An Introduction to Arthropod Pest Control

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Contents

Plate sections between pages 144 and 145, and pages 240 to 241.

1

A brief history of arthropod pest control

Introduction

Two of the most important challenges facing humanity in the twenty-first century comprise food production and disease control. These are challenges that are associated with the increasing global human population (Figure 1.1) and with the control of arthropod pests, the subject of this book. The importance of these challenges cannot be overemphasised.

Arthropod pests are responsible for global pre- and postharvest crop losses of approximately 20–50% of potential production and for transmitting a number of the world's most important diseases (Table 1.1). For example, it has been estimated that the protozoan organism causing malaria infects approximately 500 million people worldwide – almost 10% of the people on earth.

It is undoubtedly the case that humanity's problems with arthropod pests are not new and they certainly predate the development of agriculture approximately 10 000–16 000 years ago. Arthropods first appear in the fossil record over 500 million years ago during the Cambrian[1] period at the start of the Palaeozoic. The oldest insect fossils to have been found so far are dated to the Devonian, a period that began 400 million years ago. Modern insects begin to appear in the fossil record about 280 million years ago. However, the time scale over which different insect orders are detected in the fossil record

[1] Geological time is split into four major phases that are known as the Precambrian, Palaeozoic, Mesozoic and the Cenozoic. Each of these major phases is then further subdivided, e.g. the Cambrian is the first phase or subdivision of the Palaeozoic. See glossary for further details.

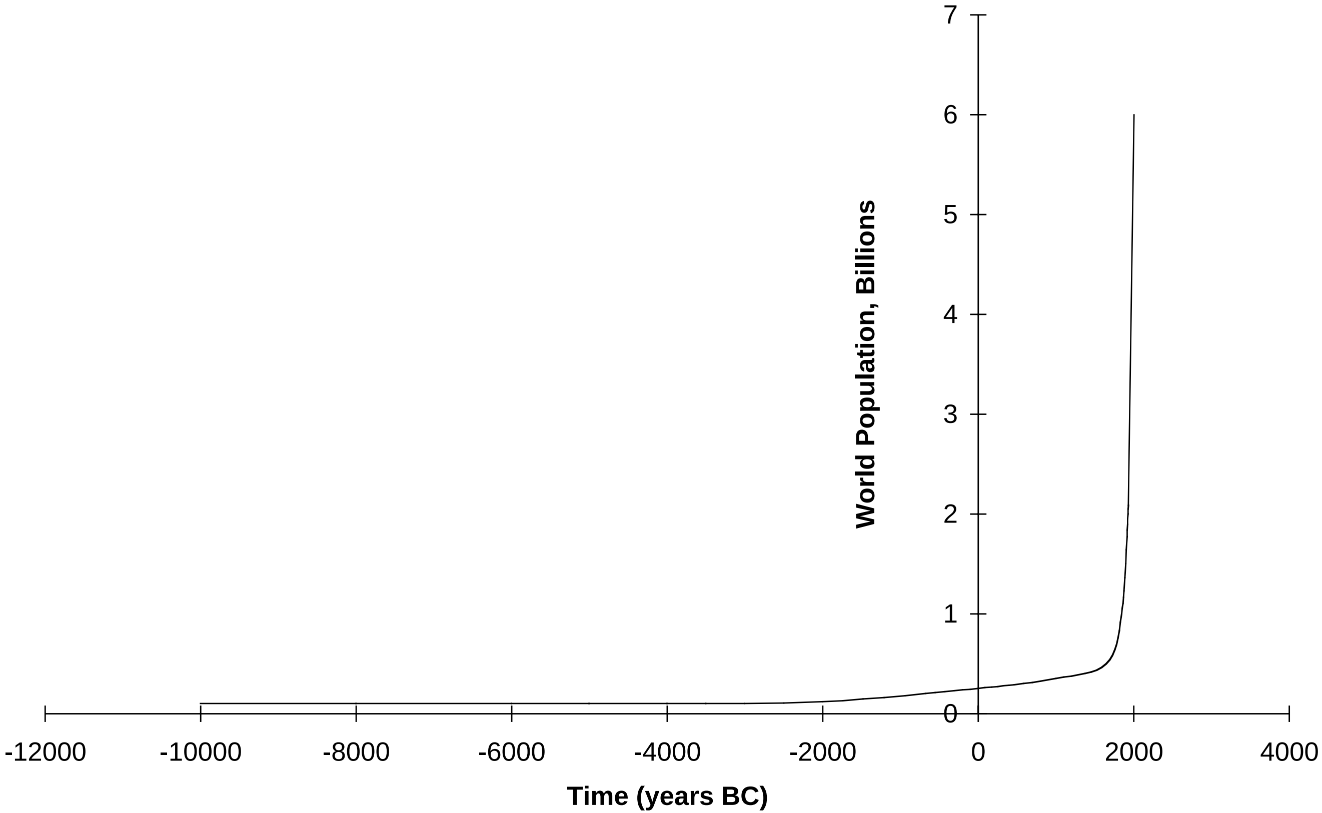

Fig. 1.1. Growth in the global human population since 10 000 BC.

