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Chemical control in integrated pest management

Introduction

Over the last decade, global demand for pesticides has continued to grow (Fig. 1.1), although in Europe in particular some governments have adopted policies to limit their use. The restrictions have been in response to public perception of the risks associated with pesticide use in terms of residues in food and adverse effects on the environment. The perception is based erroneously on three false premises (Van Emden and Peakall, 1996) that good crops were obtained in an ideal pre-pesticide era, that chemicals like pesticides never occur in nature, and thirdly that these unnatural pesticides are causing an increase in cancer. In practice, plants contain many chemicals which are highly toxic. For example cyanide in cassava has to be removed by careful food preparation.

Without modern technology (including the use of pesticides) tripling world crop yields between 1960 and 1992, an additional 25–30 million square kilometres of land would have had to be cultivated with low-yield crops to feed the increased human population (Avery, 1997). Clearly, use of pesticides plays an important role in optimising yields. Modern technology is changing and many of the older pesticides, such the persistent organochlorine insecticides, are no longer registered for use as newer more active or selective chemicals take their place. At the same time, the agrochemical industry has invested in biotechnology and seed companies to exploit use of transgenic crops.

However, the growing of genetically modified crops has also aroused considerable public concern (Hill, 1998) and demands for legislation to control their use. While in many cases the transgenic crop is marketed on the basis that less pesticide will be used, other transgenic crops are associated with the application of particular herbicides, notably glyphosate used with 'Roundup Ready' crops. At present, single gene transfer often provides resistance to only one type of pest, thus the gene for *Bacillus thuringiensis* (Bt) toxin is effective against certain lepidopterous pests, but other insect groups may still have an

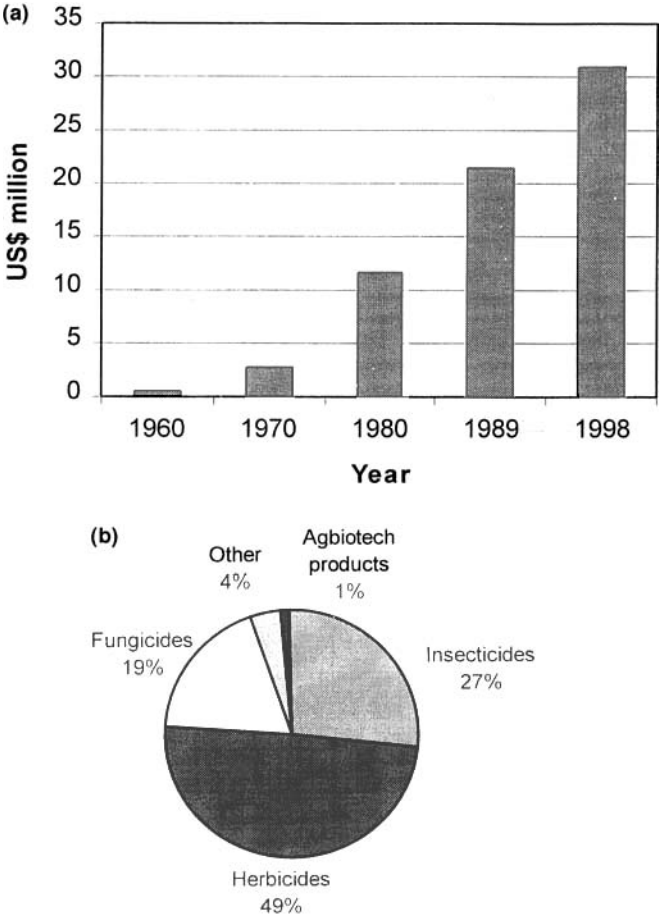


Fig. 1.1 (a) Increase in World Market for pesticides in US$ billion. (b) 1998 World Market for pesticides showing proportions of different types.

adverse effect on a crop and require an insecticide treatment (Hilder and Boulter, 1999). Furthermore, it has been quickly appreciated that pests resistant to the toxin in transgenic plants can be selected as occurs with overuse of a chemical pesticide, so the new varieties have been introduced with insecticide resistance management strategies (Merritt, 1998). The planting of genetically modified plants is therefore similar to use of new varieties from traditional plant breeding, and in relation to pest management their availability provides another tool to be integrated in the cropping programme.

