Economic Community of Central African States (ECCAS), Economic Community of West African States (ECOWAS), Intergovernmental Authority on Development (IGAD), Southern African Development Community (SADC)). Meanwhile, the pace of innovation by agrochemical manufacturers continues and replacements for restricted neonicotinoids are already being marketed. Some of these exploit the same neurotoxic mechanisms as neonicotinoids and thus should be subject to the same scrutiny as to potential side effects on non-target organisms and the ecosystem services they provide. Results of research on such side effects are already emerging for sulfoxaflor (Siviter *et al.* 2018) and flupyradifurone (Tosi and Nieh 2019), indicating similar potential ecosystem effects to those demonstrated by the neonicotinoids.

Finally, we note that in parallel with this review, the Pesticides Politics in Africa Conference (31 May 2019) issued the 'Arusha Declaration'[33] containing many of the priorities identified by our analyses.

BOX 6

KEY MESSAGES TO COMMUNICATE TO POLICYMAKERS

Background

African agriculture is critically important socially and economically and is facing many challenges in ensuring food security for a growing population in a changing climate, with structural changes in land use and management, and intensification trends including the use of pesticides. At the same time, through their engagement in the IPBES, all countries in Africa (and the rest of world) have recognised the threats to sustainable development and future human well-being caused by the huge losses in biodiversity and ecosystem services on which our societies depend.

A synergistic relationship between agriculture and ecosystem services (particularly pollination and natural pest control) is a foundation of sustainable agriculture. Such services are provided mainly (although not exclusively) by invertebrates and the rapid decline in biodiversity in general and insects in particular that has been recorded globally is a source of concern, with implications for productivity and future food security as well as for biodiversity decline.

One factor that has been shown to contribute to loss of ecosystem services in Europe and elsewhere is the adoption of systemic insecticides that affect non-target species, posing a threat to beneficial insects such as honey bees, bumblebees and solitary bees (as well as wider biodiversity effects). As a result, the use of some of these insecticides has been restricted in the EU and some other countries. The scientific evidence and debate on this issue was informed by a study on the impact of neonicotinoids on agriculture and ecosystem services by EASAC (2015). This and the more recent (2016) IPBES assessment have emphasised the high value and importance of beneficial insects on agricultural productivity and the quality of crops, and the extent to which agriculture depends on such services as pollination and natural pest control. In the African context, the IPBES report states, "Articulating clear processes that allow the environment to contribute to food security through Africa's agricultural biodiversity, supporting ecosystem services (e.g., pollination, pest control, soil carbon), land restoration and increased resilience to climate change, are critical to inform the decision-making process".

Against this background, the IAP and NASAC have supported this project to examine the implications for ecosystem services and sustainable agriculture in Africa of the increasing use of systemic insecticides, especially of the neonicotinoind group.

Two workshops were held (Pretoria on 15–16 November 2018 and Nairobi on 13–15 May 2019) that brought together experts from 17 African countries. Proceedings from these workshops have been published by ASSAf (2019a, 2019b), and the information and conclusions published in a major report "Neonicotinoids use and effects in African agriculture". This report provides an overview of available information on neonicotinoids in Africa, evidence of environmental and ecosystem effects, relevant activities in African countries (e.g. regulation, research and agricultural extension services) and gaps in information.

Key Messages for Policymakers

1. *The sustainability of African agriculture is critical to food security and in maintaining its contribution to African economies and supporting rural communities. Maintaining the biodiversity*

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[33] *https://www.muhas.ac.tz/uploads/files/Pesticides%20Politics.pdf*

which supports the ecosystem services on which agriculture depends is critical to maintaining resilience against climate change and other environmental pressures. In this context the negative effects of neonicotinoid insecticides on ecosystem services shown in research and field studies globally are of concern to Africa.

