INSECTICIDE AND FUNGICIDE HANDBOOK

Hubert Martin

INSECTICIDE AND FUNGICIDE HANDBOOK

FOR CROP PROTECTION

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edited by

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FOREWORD

It is now generally accepted that, in the present state of knowledge, pesticides are indispensible for food production. By definition, their use is detrimental to certain forms of life—the pest and pathogen—and the danger is that this toxicity may be exerted in unwanted directions, to the detriment of the user, the consumer and to the biological environment in which the materials are used. These hazards are scrutinised by appropriate authorities who report to the Ministers concerned. If necessary, safeguards are put into effect, either by Statutory Regulations or by advisory means. The adequacy of these safeguards is obviously dependent on a strict adherence, by the user, to the rules and recommendations proposed. The main purpose of this Handbook is to place before the grower and advisor the information necessary for the correct use of pesticides in crop protection.

The chemist has been successful, in recent years, in finding new compounds of more selective toxicity and, yearly, the list of hazardous pesticides is being reduced by the introduction of less noxious alternatives. A second purpose of this Handbook is to record this progress and to advise the grower on better methods of crop protection. In some instances, the new methods have been described in advance of their inclusion in official recommendations; if so, they must be regarded as tentative and for the information of the keen grower.

The material of the Handbook has been assembled by the Recommendations Committee of the British Insecticide and Fungicide Council, with the unstinted help of colleagues within the National Agricultural Advisory Service or at the state-aided Research Stations. In this first edition it has been found necessary, for reasons of space, to limit the text to the subject of crop protection, but the inclusion, in future editions, of farm storage may become possible. Suggestions for improvement, and correction of any errors or omissions, would be most welcome and should be sent to the Secretary of the Recommendations Committee, Lenton Experimental Station, Lenton House, Nottingham.

Every effort has been made to ensure that the recommendations are correct, but the British Insecticide and Fungicide Council cannot accept responsibility for any loss, damage or accident arising from carrying out tne methods advocated in this Handbook.

H. G. SANDERS M.A. PH.D

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CONTENTS

1 THE BIOLOGICAL BACKGROUND

Pests

1.1 Insect life histories 1
1.2 Destructive insects 3
1.3 Useful insects 5
1.4 Control measures 6
1.5 Economics of treatment 9
1.6 Development of resistance to pesticides 11
1.7 Increasing importance of previously non-damaging organisms 12
1.8 Effects on soil 12
1.9 Conclusions 13

Plant diseases

1.10 Factors influencing disease incidence 16
1.11 Control measures 18

2 THE CHEMICAL BACKGROUND

2.1 Insecticides 22
2.2 Fungicides 23
2.3 Formulation 24
2.4 The active components 27
2.4A Chemicals included in the A.C.A.S. 29
2.4B Chemicals not included in the A.C.A.S. 52

3 THE APPLICATION OF PESTICIDES

3.1 Spraying
3.1A Methods and terminology 56
3.1B Equipment 57
3.2 Specifications of main components 59
3.3 Operation 63
3.4 Nozzle arrangements and procedures for particular crops 68
3.5 Dusts and dry applications 71

4 THE SAFE AND EFFICIENT USE OF PESTICIDES
4.1A The notification of pesticides scheme 77
4.1B The Agriculture (Poisonous Substances) Act 1952 80
4.2 The agricultural chemicals approval scheme 86

5 PEST AND DISEASE CONTROL IN CEREALS
5.1 Wheat 89
5.2 Barley 95
5.3 Oats 97
5.4 Rye 99

6 PESTS AND DISEASES OF POTATO
6.1 Pests 101
6.2 Diseases 107

7 DISEASES AND PESTS OF SUGAR BEET, FODDER BEET AND MANGOLDS
7.1 Fungal diseases 112
7.2 Pests 117

8 PEST AND DISEASE CONTROL IN GRASS AND FODDER CROPS
Pests
8.1 Cereals 122
8.2 Grasses 123
8.3 Leguminous crops 126
8.4 Cruciferous crops 128
Diseases
8.5 Cereals 132
8.6 Grasses 133
8.7 Leguminous crops 136
8.8 Brassica crops 138