Table 1.1. *The world's most important arthropod-borne diseases*

Disease	Vector	Agent	Cases	Deaths
Malaria	Mosquito	Protozoa (*Plasmodium*)	300–500 m	1.5–2.7 m
Filariasis	Mosquito	Filarial worms	120 m	NA[a]
Dengue	Mosquito	Virus	50 m	0.5 m
Onchocerciasis	Blackfly	Filarial worms	18 m	NA[b]
Chagas	Triatomine bugs	Protozoa (*Trypanosoma*)	16–18 m	20 000–50 000
Leishmaniasis	Sand flies	Protozoa (*Leishmania*)	12 m	NA[a]
Trypanosomiasis	Tsetse flies	Protozoa (*Trypanosoma*)	300 000–500 000	NA[a]
Yellow fever	Mosquito	Virus	200 000	30 000

Notes:

[a] Accurate estimates not available.

[b] Onchocerciasis or 'river blindness' causes chronic rather than acute illness. The WHO estimates that, of the 18 m people infected, 6.5 m suffer from severe dermatitis and 270 000 are blind.

Source: Data collected from the World Health Organization (WHO) *World Health Report 1998*.

stretches up until 75 million years ago, during the Cretaceous period at the end of the Mesozoic. For example, silverfish (order Thysanura) are detected in the fossil record from the Devonian while caterpillars (order Lepidoptera) are not detected until the Cretaceous.

By contrast, *Homo sapiens* has been around for about a 100 000 years. It should therefore come as no great surprise to know that so far we have not been able to conquer the problems that arthropod pests pose. These animals have had far more time than humans to evolve and adapt to life on earth.

This first chapter gives a brief historical account of arthropod pest control. The chapter begins by considering the importance of the development of agriculture as a method for food acquisition. The cultivation of plants and the domestication of animals would have vastly increased the opportunities for humans to associate with arthropod pests. This is followed by a description of some of the earliest recorded examples of attempts to control arthropod pests. A brief review of pest control from 1600 to 2000 AD is then given. The chapter ends with a description of some of the modern high-tech methods of pest control that have been developed for use in the twenty-first century. In short, this introduction serves as a foreword to the book as a whole.

Neolithic agricultural development and pest control

The earliest evidence of domesticated plants and animals, the basis of agricultural development, dates from between 16 000 and 10 000 years ago. The earliest evidence comes from Mesopotamia[2] and from the Nile delta in Egypt. The later evidence comes at the start of the Neolithic period (8000 BC) from Europe, a period that is dated from the end of the European ice age. Wherever agricultural development began, it was certainly invented more than once because there are no links that can be accurately made between the farmers of such far-removed areas as the Americas and the Middle East.

As a method for food acquisition, agriculture would have had profound and long-lasting effects upon the development of human populations and consequently upon the development of problems associated with arthropod pests. The change from a hunter–gatherer lifestyle to that of a farmer would have had many implications. First, an increased food supply would mean that more individuals could be supported within the family unit. One result of this would be that families would tend to increase in size as it would be advantageous to have more hands to work the land. Second, growing crops would have required the development of a more permanent home base from which to run a farm. This would have led to the development of early fixed settlements, a prelude to villages, towns and cities. Jericho in Palestine is the oldest documented permanent human settlement and was founded around 9000 BC. Third, a more reliable and guaranteed food source would have left more time for other pursuits that are often characteristic of the development of civilisations. These would have included artistic pursuits such as writing and music. Fourth, lessons would have begun to be learnt about soils, the climate and successful agronomic practices. This would have been especially the case as populations expanded and moved to occupy new geographical areas. In Europe,

[2] Mesopotamia – the region between the rivers Tigris and Euphrates, including parts of what is now eastern Syria, south-eastern Turkey and almost all of Iraq – is also thought to be the traditional site of the garden of Eden.

where people practised slash-and-burn agriculture it would have been necessary to move on a regular basis anyway. Fifth and last, increased crowding (of people, crops and animals) would have exacerbated problems associated with arthropod pests and so would have stimulated the development of the first selective breeding and domestication programmes and the first attempts to try to control pest species. In short, the development of agriculture represented a major step forward in human cultural evolution. It was also a development that would, for the first time, have brought humans into mass contact with the arthropod pests that would have used their crops and their animals for food and reproduction. Such contact would undoubtedly have led to the development of attempts to control these noxious organisms.

Early attempts at pest control

The earliest attempts to boost (or sustain) agricultural production concentrated upon agronomic practices that ensured an adequate water supply, the use of fertile soil and the choice of the most well-adapted cultivars. Progress with the control of pest species would therefore have been slow, although practices such as rotations and cultivar selection would undoubtedly have helped. The usual response by people to large-scale attack by pests was to suffer or move. For example, the exodus of the Israelites (*c.* 1300 BC) described in the Old Testament has been attributed to plagues of locusts, flies and lice that consumed crops and spread disease among the inhabitants of the Nile.