Despite the criticisms of pesticide use, farmers will continue to need to apply them, because chemical control remains the most cost effective and rapid way of combatting the effects of weed competition and crop loss due to pathogens and insect pests. Our knowledge of the chemistry and suitability of an increasingly wide range of pesticides can now provide a more rational approach to their use and avoid the adverse outcomes associated with extensive use of the persistent organochlorines and the highly toxic organophosphate insecticides. International efforts have improved registration, and pesticides now commercially available have been rigorously evaluated with greater harmonisation of test procedures. Unfortunately, in many countries, especially in the less developed areas, farmers have inadequate training and too often use the least expensive pesticide, irrespective of its suitability for the pest situation; it is also frequently highly toxic, but the farmers do not have the appropriate protective clothing. In consequence, farmers in some areas have applied too many pesticide treatments and suffered economically and with poor health.

Modern farming practices have more intensive production of relatively few crops over large areas, while more traditional farming practices in tropical countries have a sequence of crops that provide a continual supply of food for polyphagous pests. Both these farming systems provide environments for pest populations to increase to such an extent that crop losses will occur unless control measures are implemented. Whereas these losses can be extremely serious and can result in total loss of a crop in some fields, for example the effect of an invasion of locusts or armyworms, the extent of damage is usually far less due to the intervention of natural enemies.

Considerable efforts have been put into training by means of farmer field schools, especially in relation to lowland irrigated rice production in South-East Asia in an attempt to get farmers to recognise the importance of natural enemies. The difficulty for the farmer is knowing when a pest population has reached a level at which economic damage will occur, so that preventative action can be taken. This decision should take into account the presence of natural enemies, but sampling for these can be quite time-consuming. Conservation of natural enemies is crucial in minimising the need for any chemical control, especially in the early vegetative stages of crop development. Areas with alfalfa or other fodder crops may provide a refuge for natural enemies, thus in Egypt berseem clover assists the overwintering survival of lacewings which are important predators of cotton pests. However, the farmer will need a pesticide when quick action must be taken to avoid economic crop loss. Various methods of assessing pest populations are used to assist farmers to determine when a pesticide may be applied as part of an integrated pest management programme.

Integrated pest management (IPM) utilises different control tactics (Fig. 1.2) in a harmonious manner to avoid, as far as possible, undesirable side effects on the environment. To many this means avoiding the use of any chemical pesticide and growing crops organically, but in many cases such a system is not sustainable where high yields are required. In some situations, the public will pay a premium for organic produce, but yields and quality are generally lower in comparison with crops receiving minimal intervention with chemical control.

Weeds are frequently the most important factor during crop establishment

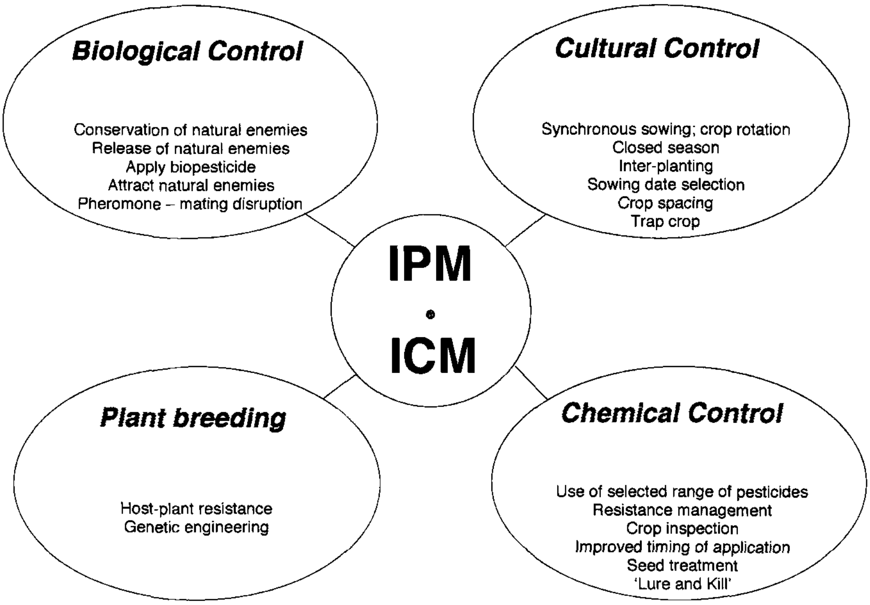


Fig. 1.2 IPM/ICM – the need to integrate different techniques.