9 DISEASES AND PESTS OF FRUIT AND HOPS
9.1 Apple 140
9.2 Pear 159
9.3 Apricot, nectarine and peach 163
9.4 Cherry 165
9.5 Plum and damson 168
9.6 Hazelnut, cobnut and filbert 171
9.7 Currants and gooseberry 172
9.8 Blackberry, loganberry and raspberry 180
9.9 Strawberry 183

9.10 Grape vine 188
9.11 Hop 189

10 Pest and Disease Control in Grasshouse Crops
10.1 General 194
10.2 Specific crops
Bean 197
Carnation 198
Chrysanthemum 200
Cucumber and melon 205
Cyclamen 208
Grape 209
Lettuce 210
Mushroom 212
Rose 215
Tomato 217

10.2 Miscellaneous commercial glasshouse plants 223

11 Diseases and Pests of Vegetable Crops
11.1 General diseases and pests 225
11.2 Specific crops
Broad Bean 227
Beet 228
Brassica crops 228
Carrot 233
Celery 235
Lettuce 236
Mint 238
Onion 238
Pea 240
Spinach 241
Tomato (outdoor) 241
Watercress 242

12 Disease and Pest Control in Ornamental Plants and Turf
12.1 Disease control 243
12.2 Pests 256

APPENDIXES

1 Properties of Insecticidal and Fungicidal Chemicals 275
2 Amounts of Formulation in terms of a.i. 287

Index of Scientific Names 288
General Index 295

CHAPTER I

THE BIOLOGICAL BACKGROUND

Agricultural and horticultural practices aim to establish reasonably uniform crops over relatively restricted areas. These conditions provide a potentially favourable environment for the development of pest and disease epidemics. But many other factors play their part both in determining the likelihood of an attack and the rate at which the infestation or infection may increase and become of economic significance. The influence of these factors depends to a large extent on the biology of the insects and disease organisms concerned, and varies greatly from one to another. An appreciation of the interreactions of these factors is essential if control measures are to be effective. The various recommendations given in later chapters of this book have been determined with the biological background of the pest or disease concerned constantly in mind.

The approach to pest and disease problems is essentially different, and hence the two parts of this chapter have been treated separately. When insects become pests on crop plants, they can be readily seen and destroyed: if an attack cannot be entirely prevented it can often be cured. On the other hand a disease only becomes apparent when the symptoms on the plant indicate that the pathogen is already established within it: prophylactic methods of control are therefore necessary and prevention rather than cure is a more practical possibility.

PESTS

1.1 INSECT LIFE HISTORIES

Most insect species lay eggs although, in certain groups, living young may be produced at some stage in the life cycle. Young insects hatch from the egg in several ways; for example, the young of moths and butterflies eat their way out while many of the grasshoppers, crickets and related forms apply pressure to the egg from within by an everted, blood-filled sac behind the head; many other insects break through the egg with a spine which is an outgrowth from the cuticle of the head. The newly-hatched insect is outwardly different from the adult and becomes successively closer to the adult form by a series of moults during each of which the old, tight skin is cast off leaving the insect with a new skin previously secreted below the old one.

There are two major divisions in insect classification depending on the degree of transition which occurs between the immature and mature forms. In the first, the newly hatched insect is similar to the adult but has undeveloped reproductive organs and wings. Immature stages are known as nymphs and increase in size by a number of moults until they become adults. The new skin is soft but soon hardens. Growth in size therefore only occurs on moulting. During this period of growth the genitalia and wings develop, becoming functional when the insect reaches maturity. The well-known aphids typify this form of development and adults and nymphs at all stages can often be seen on an infested plant. The other type of transition occurs in insects such as moths and butterflies, beetles and two-winged flies where the juvenile form is a larva which differs fundamentally from the adult, usually having different mouthparts and a totally different feeding habit. When the larva is fully grown it changes to the adult form by passing through a physically quiescent but physiologically active stage, the pupa or chrysalis.

