Biodiversity and Insect Pests

Key Issues for Sustainable Management

Edited by

Geoff M. Gurr, Steve D. Wratten and William E. Snyder with Donna M. Y. Read

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Preface

Agriculture accounts for approximately 40% of the land area on planet Earth and has been a major factor in global biodiversity decline. It is ironic, then, that agriculture is now showing conspicuous signs of faltering because of a breakdown in the services provided by nature. Pest control, soil fertility and nutrient cycling are amongst the most important of these. Industrialised agriculture, in striving for greater levels of productivity, uses inputs such as millions of tons of pesticides and fertilisers to replace natural processes. Reliance on technologies based on non-renewable resources has widely acknowledged problems including pollution, human safety and – in the case of pesticides – reduced efficacy as a result of resistance developing in pest populations.

It is time to consider how agriculture worked in such a sustainable manner for thousands of years before the rise of industrialised agriculture. Much is to be learned from traditional practices of diverse crop systems in which biodiversity is maintained. But if agriculture is also to meet the future needs of an increasing human population, ecological science must rise to the challenge of providing more than theoretical understanding and ingenious new research methods. Practicable methods are also required that will permit highly productive farming systems which, by virtue of their ecological foundation, are more sustainable.

The chapters in this book address this challenge from the perspective of insect pest management. Insect pests continue to cause severe crop losses worldwide but novel pesticides and genetically modified plants are not the only technologies available for their control. This book explores ways in which biodiversity can be harnessed to achieve sustainable pest management. Vegetation diversification at scales ranging from the field up to the landscape can reduce pests either directly or by enhancing the activity of predators and parasites. Biodiversity is also a source of genes for better crop varieties and of compounds that can be used as botanical insecticides or that work by more subtle chemical ecology mechanisms.

The role of biodiversity in pest management is a burgeoning area of research and novel pest management strategies are now being implemented successfully in many countries. Forms of ecologically based pest suppression are important examples of the ecosystem services that can be provided by biodiversity. Moreover, pest suppression can be achieved concurrently with providing other benefits such as pollinator enhancement, wildlife conservation, dual crop production and even carbon sequestration.

Our aim as editors as we planned this book in 2010, the United Nations International Year of Biodiversity, was to achieve a comprehensive synthesis of this exciting and important field of applied science. To this end we recruited authors who include leading researchers and practitioners and combined their wide experience with that of carefully selected younger scientists with innovative thinking. With wide international coverage including Africa, America, Asia, Australasia and Europe, our treatment of the subject is significantly broader that that available from mainstream, English-language journals.

We have strived to make the material in this book accessible to advanced undergraduates and newcomers to the field, with plenty of illustrative features, while still offering the specialist reader a current synthesis and stimulating new ideas. Chapters are arranged under a series of headings (Introduction, Fundamentals, Methods, Application and Synthesis), but these should not be viewed too rigidly. Many of the chapters include a blend of material; especially when stressing the link between aspects of theory and the success of real-world use. Ultimately, we hope that the book will prove useful in placing pest management on a more sustainable footing.

We thank the chapter authors for their generous contribution of ideas, attention to detail and (nearly always) keeping to schedule. Many also served as reviewers for other chapters. We very much appreciate the assistance of the many colleagues who acted as reviewers for chapters: Helmut van Emden, Daniel Karp, Myron Zalucki, Sarah Wheeler, Debbie Finke, Gary Chang, Cory Straub, Deborah Letourneau, Stephen Duke, James Hagler, Wopke van der Werf, Nuria Agusti, Matt Greenstone, Mark Jervis, Jana Lee, Marcel Dicke, Liu Shu Sheng, A. Raman, Bob Bugg, Samantha Cook, Norman Arancon and Katja Poveda. This book would not have been possible without Donna Read, whose input went way beyond proofreading and formatting.

Geoff M. Gurr

Steve D. Wratten

William E. Snyder

August 2011

Foreword

Agriculture has been practised for several thousand years but it is only in the past few generations that the traditional practices that sustained agriculture have come to be replaced by modern and largely industrialised systems. Despite dramatic increases in food production, it is now recognised that agriculture can negatively affect the environment through overuse of natural resources as inputs or through their use as a sink for waste and pollution. Such effects are called negative externalities because they impose costs that are not reflected in market prices. What has also become clear in recent years is that the apparent success of some modern agricultural systems has masked significant negative externalities, with environmental and health problems widely documented. These environmental costs shift conclusions about which agricultural systems are the most efficient, and suggest that alternative practices and systems which reduce negative and increase positive externalities should be sought.

The growing human population and rapidly changing consumption patterns will bring increasing demands for food, fuel and fibre. It is estimated that world population will reach some nine billion by the middle of the twenty-first century. This will require agricultural production to increase by at least two-thirds; perhaps doubled if those in developing countries are to approach levels of animal protein intake that are taken for granted in industrialised countries. The scale of this challenge is daunting but studies of agricultural sustainability in developing countries suggest overall yield increases of 80–100% are possible in many countries and systems. One analysis of 286 projects in 57 countries showed improvements had been made by 12 million farmers on 37 million hectares of farmland (Pretty et al., 2006, *Environmental Science and Technology*, 4, 1114–1119); a recent study of African agriculture found that 10 million farmers and their families had more than doubled yields on another 13 million hectares (Pretty et al., 2011, *International Journal of Agricultural Sustainability*, 9, 5–24). Food outputs by such sustainable intensification have been multiplicative – by which yields per hectare increased by combinations of the use of new and improved varieties and new agronomic-agroecological management, and additive – by which diversification resulted in the emergence of a range of new crops, livestock or fish that added to the existing staples or vegetables already being cultivated.