at a time when demands for farm labour are high. Traditional hand weeding is very labour intensive and often not very effective, while general disturbance of soil by cultivation can increase erosion of some soils. Virtual weed-free conditions are possible with the range of herbicides now available, and on some well structured soils it is no longer necessary to plough every year as seed can be direct drilled after applying a broad action herbicide that is inactivated on contact with the soil.

Herbicide use has increased most where labour costs are high, there is a peak labour demand, or where mechanical hoeing will cause damage to the young crop. In conjunction with other agronomic practices such as tie ridging and planting along contours, herbicide use can reduce soil erosion by minimizing soil disturbance. Improved row weeding either by hand hoeing or by application of a herbicide increased yields by up to 35% in West Africa (Carson, 1987). With changes to direct seeding of rice and other factors, there is therefore an expectation that herbicide usage will increase in many crops in the tropics where traditional labour is no longer readily available for hand weeding or hoeing.

Wherever possible, farmers will select disease-resistant cultivars to reduce the need for fungicide treatments, but in some situations the farmer will continue to grow varieties which are susceptible to particular pathogens because of other qualities, such as taste and yield. The extensive damage to potato crops due to *Phytophthora infestans* that led to the Irish famine can be avoided by careful use of fungicides. The risk of selecting strains resistant to the fungicide can be reduced if the number of applications is restricted by monitoring climatic conditions so that treatments can be timed to coincide with periods favourable to the pathogen. Field application of fungicide will often improve fruit quality at harvest and allow longer storage.

The visibility of an insect is in no way related to the amount of damage and economic loss that can occur. Often farmers react to the presence of a low population of insects and may fail to distinguish between pest and beneficial species. The intervention of predators and parasitoids will often suppress a pest population such that economic damage is avoided. Thus, precipitate action with insecticides, especially those with a broad spectrum of activity, often disrupts this biological control too early in the crop, and in the absence of natural enemies, pest populations can increase dramatically. Furthermore, plants have evolved to withstand considerable damage due to insects by compensatory growth and production of chemicals toxic to the pests. Thus in integrated pest management programmes (Matthews, 1984; Van Emden and Peakall, 1996) pesticide use should always be confined to when a pest population has exceeded an economic threshold. The difficulty for the farmer is knowing when that economic threshold has been reached and then being able to take rapid action with minimal disruption of beneficial insects.

Pesticides

Thirty years ago Smith (1970) pointed out that despite intensive research into alternative methods of controlling pests, pathogens and weeds, pesticides remain our most powerful tool in pest management. This is particularly true when rapid action is needed. Southwood (1977) stressed the need to conserve pesticides as a valuable resource and reduce the the amount of chemical applied and the number of applications, to decrease the selection pressure for resistance, prolong the useful life of each pesticide and reduce environmental contamination. Over twenty years later, these comments remain true, even though much emphasis has been given to the development of transgenic crops. Pesticides will therefore continue to be an important part of integrated pest management programmes. There is, however, a greater realisation that pest management is only part of the wider requirement of integrated crop management, as investment in controlling pests can only be economic if there are sufficiently high potential yields. In practice, those marketing the produce (the supermarkets and food processing companies), are having a greater influence on pesticide use by insisting on specific management programmes.