In the first group, the insects which feed on plants do so both in the adult and nymphal stages. For example, aphids at all stages of growth may be found feeding on plum (A.L. 34) and apple (A.L. 106, 187), soft fruit (A.L. 176), beans (A.L. 54), brassicae (A.L. 269) and lettuce (A.L. 392). Thrips feeding on peas (A.L. 170) and capsids on fruit trees (A.L. 154) are also included in this category.

In the second group most plant destruction and damage occurs as a result of feeding by the larval stages. Caterpillars of moths and butterflies are voracious feeders, larvae of codling moth feed inside apples (A.L. 42), cabbage caterpillars on brassicae (A.L. 69) and cutworms (A.L. 225) on the roots and shoot bases of various plants. Among the beetles, Colorado beetle larvae attack potato foliage (A.L. 71), raspberry beetle larvae feed inside the developing fruits of raspberries and loganberries (A.L. 164), wireworms or larval click beetles feed on the underground parts of such plants as cereals and potatoes (A.L. 199) and grain weevil larvae destroy individual cereal grains by feeding within them (A.L. 219). Among the two-winged flies, cabbage root fly larvae feed on brassica plants especially plants in the seedling stage (A.L. 18); larvae of carrot fly (A.L. 68), celery fly (A.L. 87) and onion fly (A.L. 163) feed on appropriate vegetables while wheat bulb fly larvae (A.L. 177) and frit fly larvae (A.L. 110) are common pests of grain crops. A general feeder on roots is the larval crane fly or leatherjacket (A.L. 179). The larvae of narcissus flies feed in daffodil and narcissus bulbs (A.L. 183), and secondary rots frequently destroy the bulbs. Among adult insects in this group, beetles and weevils frequently feed on plant tissue. Weevils feed on pea, bean and clover plants (A.L. 61), apple blossom (A.L. 28) and grain (A.L. 219), Colorado beetles destroy potato foliage (A.L. 71) and flea beetles eat holes in seedling brassica and other leaves (A.L. 109). Other insects worthy of mention are wasps which damage ripe fruit (A.L. 451) and leaf-cutter bees which do not feed on plant tissue but make their nests of segments of leaves.

Of the other creatures which are allied to insects, those which damage plant growth include millepedes, symphylids and spider mites; slug and nematode damage also falls within the province of the entomologist. Millepedes (A.L. 150) at all stages in the life cycle feed on vegetable matter such as roots, bulbs and tubers and they are often abundant at the sites of primary damage caused by other pests such as slugs. Symphylids (A.L. 484) most commonly attack glasshouse crops such as tomatoes, cucumbers and lettuce, feeding on the root systems until the plants wilt and die. Red spider mites are most destructive, feeding on glasshouse crops (A.L. 224) and also attacking outdoor crops especially when the weather is hot and dry (A.L. 226). The mites suck sap from leaves and sometimes spin webs over the foliage causing it to wither and die.

1.2 DESTRUCTIVE INSECTS

The foregoing paragraphs show that insect damage to crops is mainly associated with feeding, and reference must now be made to various types of feeding. Some insects feed by chewing plant tissue and others by sucking sap from the plant. Secondary damage occurs when waste products such as excreta and honeydew spoil the produce.

(*a*) **Chewing insects** damage crops in many ways according to the form of the mouthparts and the part of the plant attacked. *Leaf eaters* include various caterpillars (A.L. 69) such as those of cabbage white butterflies, cabbage moths and diamond back moth (A.L. 195) which cut away and eat sections of leaf tissue. Adult weevils attack peas, beans and clover by eating U-shaped notches in the leaf margins, often considerably reducing the leaf area. *Stem borers* such as the larvae of frit fly and wheat bulb fly have the mouthparts reduced to a pair of hook-like organs which rasp away the internal conducting tissue of cereal plants. Shoots are frequently killed in this way and the crop loss is often extensive. *Miners* tunnel and feed between the upper and lower epidermis of the leaf. Damage is caused mainly when the plant is attacked in the seedling stage as in tomato (M.A.F.F. Bull. 77). On a crop of chrysanthemums (M.A.F.F. Bull. 92), leaves may be disfigured to such an extent that they must be removed before the flowers are sold. *Root-eaters* diminish the vigour of the plants by eating and severing the roots. Wireworms, cutworms and leatherjackets occur generally on farm and market garden crops. Clover weevils attack roots just below the soil surface often severing the main root, while pea and bean weevil larvae destroy root nodules. Some insects such as swede midges lay their eggs near the growing point of their host plants, and subsequent feeding by the larvae may destroy the shoot, causing such damage as blindness in cauliflowers. Many insects destroy fruits and seeds; blossom weevils lay their eggs in the flower buds of strawberries and then puncture the stalks so that the buds wither (M.A.F.F. Bull. 95). Raspberry beetles, codling moth and wasps have already been noted as other pests of fruit. Although insect damage to a plant may be relatively insignificant in itself, the damaged part of the plant often allows entry of disease organisms which cause the plant to decay or rot.