The use of chemicals to control pests can be traced back at least 4000 years. For example, the Hindu book, the *Rig Veda*, written in India in 2000 BC, makes reference to the use of poisonous plants for pest control. It is also known that plants were used as sources of insecticidal compounds by the Egyptians during the time of the Pharaohs. Ancient Romans are credited with having used false or white hellebore as a rodenticide. Homer, in 1000 BC, mentions the use of sulphur as a fumigant while Pliny, in 77 AD, makes reference to the use of arsenic, soda and olive oil. Lastly, in 970 AD, the Arab scholar Abu Mansur described over 450 plant products with toxicological and/or pharmacological properties.[3] Despite such knowledge, though, progress in pest control until at least the 1500s was agonisingly slow. Agricultural development had been critical in the development of early civilisations and empires in Asia, the Middle East and South America. However, such development had largely

[3] For example, see review by Yang, R.Z. & Tang, C.S. (1988). Plants used for pest control in China: a literature review. *Economic Botany*, **42**, 376–406. See also glossary for more detail on Abu Mansur.

Table 1.2. *Exchange of agricultural products – selected examples from the Columbian exchanges (1492–1503)*

New World → Old World	Old World → New World
Avocado	Barley
Chocolate	Banana
Corn	Cattle
Peanut	Chicken
Peppers	Citrus
Potato	Lettuce
Sunflower	Onion
Tobacco	Pear
Tomato	Wheat

Source: Modified from Tribe, D. (1994). *Feeding and Greening the World*. Wallingford: CAB International.

occurred because of improvements in agronomic practices, most notably in the provision of good nutrient supplies for crops. This is not surprising since it was agronomic practices that were the greatest constraint to increased yields. Pest control, using cultural techniques such as crop rotations, would have happened. However, this control occurred more because of a desire to improve yields through better agronomy than as a result of any preplanned pest control strategy.

The development of agriculture and pest control in western Europe during this time period was a completely different matter. This region was something of a rural backwater that was years behind the empires that had already developed elsewhere in the world. Technical developments such as horseshoes, fixed-mouldboard ploughs and watermills were gradually introduced to farmers in Europe. However, early essays on agriculture, written by the classical scholars Cato, Varro and Columella, were still being used in Europe right up until the sixteenth century.[4]

The events of greatest significance to pest control at this time came at the

[4] In fact, many of these essays were still in use through the seventeenth and eighteenth centuries, particularly after English translations of the original Latin texts became more widely available. See glossary for further details.

Table 1.3. *Examples of major pests that have invaded North America from Europe, Asia and South America from the eighteenth century to the present*

Common name	Latin name	Date of arrival
Housefly	*Musca domestica*	1769
Codling moth	*Cydia pomonella*	*c.* 1800
Cabbageworm	*Pieris rapae*	*c.* 1860
Cottony cushion scale	*Icerya purchasi*	1868
Gypsy moth	*Lymantria dispar*	1869
Boll weevil	*Anthonomus grandis*	1892
European corn borer	*Ostrinia nubilalis*	1908
Pink bollworm	*Pectinophora gossypiella*	1915
Cereal leaf beetle	*Oulema melanoplus*	1940
Mediterranean fruit fly	*Cerratitis capitata*	1975
Russian wheat aphid	*Diuraphis noxia*	1986

end of the fifteenth century with the four voyages of Christopher Columbus to the New World (1492–1503). These voyages led to the exchange of plants and animals between the Old and the New World and, consequently, to the exchange of insect pests. Tables 1.2 and 1.3 list of some of the plants and insect pests that were exchanged between continents as a result of these and other voyages. It was these and later exchanges that eventually led to the development of modern systems of plant quarantine. The movement of pest species also led to the development of pest control based upon the use of predatory species imported from a pest's country of origin (classical biological control – see Chapter 5).

Pest control after the sixteenth century

The explorations of the New World and the opening-up of trade routes with Asia not only led to the movement of pests but also to the discovery of new means for controlling pests. Many native cultures were already using extracts from plants for the control of arthropod pests and early explorers rapidly exploited such technology. For example, the first explorers of the Americas observed that native Indians in Venezuela were using the powdered seeds of a lily, *Sabadilla officinarum*, to protect crops from insect attack. This observation led to the export of this crop to Europe, and to the use of the extract for pest control right up until the middle of the twentieth century. Similar events happened with the discovery that nicotine was widely used in North America for pest control, that quassia (from *Quassia amara*) was widely used in Central America and that sweet flag (*Acorus calamus*) was widely used in China and India. One result of these explorations was that, during this period, plant-based chemical control of arthropod pests began to increase. A more complete list of the plants in use that were discovered during these European explorations is given in Table 1.4.

These plant-based extracts really dominated the pest control market in Europe and the colonies up until the end of the nineteenth century. However, from the sixteenth century onwards, inorganic compounds (some of which had been mentioned 2000 years earlier) began to become more widely available and hence, more widely used. For example, arsenic mixed with honey was used as an ant bait from the mid-1600s onwards. Copper arsenite, lead arsenate and calcium arsenate all became widely available from the end of the nineteenth century onwards. In the early 1900s sodium fluoride and cryolite (an aluminium salt of fluorine) were marketed for pest control. Finally, a number of other formulations based on sodium, mercury, copper and tin were also developed.

Many of these inorganic chemicals for pest control had two features in common: they had high mammalian toxicities and they acted as stomach poisons (they needed to be consumed by pest species to be effective). Both of these characteristics led to a decline in their use and they were eventually replaced by more selective and effective synthetic organic compounds. Most of the inorganic pesticides that remain in use today (2002) are fungicides.