2. *This study has considered the extensive scientific evidence, gathered globally, on the effects of neonicotinoids on insects such as bees, on ecosystem services such as pollination, as well as adverse effects on the wider environment through leakage into soils and freshwater systems. Neonicotinoids are also used in seed dressings as a prophylactic treatment, which not only leaks most of the insecticide into the environment but also increases the likelihood of emerging resistance in target species that would necessitate higher doses and/or additional applications. These insecticides are now registered and in use in most if not all African countries and it is essential to apply in the African context, the knowledge available from elsewhere and which has led to restrictions on their use in several countries and regions outside Africa.*
3. *This study has found widespread scientific and anecdotal evidence of negative trends (including loss of honey bee colonies, biodiversity and ecosystem services, widespread contamination of products, soils and freshwater systems by neonicotinoid residues) in Africa. Nevertheless, usage in Africa is currently less than had been occurring in intensively farmed areas of Europe, and thus an opportunity exists to learn from the negative consequences found elsewhere to promote insecticide uses that are more compatible with a sustainable and resilient future in Africa.*
4. *African biodiversity exhibits a huge range – from arid and semi-arid lands to tropical rain forests – and thus agro-ecosystems and agricultural methods (and their social and cultural contexts) are similarly wide-ranging. While there is a need for better knowledge on trends in pollination and other ecosystem services, any comprehensive and quantified review across such a diverse continent would be extremely time-consuming and expensive. This review therefore concludes that a precautionary approach needs to be taken on the basis of the existing scientific evidence on the negative effects of neonicotinoids.*
5. *This review stresses the urgency of reducing tensions between agricultural intensification and Africa's rich and abundant biodiversity and ecosystem services and, in that regard, recommends that African regulatory systems should pay close attention to the results of the regulatory reviews already conducted in Europe which have led to restrictions on the use of neonicotinoids outside of enclosed facilities. Given the advent of trans-frontier conservation areas, this should be done as far as possible within the ambit of the Regional Economic Communities and the African Union, and their responses to the IPBES report on global biodiversity.*
6. *Ensuring food security within a sustainable agricultural system requires farmers to be provided with the expertise and advice to minimise pesticide use and ensure that, when they are used, they are applied in as safe a manner as possible (ecological intensification). This study recommends that countries should strengthen expertise (e.g. in universities) and extension services to disseminate methods of IPM methods and to develop the potential of maximising synergy between natural ecosystems and agriculture (agroecology). Such methods should incorporate indigenous knowledge systems, maximise non-chemical methods of pest control and promote best practice in the minimal use of all pesticides. Such services should provide expert advice independently of pesticide manufacturers and suppliers/traders.*
7. *International funding agencies and national governments should substantially strengthen the provision of research, advice and training on sustainable agriculture in national agricultural research institutes and extension services, supported by regional centres of expertise.*
8. *The scientific resources available within the African continent are limited and are dispersed across large distances and different languages and cultures. At the same time, science continues to offer solutions to agricultural development and innovation; making full use of this potential and strengthening synergy between available resources are thus important, along with collaboration on common research priorities. The science academies of Africa have a role to play in realising this potential.*

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Annex 1 Workshop Participants

(Pretoria, 14–16 November 2018; and Nairobi, 13–15 May 2019)

1. From African Academies and Universities

Country	Name(s)	Institution
Benin	Professor Abdou Paraiso	University of Parakou
Botswana	Professor Motshwari Obopile	Botswana University of Agriculture and Natural Resources
Cameroon	Professor Leonard Ngamo Tinkeu	University of Ngaoundéré
Côte d'Ivoire	Professor Akpa Akpesse	University Félix Houphouët-Boigny
Egypt	Professor Salah Soliman Professor Youssef Dewer	Alexandria University Central Agricultural Pesticide Laboratory
Ghana	Dr Enock Dankyi	University of Ghana
Kenya	Dr Saliou Niassy Professor Mary Gikungu	International Centre for Insect Physiology and Ecology National Museums of Kenya
Malawi	Dr Elizabeth Bandason	Lilongwe University of Agriculture and Natural Resources
Namibia	Dr Penny Hiwilepo-van Hal	University of Namibia
Senegal	Professor Papa Ibra Samb	National Academy of sciences and Techniques
South Africa	Professor Christian Pirk Dr Misheck Mulumba Dr Tiou Masehela Dr Khutso Phalane-Legoale Ms Laura Bester	University of Pretoria Agricultural Research Council South African Biodiversity Institute Academy of Science of South Africa University of Pretoria
Sudan	Professor Nabil Hamed Hassan Bashir Dr Yousif Assad	Blue Nile National Institute for Communicable Diseases University of Gezira
Tanzania	Dr Mkabwa Katambo	University of Dar es Salaam
Tunisia	Dr Samir Abbès	Laboratory of Genetic, Biodiversity and Bio-resources Valorization
Uganda	Dr Patrice Kasangaki	National Agriculture Research Organization
Zambia	Professor Philip Nkunika	University of Zambia
Zimbabwe	Professor Charles Nhachi	Zimbabwean Academy of Sciences

