Chapter 1
Introduction: An Overview of the Impacts of Invasive Insect Species on Agriculture

Saliou Niassy, Sunday Ekesi, Lorna Migiro, and Washington Otieno

Abstract Agriculture plays a vital role in Africa, providing food and income. It contributes significantly to socio-economic development in rural and peri-urban areas. Among the many challenges that affect the productivity of the sector, invasive insect pests hold a ruinous position, as they inflict heavy economic yield losses. Over the past two decades, repeated scenarios of the invasions process have been experienced, characterised by the lack of preventive measures, weak and fragmented phytosanitary systems in terms of resources and infrastructure, policy and regulatory framework, and lack of capacity. This situation partly explains the high frequency of invasions and the high costs of emergency responses. Despite valuable research efforts being made to address incidences of invasive insect species, there is limited visibility of the successes and outcomes. It is imperative to shift from a passive stance and adopt predictive and proactive approaches to tackle these pests. This book, therefore, presents a panoramic view of invasive species research carried out in Africa. It is the fruit of a collaboration between several research entities and projects. It provides a slice of research work in the field of invasive insect pests management in Africa, and calls for a concerted effort to be made to harmonise research activities and promote knowledge exchange. The Volume covers a wide range of topics, which feeds into extension programmes and policy-making processes on the continent.

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Agriculture still occupies the majority of African populations, generating food and income, thereby contributing significantly to the nutritional requirements of the continent (Fairhurst 2017). It contributes significantly to socio-economic

S. Niassy (✉) · S. Ekesi
International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya
e-mail: sniassy@icipe.org

L. Migiro · W. Otieno
CABI, Nairobi, Kenya

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development in the rural areas and in the peri-urban regions of many African cities (FAO 2009; AGRA 2017). Among the many challenges that affect the sector, insect pests, both native and invasive, hold a ruinous position, as they inflict direct damages, while some of them are vectors of destructive viruses (Paini et al. 2016). The term 'invasive' generally refers to alien organisms, particularly for their ability or potential to establish and overcome various barriers to reproduction, dispersal and proliferation in new ecosystems, and their ability or potential to cause harm to humans, plants and the environment (Richardson et al. 2000). This book deals with invasive insect pests that also have economic and environmental impacts.

The economic repercussions arising from invasive species are far-reaching, and losses are estimated at several billion USD (Paini et al. 2016; Pratt et al. 2017). A study conducted in Florida on the estimated costs and regional economic impacts of the outbreak of the Oriental fruit fly *Bactrocera dorsalis* Hendel presented various scenarios of losses, ranging between $4 and 23 million, which is equivalent to 124 to 726 full-time and part-time jobs, and $10.2 million to $58.5 million in industry output. The costs of the response efforts to combat the fruit fly outbreak were estimated at $3,5 M (Alvarez et al. 2016).

Across Africa, fruit flies are estimated to cause annual losses of USD 2 billion in fruit and vegetable production (Ekesi et al. 2016). In West Africa for instance, yield losses are estimated at between 50 and 80% of the production, which translates into economic losses of 9 M Euro – more than one third of the total value of the exports. Fruit fly infestations also cause indirect damage to the economy, by reducing foreign exchange earnings from fruit exports due to quarantine restrictions and the loss of opportunities for export to lucrative global markets (Ekesi et al. 2016).

Outbreaks of *Chilo partellus* Swinhoe, Maize Lethal Necrosis Disease, *Parthenium hysterophorus* Linn, *Liriomyza* spp. and *Tuta absoluta* Meyrick, suffered by mixed maize smallholders in six countries, resulted in current combined annual losses of USD 0.9–1.1 billion and future annual losses (next 5–10 years) of USD 1.0–1.2 billion (Pratt et al. 2017).

Invasive species indirectly constitute a severe threat to biodiversity. They generally displace native and associated species, inducing changes in habitats, in general (McNeely 2001). The populations of native species and their associated organisms are threatened where invasive species have established themselves, as compared with areas where they have not been introduced (Rouget et al. 2016). This was observed during the emergence of *Chilo partellus* Swinhoe, which has a comparative advantage over *Busseola fusca* Fuller (Kfir 1997), and the same is being observed between Fall armyworm (FAW), *Spodoptera frugiperda* J. E. Smith and stemborers.

Biological invasions have three major phases: arrival, establishment, and spread. During the arrival phase, it is possible to eliminate invasive species if there are technically trained personnel available who can detect the pest. During the late establishment phase, when the population starts spreading, eradication becomes costly and unlikely. The ultimate option is to manage the pest locally, and intense effort is required (Alvarez and Solis 2019).