(*b*) **Sucking insects** have mouth-parts adapted for piercing plant tissue and sucking out sap. Within the needle-like proboscis, or beak, are two fine tubes through one of which saliva from the insect may pass into the plant and through the other sap from the plant into the insect.

In temperate areas of the world, great damage is done by aphids. Their capacity for rapid build-up on crops is brought about by the fact that they bear living young which results in a telescoping of generations and enables them to produce more generations in a year than exclusively egg-laying insects. Apart from the debilitating effect on the plant of large numbers of aphids feeding on the sap, otherwise profitable parts of the plant are often rendered unsaleable because of physical deformation or fouling by cast skins and honeydew. The latter is made up of the unused part of the sap which has passed through the aphid body and been ejected. Moulds grow freely on these sugary excreta which become even more objectionable.

Although the entry of fungi and bacteria into the punctures made by these insects can cause secondary damage, the greatest potential danger lies in the transmission of viruses by the aphids to the plants. Viruses such as raspberry mosaic, sugar beet yellows (A.L. 323), barley yellow dwarf and those which attack brassicas and potatoes (A.L. 139) are spread within and between crops by winged aphids. Virologists recognise two main types of virus, the persistent and the non-persistent. To acquire and transmit the former, an aphid must feed on an infected plant. The sap containing the virus passes from the plant into the insect gut. From here, the virus migrates to the salivary glands from where it can be injected with the saliva into a healthy plant when the insect is feeding. The migration of the virus from the gut to the salivary glands of the insect may take hours or even days. On the other hand, non-persistent viruses are easily acquired by the aphid merely probing within the epidermal cells of the plant, a common procedure before feeding commences. The virus is carried on the mouth-parts and is thus readily transmitted from one site to another in a few minutes.

The general effect of virus infection is to reduce the growth and yield of the plant and to reduce the vigour of the vegetative offspring.

1.3 USEFUL INSECTS

(*a*) **Pollinators.** Flower-visiting insects, including hive bees, are of great importance in the pollination of seed-producing crops and fruit. The use of insecticides when bees are working the crop can seriously reduce their numbers and possibly the yield of the crop. The residual effects of insecticides vary but it is usually safe for bees to work in an area forty-eight hours after an insecticide has been applied. Different formulations of the same insecticide, particularly chlorinated hydrocarbons, vary in their toxicity to bees. Some honeybee colonies are known to have developed a partial resistance to some insecticides, for example, chlordane, DDT and methoxychlor, but there is no evidence of resistance to others such as gamma-BHC, dieldrin, aldrin, heptachlor, malathion, parathion, and carbaryl.

(*b*) **Parasites and predators.** Insects become pests usually because they grow, feed and breed quickly on their host plants. Numbers usually fluctuate, a decline being generally associated with unfavourable weather factors such as cold or heavy rain over a period of time, a dwindling supply of food as the crop is progressively destroyed or becomes too small to support the rapidly increasing numbers of insects, or with the activities of insect enemies. The latter may be predators of the pest, using it as a source of food, or parasites which use the pest insect as food and shelter for their developing young. The interrelationships between pests and their enemies are complex and vary from example to example. But in general, as the pest insects increase in density, so the available enemies are able to find them more quickly, with the result that the populations of parasites and predators increase. Eventually there are so many individuals searching for prey that the pest numbers decline and shortly thereafter the parasites and predators are themselves restricted for want of hosts. Thus, many pest fluctuations may be due to the effect of their insect enemies, although it must be noted that often a pest insect can reach epidemic proportions before its enemies are sufficiently numerous to effect any worthwhile degree of control.

