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Advances in monitoring of native and invasive insect pests of crops

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Introduction

Insect pests remain a major threat to crop production primarily because of their ability to inflict severe damage on crop yields, as well as their role as key vectors of disease. Early identification of pests is critical to the success of integrated pest management (IPM) programmes and essential for the development of phytosanitary/quarantine regimes to prevent the introduction of invasive insect pests to new environments.

This volume reviews the wealth of research on techniques to monitor and thus prevent threats from both native and invasive insect pests. The book is split into three parts: Part 1 chapters draw attention to detection methods for crop insect pests, focusing specifically on techniques to trap and monitor them as well as developments in sampling and survey design, detection techniques and ways to monitor airborne movement of crop insect pests. Chapters in Part 2 focus on identification, modelling and risk assessment, highlighting advances in image-based identification and analysis, population growth models and pest risk assessment techniques. Part 3 chapters review invasive species and how their potential economic impact can be assessed, including the development of effective phytosanitary measures to prevent invasive insect pests and successful IPM programmes to control or eradicate them.

Part 1 Detection

The first chapter of the book draws attention to advances in techniques for trapping crop insect pests. Chapter 1 begins by describing the basic components of an insect trap. It then moves on to discuss methods to make traps more attractive for an insect, emphasising the use of methods such as visual and olfactory cues. The chapter also highlights common trap types for catching insect pests, focusing specifically on water traps, sticky traps, suction traps, interception traps and funnel and cone traps. Case studies of their usage and an evaluation of their merits and limitations are also included. Automated traps for insect pests are also reviewed, such as time-sorting traps, automated counting and identification and automated visual identification.

The next chapter reviews current insect pest monitoring systems for native and invasive pest species of corn, soybean, and cotton in the U.S. Chapter 2 presents case studies of European corn borer, corn earworm, western bean cutworm and western (*Diabrotica virgifera* LeConte) corn rootworm as pests of corn; soybean aphid, stink bugs, and Japanese beetle as pests of soybean; and tobacco thrips, plant bugs and bollworm as pests of cotton. It discusses how new technology has driven recent improvements in monitoring of these pests from the lab, field and areawide levels. It also discusses recent trends and tools for insect resistance management.

The subject of Chapter 3 is interpreting data from insect pest trap networks. The chapter begins by highlighting models to analyse trap networks, focusing primarily on the development of the TrapGrid network. TrapGrid can be used to quantify the probability of capturing insects instantaneously or over time using a function that relates distance from a given trap to probability of capture and two models of insect dispersal. Brief descriptions of other modeling approaches to these questions, some of which have seen application outside of research, are discussed followed by ideas for the application of TrapGrid, including a way to determine trap attraction (the parameter λ in the model) and how to compare alternative trap layouts on a landscape scale. A working example is also provided, comparing two alternative trap layouts in a 1 km^2 area via quantification of capture probability instantaneously and over 30 days.

Chapter 4 focuses on developments in crop insect pest detection techniques. The chapter first discusses the use of camera systems for pest detection at micro-scale ranges, then moves on to review how drone/camera systems can be used at meso-scale detection ranges. This is followed by an overview of the use of Landsat systems for pest detection and macro-scale detection ranges. A section on sound- and vibration-sensors is also included. The chapter provides a case study focused on augmenting traditional pest detection and biological control with nanoscale- and micro-scale sensor technologies, before concluding with an overview of future goals and developments for insect pest detection technologies in crops.

The final chapter of Part 1 explores monitoring airborne movement of crop insect pests and beneficials. Chapter 5 highlights the importance of trapping methods when it comes to monitoring specimens. This is then followed by a review of the visual observation of insects and a discussion of various forms of radar that can be used, such as scanning entomological radars, vertical-looking and weather surveillance radars. A section on optoelectronics is also provided, focusing specifically on short-range and long-range monitoring as well as imagers and the strengths, limitations and prospects of these devices. The chapter also provides a review of radiotelemetry and harmonic radar as well as a case study on moths over a cotton crop.

Part 2 Identification, modelling and risk assessment

Part 2 opens with a chapter that reviews progress in developing automated image-based systems for identifying crop insect pests. Chapter 6 identifies the challenges in distinguishing insect pests in field conditions and ways they can be addressed. The chapter outlines key steps in image-based identification (image capture, processing, segmentation, feature extraction and classification) and the growing use of artificial intelligence to increase accuracy and reliability. It also provides examples of commercially-available systems and considers future developments. The chapter is aimed at practitioners and scientists new to the topic and as a useful reference on the pros and cons of different monitoring strategies for those already in the field.