The approaches to invasive species management are highly variable and poorly reported, with costs being rarely quantified (Abate et al. 2000; de Bon et al. 2014). The most commonly used response to invasive pests, in general, is the extensive use of broad-spectrum synthetic insecticides, which not only compromise environmental health, but also negatively affect beneficial ecosystem service providers, as well as consumers (Mutengwe et al. 2016; Porteous 2017). Synthetic pesticides are often adulterated or applied at inappropriate application rates due to illiteracy and inadequate labelling, hence becoming largely ineffective and causing pest resistance. The harmful effects of pesticide residues seriously threaten human and environmental health, and result in market bans being placed on lucrative exports (Lux et al. 2003). The threat posed by these pests interferes with Africa's attainment of several Sustainable Development Goals (SDGs), and the perpetual vulnerability of the agricultural sector. It is, therefore, imperative to identify alternatives that could sustainably prevent and manage these pests, while mitigating their adverse effects on the environment, and ensuring the accessibility of horticultural produce to export markets (Simberloff 2014).

Over the past two decades, Africa has experienced the invasion of the Asian fruit fly *B. dorsalis* in Africa (in 2003 – Lux et al. 2003), the South American tomato moth *T. absoluta* (Tonnang et al. 2015), and most recently, the fall armyworm *S. frugiperda* (Goergen et al. 2016). Notwithstanding these experiences, there seems to be a repeated scenario for the invasion processes, which generally catch national quarantine systems off-guard and smallholder farmers defenceless. The problems posed by invasive insects are complex, costly and time-consuming. On the one hand, an invasive pest may be introduced accidentally or deliberately from outside its natural habitat or area of origin, but without its complex of natural enemies or biocontrol agents, thus making it a threat to livelihoods in the invaded areas (Emerton and Howard 2008). In a context of a weak agricultural setup and lack of capacity to identify, report and prevent invasions, invasive species spread at very high speeds, escaping all attempts at management.

On the other hand, there are weak national phytosanitary systems in terms of infrastructure, policy and regulatory framework. In most African countries, the Research for Development (R4D) continuum is in place, but with policy instruments being outdated, inadequate or unenforced (Cressman 2008, 2013; Tonnang et al. 2015; Early et al. 2018).

The traditional national disaster coordination strategy that is put into effect after a pest has become established consists of declaring a state of emergency, mobilising funds, and the constitution of a task force or multi-institutional technical team. However, most initiatives for the management of invasive pests are being implemented in isolation, resulting in fragmented efforts and limited initiatives and institutional subsidiarity and complementarity. The failure to address the listed areas for improvement results in the symptomatic lack of preparedness, characterised by the slow response to invasions, poor communication and information sharing, and insufficient coordination and cooperation, as well as fragmented control measures being taken, especially in the fight against trans-boundary pests. Factors such as mobility, the increase in trade between regions, and climate change also need to be considered. Invasive insect pests are generally of global or regional magnitude; therefore, the concerted efforts of actors are required to prevent, prepare and curtail the potential invasions. Since several entities are involved in the development and scaling of solutions, it is critical to adopt a more predictive and proactive approach. These approaches can be formulated through capacity building in effective surveillance systems; cross-border research to develop novel solutions; and the sharing of research experiences and success stories at institutional, national and regional levels, which would enable a more coherent response to be taken to invasive pests.

A body of work has been generated by African entomologists and their collaborators that endeavours to identify sustainable solutions to invasive pests. Indeed, there is no single “silver bullet” to deal with the invasive species problem; various tactics need to be employed that build on a solid understanding of the origin, identity, ecology, and biology of the pest.

CABI, for example, has developed the Plant Protection Compendium and Plantwise, which are accessible to the public and include information on prevention through surveillance, early detection and eradication, deployment and dissemination of technologies through the use of diagnostic tools for rapid identification, use of host resistance, integrated management, coordinating action against emerging threats, networking for surveillance, enhancing human resource skills development, and upgrading infrastructure.

In the same vein, it is encouraging to note that novel initiatives, such as the use of ICT (Mobile Applications such as FAMEWS, NURU, and wefarm), are being promoted for forecasting, scouting, reporting, learning, and knowledge exchange during invasive species outbreaks in Africa.

Valuable contributions have been made in the field of GIS, modelling and remote sensing for the collection, prediction and interpretation of data (Guimapi et al. 2016). GIS, modelling and remote sensing outputs inform the best ways possible to apply management tools most efficiently, while saving resources (Coulibaly et al. 2007; Nwilene et al. 2008).

The IPM strategies (or components) for dealing with most of the essential invasive species are being piloted and scaled across Africa, with high economic and ecological success (Macharia et al. 2005).

Approaches that were initially designed for pest monitoring are being upgraded into management tools, through the adoption of mass-trapping that uses semiochemicals and killing agents, e.g. biopesticides or minimal doses of soft-killing synthetic chemicals. Accordingly, invasive pests such as thrips, fruit flies, stemborer moths, leaf miners, to cite few, can be easily monitored, controlled and eventually suppressed by using an arsenal of IPM technologies, with limited impact on the environment and the consumer.