Developments in the products available for controlling arthropod pests were matched in the eighteenth and nineteenth centuries by technological developments in agricultural equipment and by the development of scientific approaches towards farming. For example, the French inventor Victor Vermorel designed and marketed one of the first commercial crop sprayers in 1880. One result of these developments was that farmers began to experiment with farming. As a result, food output (in Europe and North America) and the global human population continued to increase while pest control on farms began to become more effective.

The really dramatic changes in agricultural output (in Europe and North America) and in arthropod pest control (globally) however were to have their origins in events that happened before and during World War II. These changes were to herald what was perhaps to be the zenith of chemical pest control during the years 1945–70. During this time period, four major groups

Table 1.4. *Insecticidal plants discovered by Europeans after the sixteenth century*

Plant[a]	Active compound	Date of discovery	Native use[b]	European use[c]
Sabadilla officinarum	Sabadilla	*c.* 1500s	Crop protection (powdered seeds, South America)	Crop protection
Nicotiana tabacum	Nicotine	Late 1500s	Crop protection (Crude liquid extracts, North America)	Crop protection
Quassia amara	Quassin	Late 1700s	Aphid control (Extracts from wood chips used in Central America)	Aphid control
Heliopsis longpipes	Heliopsin	Early 1800s	Leaves burnt, used as a fumigant (Mexico, for fly control)	Not widely used
Ryania speciosa	Ryanodine	1940s	Stem used to make poison for arrows (Amazon basin)	Used against Lepidoptera
Calceolaria andina	Napthoquinones	1990s	Unknown native use (plants from Chile)	None so far
Derris chinensis	Derris	Mid-1900s	Fish poison (East Asia)	Crop protection
Acorus calamus	Not yet determined	Early 1600s	Insect repellent and crop protection	Insect repellent

Table 1.4. (*cont.*)

Plant[a]	Active compound	Date of discovery	Native use[b]	European use[c]
Tagetes minuta	Thiophenes	1600s	Fly control	Fly control and intercropping
Chrysanthemum cinerariaefolium	Pyrethrum	*c.* 1800	Fly control and crop protection	Public health and crop protection
Azadiractica indica	Neem	1970s	Public health and crop protection	Public health and crop protection

Notes:

[a] Plants referred to are the first plants identified to contain the active chemical. It is now known that many plant species can produce the same active ingredient.

[b] Native uses are given in broad terms, i.e. crop protection would refer to a general use against a range of crop pests.

[c] European use refers to whether the compound became widely used in Europe, at least once. There are many other plant species that are known to produce chemicals that are toxic to pests but these have not yet been widely used in Europe.

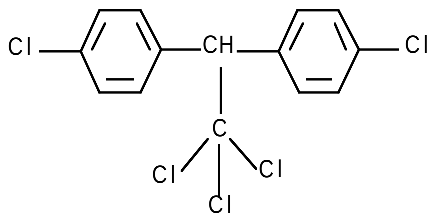

Fig. 1.2. Dichlorodiphenyltrichloroethane (DDT). The chemical structure is shown because this is probably the best-known pesticide worldwide. The structure exerts its toxic effects by disrupting the passage of nerve impulses along axons.

of synthetic organic insecticides – organochlorides, organophosphates, carbamates and pyrethroids – were all first discovered and developed for widespread use. All of these major groups of insecticide are still in widespread use around the world today.

The development of modern chemical pesticides

Modern twentieth century arthropod pest control began with the discovery in 1939 that dicholorodiphenyltrichloroethane (DDT) was toxic to insects (Figure 1.2). The insecticidal properties of this chemical compound were recorded by Paul Müller, a research scientist working for the Geigy Chemical Company. He was awarded the Nobel Prize for Medicine in 1948 for his research. This chemical, which is perhaps the best-known insecticide worldwide, revolutionised pest control. It is relatively cheap to produce, has a broad spectrum of activity and is selective in its toxicity. DDT was first used during the war to protect troops from diseases such as yellow fever, typhus, elephantiasis and malaria. The success of the pesticide was better than anyone had thought possible and after the war DDT was used widely to combat these diseases in the civilian population. For example, in India alone cases of malaria declined from 75 million to fewer than 5 million *per annum* in a decade. It is because of this and other successes that DDT continues to be used today for vector control in a number of developing countries. After the war, DDT was also widely used in agriculture to protect crops from pests. The discovery of the toxic properties of DDT spawned research into the toxic properties of related organic molecules. The result of this research was that the organochloride insecticides became a major force in pest control throughout the late 1940s and 1950s.

At the same time as the discovery of the insecticidal properties of the organochlorides came the discovery of the organophosphate insecticides. A German chemist G. Schrader had been looking for a replacement for nicotine. This chemical was in short supply at the time and in 1941 he finally produced his first compound, schradan. Schradan is very toxic to mammals but its discovery led to the development of a group of insecticides that has finally numbered more than 100 active ingredients in over 10 000 different formulations. However, since this research was linked with wartime German studies on the organophosphorus nerve gases (sarin[5] and tabun), this was hardly an auspicious start for these chemicals (see Chapters 3 and 4 for more detail). The organophosphate insecticides are still in wide use all over the world today.