Chapter 7 looks at advances in insect pest monitoring using pest population growth and geospatial data for pest risk management. The chapter reviews approaches and provides case studies of current advances that are in development or have been applied in operational IPM systems. It first analyses incorporating knowledge of expected pest population growth to adjust economic thresholds for use in applying remedial IPM tactics to individual fields. The chapter then turns to principles and advancements in using spatial data, including spatially-referenced pest, crop and remote sensing data. Spatial data linked to insect pest monitoring may improve strategic use of remedial IPM tactics at the field level and use of preventive IPM tactics at larger scales.

The subject of Chapter 8 is advances in pest risk assessment techniques focusing on invertebrate pests of European outdoor crops. The chapter breaks down the processes and tools available to undertake a pest risk assessment, first focusing on the ways to assess the likelihood and hazard of pest infestations. It then highlights the potential influence of the perception of risk on decision making and how risk can be reduced. The chapter also provides a worked example for a priority pest in wheat.

Part 3 Invasive species

Chapter 9 addresses the potential economic impact of invasive plant pests. The chapter evaluates techniques such as partial budgeting, partial equilibrium models, input-output models and computable general equilibrium models in terms of their economic concepts, scope and required data and skill. This is then followed by a general reflection on the question of how to choose the most appropriate technique whilst considering the trade-off between completeness in economic scope and required resources. The chapter concludes with two case studies to illustrate the potential of the methods that are most often applied.

The subject of Chapter 10 is developing effective phytosanitary measures to prevent the introduction of invasive insect pests. The chapter provides a definition of phytosanitary measures, why they are needed, how standards for phytosanitary measures developed through international cooperation and how they relate to international agreements. This chapter then explains how policy decision making and the management of invasive insect pests using phytosanitary measures is supported by the structured framework of pest risk analysis which follows international standards. Outlines of some of the more commonly used phytosanitary measures used to manage pest risk are provided. Case studies are used to illustrate the impact of phytosanitary measures. The chapter closes by identifying some of the key challenges the industry faces to inhibit the introduction and spread of invasive insect pests with the aim of stimulating future research.

The final chapter of the book is focused on mitigating invasive insect species, focusing specifically on eradication, long-term management and also highlights the importance of sampling and monitoring. Chapter 11 introduces major concepts associated with the management of invasive insects. It then focuses more deeply on eradication and long-term management, especially IPM, describing common factors associated with successful programmes and potential challenges of each strategy. Brief case studies are provided to illustrate applications of eradication and IPM to various invasive insects in different regions. Lastly, the chapter summarises recent research and technology that have progressed effective management of invasive insects and highlight areas where further research is needed.

Chapter 1

Advances in techniques for trapping crop insect pests

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1 Introduction

Monitoring of insect pests is an essential component of integrated pest management. To determine whether pest densities justify an intervention, such as an insecticide application or other control measures, their numbers need to be assessed and compared to economic thresholds (Pedigo and Buntin, 1994; Ramsden et al., 2017; Stern, 1973). Such assessments can be done by physical sampling of the crop and visual inspection or passively using traps. The method used will depend on the biology of the pest species, the ease of assessment, the availability of labour and the relationship between the stage monitored and the damage done. For example, traps may monitor the adults, whilst the damaging stage is the larva. The closer the temporal and spatial association between the monitored stage and the damaging stage, the more accurate the assessment but the less advanced the warning provided.

For traps, cost and ease of use are important practical elements for in-crop sampling. For all trapping systems, the processing times and costs are major considerations. Some flight interception traps such as Malaise traps catch a

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wide variety of flying insects, with several thousand specimens collected over a trapping period (Skvarla et al., 2021). For biodiversity assessment, non-selective traps like this are ideal; however, for monitoring crop pests, selective traps are usually required that produce as targeted a sample as possible with little bycatch. This makes for speedy and accurate processing, as well as minimising impacts on non-target species. In-crop trapping systems therefore aim to be attractive to the target pest species but not to other insects within the crop. The exceptions to this may be where two species interact, such as, two pest species [e.g. cabbage seed weevil, *Ceutorhynchus obstrictus* (Marsham), and brassica pod midge, *Dasineura brassicae* (Winnertz)] (Smart et al., 1992), or where there is an opportunity to monitor a pest and its natural enemy at the same time (Murchie et al., 1997).