Studies have shown that wherever semiochemicals are used, there is high compatibility with predators and parasitoids. Often underreported, there have been several success stories of classical biological control programmes that have significantly contributed to the reduction of pest incidences. As an example, biological control contributed to significant yield increase and pesticide reduction in the Kenya highlands through the release of the parasitoid *Cotesia vestalis* Haliday and *Diadegma semiclausum* Hellen, active against the diamondback moth *Plutella xylostella* Linnaeus (Macharia et al. 2005).

The use of nets as a physical barrier to protect crops has also been evaluated in many countries for combatting lepidopteran pests such as diamondback moth, Tomato bollworm, and many others in different climatic conditions (Martin et al. 2009). These nets are reusable for 3–5 years, which makes this technology cost-effective and adaptable to small-scale farming systems.

There is an arsenal of approaches for dealing with the sustainably of invasive species (Simberloff 2014). The only challenge that remains is to package and disseminate them as best-bet technologies in the context of the emergence of invasive species in Africa.

This book is, therefore, a compendium of research works on the sustainable management of agricultural insect pests in Africa, both in horticulture and for staple crops. Primarily, the book targets key pests such as *T. absoluta*, Fall armyworm *S. frugiperda*, and fruit flies *B. dorsalis*. This book mainly focuses on the following management techniques: the use of botanicals, resistance varieties, chemical pesticides, biological control strategies, and strengthening agricultural quarantine services and other regulatory bodies to enable active surveillance, behavioural chemical ecology, digital technologies for surveillance, monitoring and emergency response actions to be undertaken (Plantwise). Also considered are the application of scientific knowledge to help small-scale farmers to manage plant health problems, capacity building for plant health management concerning sanitary and phytosanitary standards (SPS), compliance and market access, and the use of innovations, including ICT, in agriculture for combatting invasive species. A few of the chapters deal with farmers' perceptions of the efficacy of management tools.

Chapter 2 looks at the use of botanicals for the management of *T. absoluta*. This is a field of research that has mostly been overlooked, yet has much potential for generating novel management tools. The team investigated the larvicidal potential of two leguminous trees and the effect of their extracts on eggs of *T. absoluta*, with positive results. In the same vein, Chap. 3 explores the seasonal abundance and the susceptibility of some tomato cultivars to *T. absoluta* in the context of developing an IPM package in Sudan. The outcome of the study revealed a significant difference among tomato genotypes and recommended RILG3–162, KHP 5822 and Salama, which are tolerant, for further research. In Nigeria, *T. absoluta* had deeply affected the tomato sector, despite heavy pesticide use. Chapter 4 presents a clear case of resistance development among several populations of the pest after being subjected to lambda-cyhalothrin, deltamethrin, chlorantraniliprole and lambda-cyhalothrin, spirotetramat and flubendiamide. Pest populations showed resistance to all compounds, confirming farmers' observations. This study stressed the need for an IPM strategy, including the use of pheromone trapping techniques and cultural practices (orchard sanitation), among many others, to contain the pest in the country. Chapter 5 reports on the inefficacy of relying on a single solution. The same team in Nigeria went on to narrate the adoption of an IPM package that resulted in a 57.5% reduction in pest damage. The problem with invasive species is that they keep on increasing their host range in the new environment. The team, led by ARC and the University of Gezira, presents the effects of *T. absoluta* on cowpea *Vigna ungiculata* L., with 25% damage on leaves (Chap. 6). Although data on pods have not been presented, this already showed that the pest is not only confined within the Solanaceae family, but may also attack other unusual crops as well.

Chapter 7 deals with the invasive fruit fly, *B. dorsalis*, which invaded Africa in early 2000. The study is mainly focused on the virulence of the entomopathogen *Metarhizium anisopliae* (Metchn) Sorokin, initially isolated on a Coleoptera on pupae of *B. dorsalis*, with 74% mortality at a dose of 2. 10^7 propagules/ml. These results will be extremely useful in the management of the pest, especially using powder formulations under trees where pupation occurs, since *M. anisopliae* naturally occurs in soil.

Chapter 8 presents the diversity of fruit fly species in Sudan. This chapter is particularly important in the context of developing a national strategy for the management of invasive species. Disciplines such as taxonomy and pest identification are becoming increasingly scarce among African entomologists and need to be revived.

A critical aspect of invasive species research is the characterisation of the relationship between damage and yield. For the case of FAW, for instance, panic and lack of experience led governments to spend astronomic amounts of money to purchase chemicals. However, the after emergency caused many stakeholders to realise that the correlation between leaf damage and yield can be subjected to various factors. In Chap. 9, the authors endeavour to describe that relationship by identifying the ultimate factors or parameters that enable the accurate measurement of the links between injury and yield in maize. Factors, such as time of infestation, cob tunnel length and cob biomass, are shown to follow a function, whereas the length of stem tunnel and cob mass were less reliable as indicators.