The third major group of synthetic organic insecticides to be developed were the carbamates. These chemicals were originally developed by the Geigy Corporation in 1951 but it was not until 1956 that the first commercial product, carbaryl, was marketed by Union Carbide. The development of synthetic carbamates took place because it was already known that the chemical physostigmine (a naturally occurring carbamate found in *Physostigma venenosum*, the calabar bean) had powerful anticholinesterase activity. This naturally occurring carbamate could not be used for pest control because it is unable to penetrate pest species' nervous systems although it was (successfully) used in witchcraft trials by ordeal in West Africa. Research into synthetic carbamates eventually produced over 20 active ingredients, many of which are still in use today.

The fourth major group of chemical insecticides to be developed during the time period following the end of World War II were the synthetic pyrethroids. These insecticides were developed as a result of attempts to improve the chemical stability of naturally occurring pyrethrum, a compound that was extracted from the flower heads of chrysanthemums. The first synthetic pyrethroid, allethrin, was introduced for pest control in 1949. This early research led to further improvements in the chemical stability of this group throughout the next 30 years. Today, the pyrethroids comprise almost 40 different active ingredients and in many developed countries they are the most widely used insecticides for pest control.

In addition to these four insecticidal groups (organochlorides, organophosphates, carbamates and pyrethroids) we can now also add the neonicotinoids. These compounds were successfully developed and commercialised

[5] On 20 March 1995 a Japanese cult called the Aum Shinrikyo released sarin in the Tokyo subway system in an attempt to kill members of the police force who were planning several raids on cult facilities. The release of the gas injured 3800 people and killed 12.

during the 1990s and, in some markets at least, are now becoming the insecticides of choice (see Chapter 3 for more detail).

These five major groups of insecticide continue today to dominate the chemicals used for arthropod pest control, although regional variations exist in the group of choice. In terms of their development we can characterise at least three major changes within the synthetic chemical pest control market. These changes are as follows:

- A decrease in the rate of application of insecticides (Figure 1.3). Lead arsenate, which was widely used in Europe at the beginning of the twentieth century, was typically applied at a rate of 10 000 g/ha. By contrast, alphacypermethrin, an insecticide in wide use in Europe at the end of the twentieth century can be applied at a rate of 10 g/ha.
- An increase in the research and development costs associated with bringing a new active ingredient to the market (Table 1.5). The reasons for this increase include: (1) a decline in the rate of discovery of novel molecules for pest control; and (2) an increase in the number and complexity of tests required prior to product approval (Table 1.6).
- A decline in the number, but increase in size, of the companies involved in pesticide research and development work. At the end of 1998 Hoechst and Rhône-Poulenc joined forces to create Aventis and in November 2000 Zeneca and Novartis merged to create Syngenta. With sales in 2000 of *c.* \$4 billion and \$6 billion, respectively, these are now two of the world's largest agrochemical companies (see glossary for more details).

Within agriculture, there is absolutely no doubt that the discovery and development of these and other pesticides have made, and will continue to make, an enormous contribution towards massive increases in crop yields that have taken place in countries all over the world. There is also no doubt that these chemicals have made, and will continue to make, a substantial contribution towards the control of vectors of disease. Crop breeding, government support and legislation, increased fertiliser use, mechanisation and improved agronomic practices have all also contributed to agricultural production and to pest control. However, the contribution that chemical control of arthropod pests has made to boosting agricultural productivity worldwide can still not be overstated. By 1998 the global chemical crop protection market was valued at *c.* £25 billion.

Despite the many successes that have occurred with chemicals that are used for pest control, such technology did not prove to be the panacea that most people thought it might be. Within 20 years of the end of World War II alternatives were being sought in Europe and North America to the use of