2. Invited Speakers

Name	Institution
Dr Maarten Bijleveld van Lexmond	International Union for the Conservation of Nature
Dr Jean-Marc Bonmatin	French National Centre for Scientific Research
Professor Roseanne Diab	Academy of Science of South Africa
Dr Christiane Diehl	European Academies' Science Advisory Council
Dr Sunday Ekesi	International Centre for Insect Physiology and Ecology
Dr Elizabeth Heitzmann	International Association of Butterfly Exhibitors and Suppliers
Dr Michael Lattorff	International Centre for Insect Physiology and Ecology
Mr Stanley Maphosa	Academy of Science of South Africa
Dr Peter McGrath	InterAcademy Partnership
Professor Michael Norton	European Academies' Science Advisory Council
Mrs Jackie Olang-Kado	Network of African Science Academies
Professor Francesco Pennacchio	University of Napoli Frederico II
Professor Baldwyn Torto	International Centre for Insect Physiology and Ecology
Professor Volker ter Meulen	European Academies' Science Advisory Council, InterAcademy Partnership

The Network of African Science Academies (NASAC) was established on 13 December 2001 in Nairobi, Kenya, under the auspices of the InterAcademy Panel (IAP), now known as the InterAcademy Partnership.

NASAC is a consortium of merit-based science academies in Africa and aspires to make the "voice of science" heard by policy and decision makers within Africa and worldwide. NASAC is dedicated to enhancing the capacity of existing national science academies and champions the cause for creation of new academies where none exist.

As at September 2019, NASAC comprised of the following twenty-five members:

African Academy of Sciences (AAS)
Académie Algérienne des Sciences et Technologies (AAST)
Académie Nationale des Sciences, Arts et Lettres du Benin (ANSALB)
Botswana Academy of Sciences (BAS)
Académie Nationale des Sciences du Burkina (ANSB)
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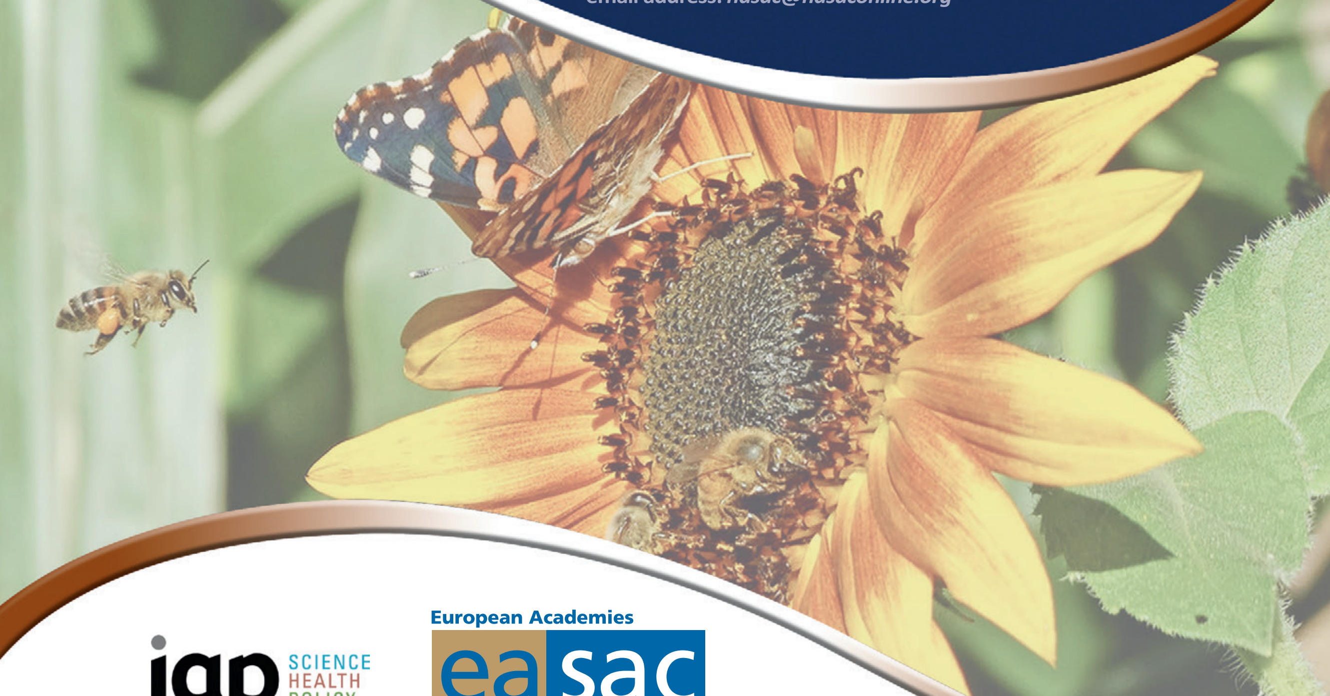

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