A good example of the value of predatory and parasitic insects can be seen on almost any large colony of aphids. Observation will show that ladybirds of various species eat these pests and also lay their eggs on the infested plants. When the larvae hatch they thrive on the ample food supply with which they are surrounded. Hover fly adults feed on nectar but lay their eggs on infested plants; the larvae move over the plant searching for aphids and may eat 400–500 before they pupate. Other larvae commonly found feeding on aphid colonies are those of certain midges and lacewings. In addition, minute wasps oviposit into aphids and the larvae feed on, and then pupate within, the host body. Parasitised aphids are easily recognised for they are swollen, shiny brown and attached to the plant by silk produced by the developing parasite. This is not the whole story for there are 'lesser fleas', hyperparasites which lay their eggs on the developing parasite larvae within dead aphids. These are obviously not useful insects inasmuch as they destroy the potentially valuable parasites.

1.4 CONTROL MEASURES

Any insect which destroys part of a pest population is exerting some measure of biological control; known pests can be influenced by the cultural operations imposed on the crop by the grower; an insect which is a pest in one country may be prevented from establishing itself in another by legislative action; finally, if an insect does increase in numbers to the stage when it is doing an economically significant amount of damage, it can usually be controlled by chemical means.

(*a*) **Biological control.** There have been cases where serious pest problems have been solved by the introduction of parasites and predators but these are relatively rare (about 20 cases in the last 50 years). In Britain, two pest insects may be controlled by parasites. Woolly aphid on apple trees is attached by the parasite *Aphelinus mali* (A.L. 187); parasitised aphids may be overwintered in cold stores and put out in the following early summer when the pest is beginning to build up. Those which over-winter in the open are unaffected by normal tar oil and DNOC, and early sprays of DDT, BHC, nicotine and lime sulphur have little effect on subsequent emergence of the parasites from their dead hosts. Once the parasites are active, however, insecticides have a lethal effect.

In glasshouses, the whitefly found on plants such as cucumbers and tomatoes may be controlled by the introduction of the parasite *Encarsia formosa*. The parasite attacks the immature stages of the whitefly and completes its life-cycle in approximately five weeks. As each parasite may lay up to 50 eggs, a severe whitefly infestation can be controlled in a few months. To ensure that the parasite does not die out, a small reservoir of whiteflies is kept by growing one or two plants which are attacked by whitefly but disliked by the parasite, e.g. Nicotiana.

More details of these and other examples of biological control can be found in M.A.F.F. Bull. 20, 'Beneficial Insects'.

(*b*) **Legislative control.** The Destructive Insects and Pests Acts, 1877–1927, form the basis of plant health legislation in Britain, the object being to prevent the introduction or spread of the more important foreign pests and diseases, and to minimise the planting of diseased material. Two examples will suffice to illustrate this aspect of control.

Colorado Beetle, which spread from the U.S.A. into Canada and thence to Europe in 1922 is not present in Britain. Despite stringent precautions at all ports and airfields, there is a potential danger of the importation of plants carrying larvae, pupae or adult beetles. Anyone finding this pest is required to inform the Ministry of Agriculture; if the presence of the insect is confirmed, control measures are undertaken at public expense, the Ministry's policy being completely to eradicate the infestation. During the years 1946–1952, a number of breeding colonies of beetles were found and subsequently exterminated. Since then, there have been no cases of infestations developing in the field although each year live beetles and larvae are intercepted on imported plants or foodstuffs.

Beet eelworm attacks sugar beet and can cause severe crop losses (A.L. 233). To prevent this happening on a large scale, the growing of susceptible crops on land known to be infested is prohibited under the Beet Eelworm Orders and the sale of plants grown on infested land is forbidden. A proper crop rotation does much to prevent a rapid build-up of this pest, and is the best possible insurance against trouble on farms where sugar beet is grown extensively.