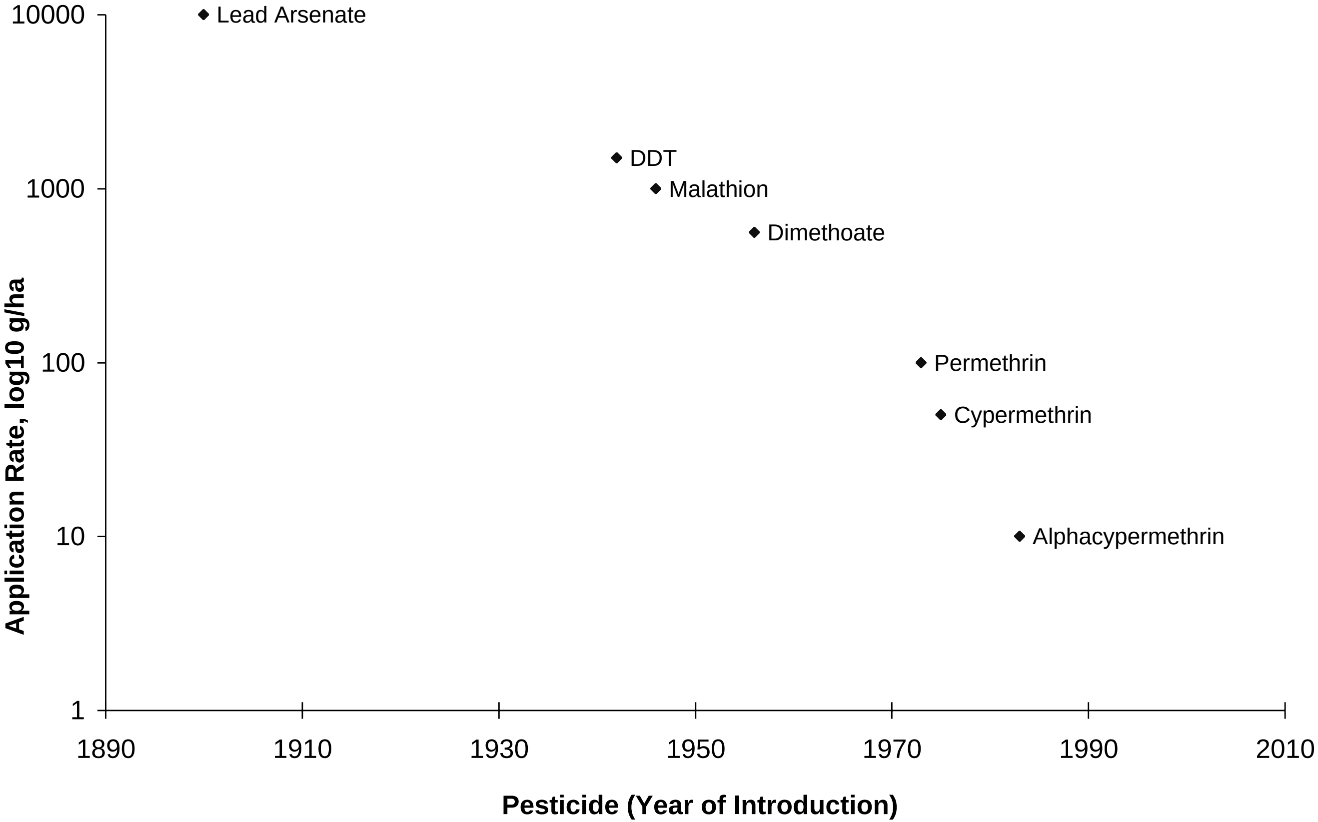

Fig. 1.3. The decline in the rate at which pesticides are commonly applied to crops over the past 100 years. DDT, dichlorodiphenyltrichloroethane.

Table 1.5. *Rate and cost of discovery of new insecticides 1950s–1990s*

Year	Rate of discovery[a]	Approximate cost
1956	1 in 1800	£0.5 million
1964	1 in 3600	£1.5 million
1970	1 in 7400	NA[b]
1972	1 in 10 000	NA[b]
1977	1 in 12 000	£10 million
1987	1 in 16 000	£10–15 million
1989	1 in 20 000	£20 million
1996	1 in 30 000	£30–45 million
1998	1 in 50 000	£50–60 million

Notes:

[a] Rate comprises the number of chemical compounds that need to be screened in bioassays in order to identify one that is useful for further development.

[b] Accurate data not available.

Table 1.6. *Increase in the number of pesticide toxicity tests required by registration authorities in Europe*

1950s	1980s	1990s
Rat feeding test	Rat feeding test	Rat and dog acute and chronic tests
Rat acute toxicity	Rat acute toxicity	Bird acute oral toxicity
	Dog feeding test	Bird 5-day dietary toxicity
	Dog acute toxicity	Bird subchronic and reproductive toxicity
	Teratogenic effects	Fish acute toxicity test
	Metabolic studies	Fish life cycle toxicity test
		Fish early-life stage toxicity test
		Fish 28-day chronic toxicity (juveniles)
		Fish bioconcentration toxicity tests
		Aquatic invertebrates acute toxicity and 21-day chronic toxicity test
		Algal growth rate toxicity test
		Midge larvae acute or chronic toxicity
		Bees acute oral and contact toxicity
		Bee brood feeding tests
		Arthropods residual exposure tests
		Earthworm acute toxicity test

chemicals for the control of arthropod pests. This search led not only to the development of new approaches towards pest control but also to the development of a new philosophical paradigm within which to apply control tactics. This philosophical paradigm is known as integrated pest management (IPM).

The development of integrated pest management

The development of alternatives to the use of chemicals for the control of arthropod pests began in earnest in the developed world following the publication in 1962 of Rachel Carson's book *Silent Spring*. This book articulated, for the first time, the increasingly widespread belief that all was not well with what was often indiscriminate and prophylactic chemical-based insect control. Resistance to insecticides had already been documented in 1914 and was becoming increasingly common (Figure 1.4), resurgent pests were becoming more common, the public was becoming increasingly concerned about residues in food and there was a general concern about the environmental impacts associated with widespread pesticide use. In short, questions began to be asked about a pest control tactic that relied on one technique (a chemical pesticide application).

The result of this questioning was the development of a new philosophical approach towards pest control. This approach was called IPM. Aided by the development of new economic and ecological models and by the development of new techniques for pest control, IPM began to develop over the period 1960–90. The essence of IPM in agricultural situations is that techniques for pest control are integrated or blended. This integration should result in: (1) pest damage that is below levels that would be economically damaging; (2) a minimum adverse impact of a chemical upon the environment (including impacts on nontarget species); and (3) a food production system that is sustainable in the medium to long term. Given such a definition, IPM can either be exceedingly complex or exceedingly simple.