The first challenge in successful pest monitoring is to produce a cheap, selective trap that is highly attractive to the pest species. The second challenge is that the trap must be effective enough to provide an accurate population assessment. The third challenge is to reduce the trap sample processing time. Correspondingly, there is increasing interest in automatic methods of sorting and identification of trap catches. The fourth challenge is to reduce the environmental impact of trapping. Indiscriminate traps such as sticky traps are notorious for their large bycatch, even including small birds, bats and lizards, whilst water traps catch beneficial insects such as bees, hoverflies, lacewings and parasitoids. There is also the difficulty of disposal. Sticky traps are awkward to handle and invariably made of plastic, which once contaminated by the sticky glue cannot be easily recycled (Solorzano et al., 2015). The handling and disposal of any chemical preservative involved also needs to be considered.

2 Basic trapping elements

There are four basic components to an insect trap. The first is a method to make the trap attractive to the pest. This is commonly achieved using an attractive colour, light (for nocturnal insects) or more selectively volatile chemicals, in particular pheromone lures. Combinations of colour and chemical attractants are common, and trap design can use both visual and olfactory cues to enhance collection (Blight and Smart, 1999). An exception to this requirement would be where the trap is intended to sample specifically background insect populations, for example with suction traps, pitfall traps or clear flight interception traps. The second component is a mechanism to retain the catch. Insects may be retained on sticky glue, water with a dash of detergent to break the surface tension, or caught into a preservative such as alcohol. Some traps may be run for the purposes of live capture, particularly for biodiversity assessment (e.g. moth trapping) or to collect specimens for further work. In such cases, the design of the trap will allow entry but minimise the likelihood

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of exit. Often traps will be left for several days or longer before being emptied, so some method of preserving the catch must be used, if identification of specimens is required. Common preservatives are alcohol, if evaporation can be minimised, and ethylene or propylene glycol (anti-freeze), where the trap is more open to the elements. Alternatively, some traps operate dry and use insecticides to rapidly kill the catch. Lastly, the trap must be mounted in such a way as to maximise catch. Often for flying crop pests, this is at the crop canopy height and unobscured by plant foliage, which changes as the crop grows; therefore, height mounts for the trap are adjustable.

3 Making the trap attractive

3.1 Visual cues – colour and light

Colour is the simplest method of increasing trap attractiveness. Insects have diverse and highly developed colour vision, with some species having up to six different spectral receptors and a visual range of <300 nm [ultraviolet (UV)] to >700 nm (Briscoe and Chittka, 2001; Fennell et al., 2019). Specific wavelengths are attractive to certain insect species. Yellow in particular has been used for attracting phytophagous insects and has been recommended for monitoring glasshouse pests since the 1920s (Lloyd, 1922). This may be because the peak colour reflectance of plants is in the yellow band at 500–580 nm (Prokopy and Owens, 1983), due to brightness/intensity effects (Döring and Chittka, 2007) or attraction of phytophagous insects to stressed/diseased plants (Hodge et al., 2011). However, other colours have also proven attractive depending on the specific pest. For example, Kirk (1984) demonstrated that within the thrips species caught in coloured pan traps in an English sports-field, there were strong species-specific colour preferences for yellow, white, or blue, but there were also some grass-feeding thrips that were caught equally in all colours. The author suggested that yellow was in general the most attractive for non-grass foliage feeders, dark colours (black or red) for biting flies and wood borers, and white or blue for predators and parasites not associated with foliage. Responses to colour are therefore specific to the ecology of the pest species and can be subtle. For example, the contrast between the trap colour and background can affect the response of insects to traps, as can the sex and physiological state of the insect (Blackshaw, 1983; Košťál and Finch, 1996; Murchie et al., 2018). Due to the sensitivity of insects to colour, when conducting choice experiments to aid in designing traps, spectral reflectance measurements in visible and UV using spectrophotometers are preferable to human-vision assessment of colour hues.

Light trapping is used extensively for monitoring flying nocturnal insects. Many species have strong attractions towards artificial light sources particularly

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