Integrated crop management

Before the widespread availability of chemical pesticides, farmers had to rely first and foremost on the selection of cultivars resistant to pests and diseases. Unfortunately, not all resistant cultivars were acceptable in terms of the harvested produce due to bitter taste, poor yield or some other negative factor. Farmers therefore adopted various cultural techniques, including crop rotation, closed seasons with destruction of crop residues, intercropping and other practices, to mitigate pest damage. Biological control was also an important factor in supressing pest populations, but many of these basic techniques were forgotten due to the perceived convenience of applying chemical controls. The use of modern methods of manipulating genes in transgenic crops merely speeds up the process of selection of new crop cultivars. Whether they will provide a sustainable system of crop production has yet to be demonstrated. As indicated earlier, the introduction of the Bt toxin gene into plants will increase the mortality of certain lepidopterous pests, but it will not affect many other important insect pests and its effect on lepidoptera could be short-lived if insects resistant to Bt are selected.

Even partial plant resistance to a pest is important. As Van Emden (1972) pointed out, only half the dosage of the selective insecticide pirimicarb was required on plants with slight resistance to the cabbage aphid *Brevicoryne brassicae*. With the lower dosage of insecticide, the natural enemies were unaffected and controlled any of the pests that survived. In some crops, particularly those in glasshouses, the use of a low dosage of a non-persistent insecticide can be followed by release of natural enemies (GreatRex, 1998). A classic example is the application of resmethrin or the biopesticide containing the fungal pathogen *Verticillium lecani* to reduce whitefly *Trialeurodes vaporariorum* populations before the release of the parasitoid *Encarsia formosa*. This is important where light intensity and temperature are unfavourable to *Encarsia* early in the season (Parr *et al.*, 1976; Hussey and Scopes, 1985).

Area-wide IPM

Individual farmers can adopt an IPM programme, but increasingly many of the control tactics need to be implemented on a much larger scale. A farmer can choose a resistant cultivar, monitor the pest population and apply pesticides if the pest numbers reach economic significance, and subsequently destroy crop residues harbouring pests in the off-season. A good example has been in Central Africa, where cotton farmers grow a pubescent jassid resistant variety (Parnell *et al.*, 1949), time insecticide applications according to crop monitoring data (Tunstall and Matthews, 1961; Matthews and Tunstall, 1968), then uproot and destroy their cotton plants after harvest and bury crop residues by ploughing. Detailed recommendations were provided to farmers via a crop manual which has been updated frequently to reflect the availability of different varieties, and changes in insecticides. However, many tactics are only effective if all farmers within a defined area adopt them. A feature of the Central African programme has been a nationally accepted restricted list of recommended insecticides, discussed below in the next section. In Egypt, the use of pheromones was adopted on a national scale.

The selection of control techniques and their subsequent regulation throughout a given area or ecosystem, irrespective of county or national boundaries, is regarded as pest management. A distinction is made between the use of integrated control by individuals and pest management implemented co-operatively by everyone within the area. Pest management may give emphasis to one particular control technique, but in general there will be reliance on its harmonisation with other tactics. Furthermore, it must be a dynamic system requiring continual adjustment as information on the pest complex and control tactics increases. Modern information technology with computer databases, the internet and 'expert' systems can provide up-to-date information to farmers and their advisers.