Realising the promise of ecologically based agriculture will require a massive and coordinated effort. A key component is the role of science to both provide a better understanding of the natural resource base and develop new technologies. The significance of this book is that it amply demonstrates the power of biodiversity to combat one of the major causes of crop loss: insect pests. Methods such as growing secondary crops on the embankments around rice fields, incorporating agroforestry into farming systems, using locally appropriate crop varieties and adopting integrated pest management were widely used in these agricultural sustainability studies. Much of what is now happening on farms has drawn from the work of the authors and editors of this book. Each of these methods, and many other biodiversity-based approaches, are detailed in chapters that span the full spectrum from underlying theory, to methods for research and implementation and, ultimately, to cases of successful application and use. This book compellingly shows that biodiversity on farms and across landscapes can provide a range of benefits to humans at the same time as contributing to suppressing pests.

Understanding, protecting and harnessing biodiversity is a key to the agricultural and food challenge before us.

Professor Jules Pretty OBE, University of Essex

August, 2011

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Introduction
Chapter 1

Biodiversity and insect pests

Geoff M. Gurr, Steve D. Wratten and William E. Snyder

INTRODUCTION: INSECTS, PLANTS AND HUMANS

This book is essentially about interactions between the three most important life forms on planet Earth: insects, plants and humans, and the ways in which they are affected by biodiversity, the complex web of life. Over a million species of insect have been formally described (20 times the number of all vertebrates), with just one insect order, the beetles (Coleoptera), representing 25% of all described species of all forms of life (Hunt *et al*., 2007). It has been estimated that the biomass of insects in temperate terrestrial ecosystems is 10 times that of the usually more conspicuous vertebrates, and that for each human there are 1,000,000,000,000,000,000 living insects (Meyer, 2009).

Insect and plant biodiversity are tightly linked, and it is generally accepted that the rise of angiosperm plants during the Cretaceous period (145–65 million years ago) was accompanied by the development of many intricate coadaptations between plants and insects. These included pollination and seed dispersal (Ehrlich and Raven, 1964; Scriber, 2010), such that many insects benefit plants. However, many other insect species are herbivores harmful to plants, and there is compelling evidence for coevolution between plant defences and the ability of insect herbivores to overcome them. An example of great relevance to agricultural pest management is the phenomenon of 'resistance breakdown'. This occurs when a pest population responds to the resistance genes bred into into a widely used crop variety by the development of increased virulence over successive generations of the adapting pest (e.g. McMenemy *et al*., 2009). This renders the host plant's resistance mechanism(s) ineffective.

In contrast to the two 'mega taxa' sketched out above, *Homo sapiens* is an evolutionary newcomer, as anatomically modern humans have existed for much less than a million years. Of course it is only in the last few centuries that technological advances have allowed numbers of this single species to escalate, approaching seven billion as of June 2011 (US Census Bureau, 2011). The impacts of this rise are such that we are now said to be living in the Anthropocene era (Crutzen, 2006), characterised by very high rates of species extinctions, pollution (including elevated atmospheric carbon dioxide levels) affecting every corner of the globe, destruction of natural ecosystems and high levels of land use for urban and agricultural purposes. Amongst the most important technological advances that have allowed this dramatic success ('success' at least in terms of the population size of *H. sapiens*) is agriculture.

The concept of 'pests' has arisen out of human agricultural practice and the desire to preserve food security by protecting crops from ubiquitous insects. Some, such as the locust (most likely desert locust, *Schistocerca gregaria* Forsk. (Orthoptera, Acridiidae)), are mentioned in the Bible and in other early written works (Nevo, 1996). For many centuries, farmers combated pests with cultural techniques ranging from hand removal of pests to the use of crop rotations. Saving the best seeds from each year's crop to sow in the following season led to the development of many landraces (locally adapted varieties) of major crop species, some of which persist to the present day (Thomson *et al*., 2009). These landraces often had useful levels of broadly based resistance to various pests to which they were exposed for hundreds of generations. More recently, other technologies were brought to bear against pests including chemistry to produce ever more sophisticated insecticides (Casida and Quistad, 1998), radiation technology to allow the development of the sterile insect technique (Dyck *et al*., 2005) and molecular biology to support plant breeding efforts (Sanchis and Bourguet, 2008). Many pest management technologies, however, are beset with problems of a technical nature (e.g. pollution, resistance breakdown, cost, etc. (van Emden and Peakall, 1996)) or a social nature (e.g. public acceptance of biotechnology in agriculture, deregistration of insecticides because of safety concerns (Cullen *et al*., 2008; Lemaux, 2009)).

Although the term 'pest' is a human construct, and pest management involves humans modifying natural processes, there is much to be learned from nature. For more than 100 million years plants have been developing strategies to defend themselves from insect herbivores. In addition to familiar morphological adaptations such as hairs and thickened cuticles, plants have also evolved a powerful arsenal of chemical defences. Insecticide scientists and plant breeders are learning much from nature about new compounds that might be used in future insecticides (Isman, 2006) and about plant genetics that might be manipulated through molecular biology (Yencho *et al*., 2000). The value of plant biodiversity as a resource from which botanical insecticides may be discovered is another important field,