Inherent in the definition of IPM is the concept of economic damage and models were developed in the 1960s that could be used to incorporate this concept. Two of the most important parameters within these models are the economic injury level (EIL) and the economic threshold (ET). These terms were first formally proposed by Stern and colleagues in 1959. The former refers to the point (in pest density) at which the cost of damage caused equals the cost of the control measure to be applied. The latter parameter recognises that control tactics take time to work and the ET is therefore the point at

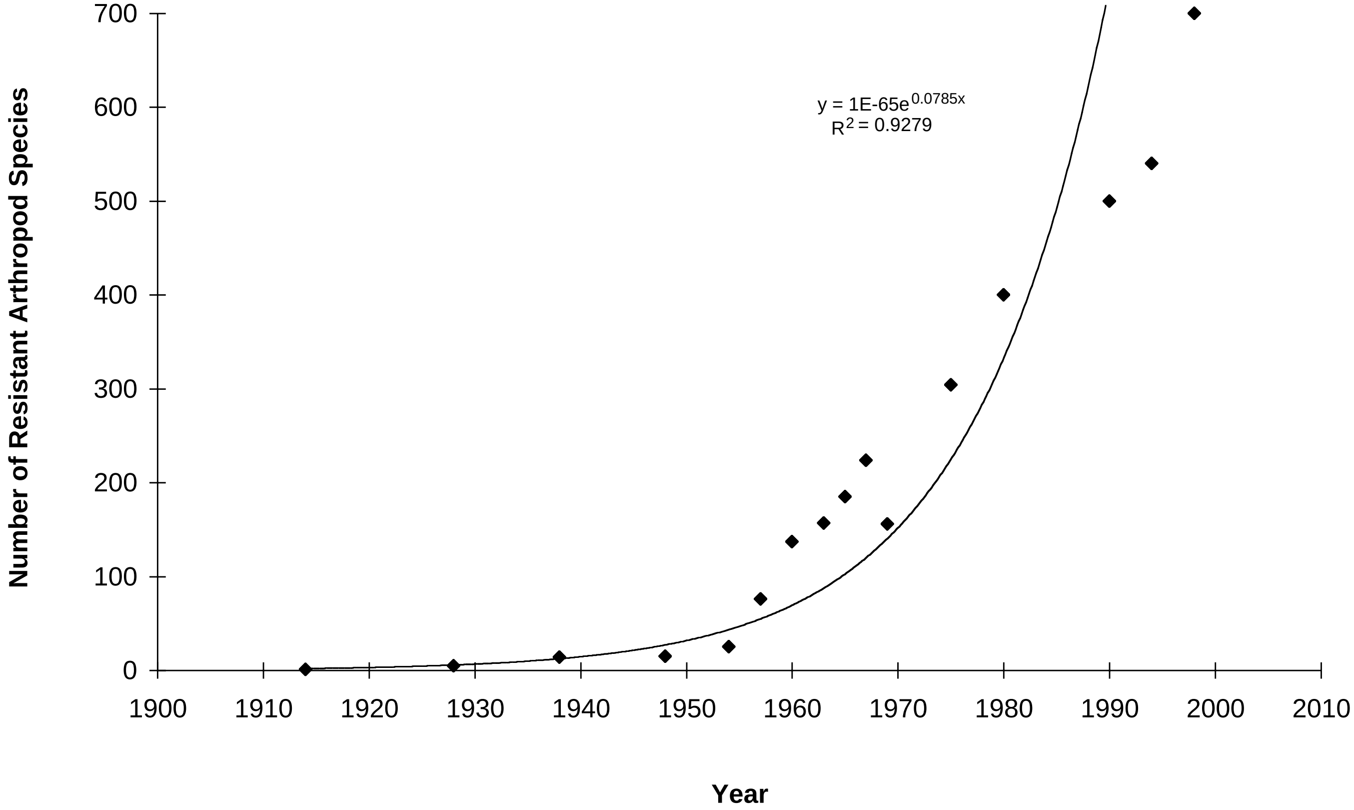

Fig. 1.4. The increase in the number of arthropod pest species that are resistant to at least one insecticide over the last 100 years.

which control measures must be applied in order to prevent a pest population from reaching the EIL. The ET is therefore always at or below the EIL. Figure 1.5 shows a schematic of these respective levels.

The magnitude of the separation between the EIL and the ET will depend on the speed with which a control tactic will work, with the current density of the pest population, with its propensity to increase before it is controlled and with the economic value of the damage being caused. The simplest models that have been produced incorporate data on pest density, product price, a damage function (a measure of damage per pest or pests), the efficacy of the control measure and the cost of the control measure. These data are incorporated as shown in the equation below:

$$\phi = C/PDK$$

where ϕ = the ET (a pest density), C = cost of control, P = the market value of the product, D = the damage function and K = the efficacy of the treatment applied.

The damage function is a measure of the yield loss that will occur in relation to injury caused by a particular pest density. This function is usually highly dependent upon environmental variables and it is typical for these to be incorporated into predictive models of crop losses and economic thresholds.