(*c*) **Cultural control.** Crop rotations, normal farm management and hygiene, and the use of healthy planting material do much to prevent unnecessary losses due to insect pests. Other practices such as manuring and irrigation, which assist plants to grow strongly and healthily also help to prevent undue damage as a result of pest attack.

Cultivation of the soil at certain times of the year exposes many soil-living insects to predation by birds. Thus, populations of leatherjackets and wireworms can be reduced by birds following the plough in autumn and spring. Using the roller on crops attacked by wheat bulb fly restricts the ease with which the larvae move through the soil in search of host plants, may crush larvae within the stems and encourages tillering.

Changing an accepted sequence of cropping is often limited by practical considerations, but where heavy infestations of wheat bulb fly occur regularly, wheat should not be grown after a crop which provides the uncovered earth in July–September which is necessary for egg laying by the adult flies.

The rotation of crops is a normal practice and is essential to prevent the build up of eelworms which attack crops such as potatoes, cereals and bulbs.

Badly drained fields provide favourable habitats for slugs especially when the humus content of the soil is high. Damage consists of hollowing of cereal grains a short time after sowing, holing in plant stems, shredding of leaves, and irregular holes in tubers and roots. As these pests are difficult to control chemically, breeding sites and ideal conditions for the slugs should be minimised, for example by drainage.

Attention to the sowing date of a crop will often ensure that plants are not in a susceptible stage when a particular pest is ready to lay eggs. In areas where carrot fly is common, risk of infestation can be lessened by delaying sowing until the end of May. The crop will largely escape damage by the first generation, and the second generation of flies will be correspondingly smaller.

At the other end of the season, crops should not be left in the ground when they have completed their growth if they are susceptible to pest attack. For example, wireworms attack mature potatoes causing a serious reduction in quality. As this damage increases the longer the crop is left in the soil, lifting should begin as soon as possible after maturity is reached.

(*d*) **Chemical control.** There can be little doubt that the use of chemicals for the control of insect pests is of primary importance in agriculture, and later chapters in this handbook give details of the wide variety of crop pests which can be controlled with these materials.

It is inherent in a competent grower's technique that his normal management minimises the risk of insect attack as far as this is possible. His resort to chemical control means that additional money must be spent on the crop, but this may mean the difference between an economic return and a loss.

Earliest records of insect control refer to the use of materials which were so noxious to humans that their effects on insects were unquestioned. But by the second half of the nineteenth century, substances were being used which are still in use today; arsenical compounds were proving reliable against Colorado beetle and Gypsy moth in the United States of America and nicotine, which had been prepared for years as a simple infusion of tobacco leaves, effectively controlled such insects as aphids thrips and mites. In the 1920's pyrethrum, produced from the powdered flowers of the pyrethrum plant, entered the insecticide market for the first time. It was the principal insecticide of medical importance during World War II until 1942, when the use of DDT became widespread. But pyrethrum, because of its rapid paralysing effect on insects and its relative harmlessness to mammals, is still extensively used, especially in fly sprays. The other principal insecticide available prior to 1939 was derris, the ground root of species of the genera *Derris* and *Lonchocarpus*.

Since 1945, the number of synthetic organic insecticides available for agricultural and horticultural use has increased enormously, and the two main groups which we shall consider are the chlorinated hydrocarbons such as DDT, and the organophosphorus insecticides such as parathion. DDT, probably the best-known of the chlorinated hydrocarbons, was developed during the early 1940's and used mainly against disease-carrying insects: it was immediately successful because of its effectiveness at very low concentrations and to its usefulness against a wide range of insects. Its introduction was rapidly followed by the discovery of the high insecticidal activity of such compounds as aldrin, dieldrin, gamma-BHC and others of the chlorinated hydrocarbon group.

The general action of the chlorinated hydrocarbons depends on the insects eating treated vegetation or walking over a deposit of the insecticide applied to the plant or other surface. To be effective, careful application is required to ensure that the feeding site, or the area over which the insect will walk is covered with insecticide.