Biological control is also an essential component in the management of invasive species. Often, classical biological control is applied because the alien species present themselves in a new environment without their original natural enemies. The local complex of natural enemies often takes time to develop new associations. Classical biological control often requires time to become effective because newly introduced natural enemies often take time to adjust in the new environment, and they need to be produced in numbers. Chapter 10 recounts a success story in East Africa, where the parasitoid *C. vestalis* imported from Southern Africa was introduced into Eastern Africa (Kenya), with satisfactory results in the lowlands of Kenya. The study explored the establishment of the parasitoid in the South Eastern and Coastal regions of Kenya after several releases and recorded the limiting factors to its establishment, confirming the molecular identity of the *Cotesia* specimens and investigating the farming practices in the region. Although it takes much time to confirm the establishment of natural enemies confidently, the introduction needs to be accompanied by specific measures, e.g. reduced chemical use and awareness creation.

Chapter 11 presents a study on maize lethal necrosis disease and thrips in Kenya.

This book on invasive species management would not be meaningful without presenting research on the Fall armyworm, one of the most recent invasive insect pests attacking cereal crops on the continent. Chapters 12 and 13 present a review of FAW in Rwanda and the farmers' perceptions of the use of chemical pesticides in an emergency context. It is imperative to emphasise that the use of chemical pesticides is a component of IPM, and it generally comes as the first line of defence in a situation where no other tool is available, for instance during the recent FAW invasion. National governments, NGOs and many other actors in the maize value chain have promoted the use of chemical pesticides. Accordingly, Chap. 13 deals with aspects of farmers' perceptions of the efficacy of several chemical pesticides recommended for the management of FAW in Rwanda.

The book also presents research on other key pests, for example the palm green pit scale *Palmapis phoenicis*, which is believed to have reached Africa through imports of shoots. The pest inflicts high yield losses and causes severe economic losses in many Arab countries, including Sudan and Egypt.

Chapter 15, therefore, describes a classical IPM approach, starting from pest identification, biology and ecology, leading to the implementation of management strategies including the use of resistant varieties.

Chapter 16 presents the use of a male annihilation technique for the management of the Mango Fruit flies in Ethiopia.

The occurrence of invasive species also leads to product export bans. This was the case in Ghana when the EU banned the import of chillies, eggplant and ridged gourds from 2012 to 2015, and then extended the ban to 2017. Chapter 18 narrates the process by which quarantine officers conducted trials to identify solutions to uplift the ban by understanding crop protection practices in Ghana. The study revealed that building capacity among the growers, staff members of quarantine inspectors, National Plant Protection Organizations (NPPO), and Plant Protection and Regulatory Services Directories could help them to implement adequate measures that would lead to pest-free produce, fit for export.

CABI's Plantwise project is one of a kind, playing a pivotal role in the detection of pests' status in Africa and beyond. Chapter 19 is dedicated to providing information and extension officer support systems called "Plant doctors". The Plantwise system also plays a crucial role in the early detection of critical pests, their monitoring and noting of changes of status.

Chapter 20 explores the use of management techniques, commonly referred to as "lure and kill", on thrips such as *Megalurothrips sjostedti*, a key pest of grain legumes in Africa. This approach is novel and very relevant in the context of invasive species management, in that it combines several tools, including semiochemicals, coloured traps and entomopathogens. The approach helps to minimise the costs of inoculum and labour, and improves the persistence of biological products.

Chapters 21 and 22 present work on the tomato red spider mite, *Tetranychus evansi*. Chapter 21 looks at the use of natural enemies, such as the predatory mite *Phytoseiulus longipes*, for promoting within-plant pest dynamics. This suggests the use of a combination of this technique with other IPM tools for the management of this pest. Chapter 22 examines the use of endophytes as a means to control mite damage on various tomato varieties.

One key element in combatting invasive pests comprises gaining an understanding of their biology and ecology. Without this, perhaps tedious, exercise, no sound management strategy can be developed. The team of Rida Musa presents a study on the flight behaviour of *T. absoluta* on tomato and different crops in Chap. 23. The male *T. absoluta* flies at low heights, during the early morning hours. This information can contribute significantly to the development of an IPM package for the pest.

1.1 Conclusion

There is an immense repertoire of research studies on invasive insect pests. The sustainable management of invasive species in Africa suggests that enhanced coordination, cooperation, and communication of research should be implemented. This book is a modest contribution to the global effort in managing invasive species. Solutions to counter some of the most devastating invasive species exist, and these have been highlighted in the book.

In addition to being accountable to the farmers who face most of the problems posed by invasive species, there is a need for a trust security fund to be established to support innovation processes and the dissemination of knowledge products to end-users.

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