While economic models may have been useful in getting growers to think about the economics of control, they are very difficult to construct and implement accurately in a field-based situation, particularly with an individual who is known to be risk-averse (i.e. a farmer). The problem of course is that all of the parameters that go into construction of the economic model can vary. Market conditions (the determinant of product price) frequently fluctuate, with the result that the price on the day on which decisions have to be made with regard to a control measure may be vastly different from the price that the farmer gets for the harvested crop. Both agronomic practices (good or bad husbandry, etc.) and geographical location (climate and market) will affect economic models of pest damage. Costs of control may vary widely between countries depending upon whether or not government subsidies are available for crop protection. Costs will also vary depending upon whether an allowance is made for environmental impact or not, i.e. what is the cash value attached to the environmental damage caused by the use of a control measure? In most cases this will be zero but this does not mean that this will always be so. Finally, consumer tastes are known to vary widely in terms of both product quality and desirability.

Despite the difficulties inherent in constructing good economic models for pest control, farmers in many countries are beginning to think in terms of ETs

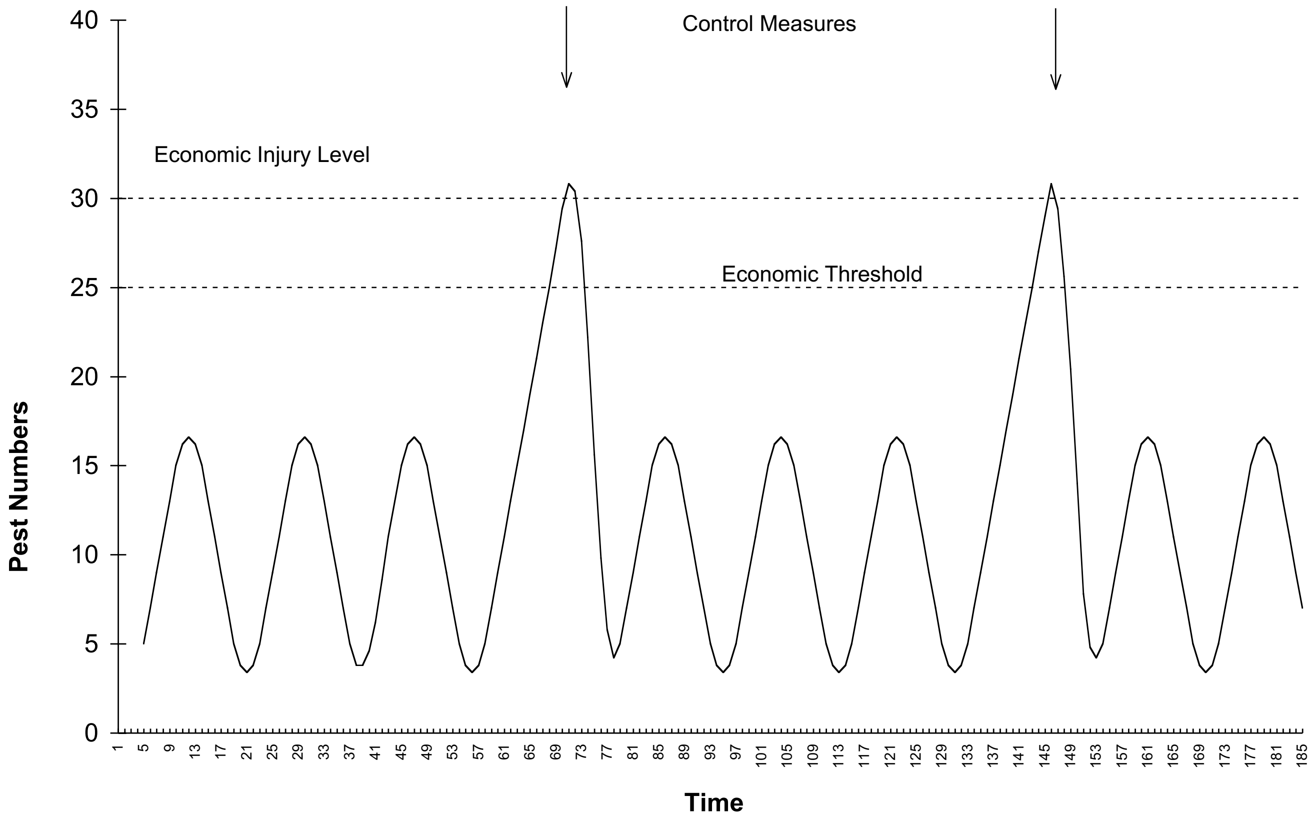

Fig. 1.5. A schematic of the economic threshold (ET) and the economic injury level (EIL). The population of a hypothetical pest is fluctuating around the number 10. At two points in the schematic the population increases to reach the ET (25). Control measures are applied to prevent the pest population increasing above the EIL (30).

Table 1.7. *Example Economic Thresholds*

Species	Common name	Economic threshold	Source
Ostrinia nubilalis	European corn borer	10–20 egg masses per 100 corn plants	Texas Agricultural Extension Service
Nezara viridula	Stink bug	1 stink bug per foot (30 cm) of a row in soybeans	Texas Agricultural Extension Service
Empoasca fabae	Alfalfa leafhopper	Spray when the number of hoppers in 10 sweep samples is equal to or above the height of the crop in inches (or centimetres). Multiply above by 4 if resistant Alfalfa is planted	Pioneer Hi-Bred International
Hypera postica	Alfalfa weevil	Use a 15-in. (38-cm) diameter sweep net and make 10 sweeps in Alfalfa when crop is 25 cm high. Spray if more than 20 larvae caught	Utah State University