Phosphorus compounds are used extensively as insecticides. They are inhibitors of enzymes which occur in insects, particularly in the tissues of the nervous system. The actual chain of events by which an insect is killed is not completely clear but the nervous system is certainly damaged beyond recovery. In general, organophosphorus insecticides such as parathion act very rapidly but they are not so persistent as chlorinated hydrocarbon insecticides. In this respect, and to a certain extent, they are useful in that they overcome the problem of residues which remain active for a long time, either in the soil or the plant.

Several of these insecticides are systemic, that is, they are absorbed into the sap stream of the plant. The insecticide may be applied as spray or granules to the soil from which it is taken up by the plant roots, or by spraying the plant, when it is absorbed through the leaves. Sap-feeding insects, for example aphids, are more readily killed by systemic insecticides than by those which have a contact action. Parasites and predators are not affected unless they come into contact with the insecticide, that is, if the plants are sprayed.

Many insecticides of this type are potentially dangerous to man, having a damaging effect on the nervous system, but some are now available such as malathion, menazon and trichlorphon, which have a reduced toxicity to man while still being effective against insects.

1.5 ECONOMICS OF TREATMENT

From the foregoing sections it is apparent that insects attack a large number of crop plants and that vast sums of money may be spent annually in attempts to control them. Quite casual observation may show that damage is occurring but intensive work is necessary to show the extent of the damage, either in terms of loss of crop or lowering of profit obtained from selling the produce. The majority of the estimates of crop losses quoted early in this century were made as a result of intelligent observation by field entomologists. More recent work has aimed at determining these losses by critical field experimentation followed by systematic survey work. Crop losses may be expressed as the average loss of crop in a particular year, or the area of land equivalent to that from which the entire crop was lost, or in terms of financial returns. The last is the most difficult to evaluate because prices fluctuate with the supply/demand ratio, and when a commodity is scarce it is more expensive than when it is freely available. Thus, a fifteen percent loss of crop might not lead to a proportionate drop in income from that crop.

A further difficulty which applies to all loss assessment is that although the individual effects of various pests and diseases of a crop may be determined, they may not be additive. Thus, an estimated loss of crop due to attacks by several pests may be much greater than the actual loss. In addition, the compensating factor which results in healthy plants adjacent to dead or dying ones giving more than the average yield can upset predictions of loss of yield. If a crop of uniform size is required for some particular market the last factor can be of importance.

When the economic aspects of crop loss are being considered the over-riding question is whether the value of the extra crop to be expected as a result of pest control is greater than the cost of chemicals and applications. On quality crops such as fruit, protection is nearly always worthwhile for the slightest blemish reduces the quality rating on the open market and the value is correspondingly decreased. On the other hand, there is little point in protecting fodder crops from insect attack unless this results in a substantial increase in yield. Between these extremes comes a host of problems associated with the limits to which pest control should be taken. One insecticidal application may give only 70 percent control of a pest; is it worthwhile making a second application to control a further 20 percent, and another to obtain almost complete control? Definite answers to such questions relating to specific pests and crops are difficult to give, mainly because there are few results available of actual damage assessment. Obviously too, conditions from field to field, and season to season vary enormously. Usually, the grower relies on his experience, or that of his advisers, in deciding whether and when to spray. But often by the time an insect has reached pest status, the damage to the crop has been done. For example, by the time colonies of wingless aphids are noticed feeding on crops, their winged parents have possibly spread virus to several localities in the area. Extensive work on the relationship between cabbage aphid attack on Brussels sprouts and yield has indicated that early infestations of a few aphids per plant are responsible for as much damage as that caused by the large numbers of aphids seen on plants during August and September. Obviously, early spraying, when the grower may not even be aware of the presence of the pest, is worthwhile in many cases. It has been estimated too, that frit fly damage to oats causes an annual loss in the region of £10 million, but about half the loss is caused by low pest densities which it is not economic to control.

Alternatively, it has been shown experimentally that an insect attack which looks dangerous may be causing little damage; extensive defoliation