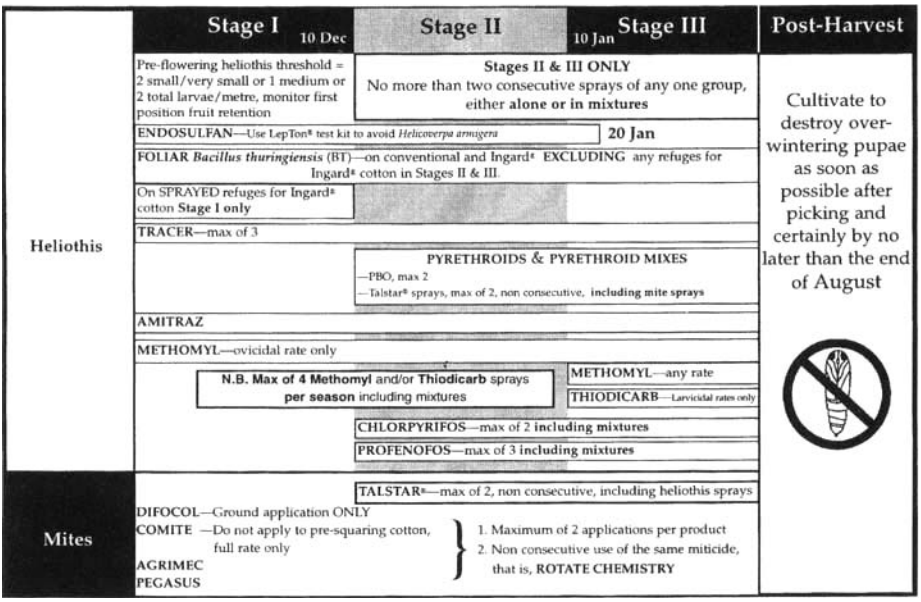
Resistance to pesticides

The agrochemical industry has become more concerned about the impact of pesticide resistance and has recognised the role of IPM in reducing selection of resistant populations (Urech *et al.*, 1997). Efforts have been made to devise resistance management strategies, and to avoid disasters such as the cessation of cotton growing in parts of Mexico and Australia due to DDT resistance. Selection for resistance occurs if a particular chemical or chemical group is applied too frequently over a period to a given pest population. Initially, the impact of resistance was noted in glasshouses with a localised population, but resistance of red spider mite to organophosphates was also apparent on outdoor irrigated vegetable crops in the tropics where the same acaricide had been used throughout the year on different crops. Thus, resistance develops rapidly if most of a pest population is exposed to a specific pesticide, if the pest can multiply quickly, or if there is limited immigration of unexposed individuals. The user is tempted to increase either the dosage or the frequency of application, or both, if control measures are unsatisfactory, but this increases the selection for resistance.

Resistance selection is reduced if part of the pest population is on alternative host plants or other crops which are not treated with the same chemical. Thus, in introducing transgenic crops with the Bt toxin gene, a proportion of non-Bt crop is required as a refuge. Resistance to insecticides by the cotton bollworm *Helicoverpa armigera* has not been a serious problem in Africa, where large areas of maize and other host plants are untreated. However, in West Africa resistance to deltamethrin has now been reported, and this may be because farmers are using pyrethroids increasingly on vegetable crops in the same locality. Major problems of resistance in *H. armigera* have occurred in India and China where farmers have applied pyrethroids extensively with knapsack sprayers. Spray directed downwards from above the crop canopy was poorly deposited where the bollworms were feeding on buds, and in consquence lack of control led farmers to repeat treatments at frequent intervals. The continued exposure of larger larvae to pyrethroid deposits without significant mortality quickly led to resistant populations.

Unfortunately, the situation has been exacerbated by the availability of a number of generic insecticides with different trade names, but often based on the same or similar active ingredient; thus when the farmer thinks he may have changed to a different pesticide, in reality, the same pesticide is applied.

In Australia, the onset of pyrethroid resistance led to the introduction of a pragmatic resistance management strategy, which limited the application of any pyrethroid insecticide to a brief period each year irrespective of the crop. The original programmes have become more refined depending on the cropping practices in a given area, and generally there should be no more than two sequential sprays of any chemical group (Fig. 1.3) (Harris and Shaw, 1998). Where two bollworm species occur in the same area, a monoclonal antibody test has been used to check the percentage of *H. armigera* in the population which is likely to be resistant to pyrethroid insecticides.



Pre-flowering heliothis threshold = 2 small/very small or 1 medium or 2 total larvae/metre, monitor first position fruit retention

Stages II & III ONLY
No more than two consecutive sprays of any one group, either **alone or in mixtures**

ENDOSULFAN—Use LepTon® test kit to avoid *Helicoverpa armigera*

FOLIAR *Bacillus thuringiensis* (BT)—on conventional and Ingard® EXCLUDING any refuges for Ingard® cotton in Stages II & III.

On SPRAYED refuges for Ingard® cotton **Stage I only**

TRACER—max of 3

PYRETHROIDS & PYRETHROID MIXES
—PBO, max 2
—Talstar® sprays, max of 2, non consecutive, **including mite sprays**

AMITRAZ

METHOMYL—ovicidal rate only

N.B. Max of 4 Methomyl and/or **Thiodicarb** sprays **per season** including mixtures

METHOMYL—any rate

THIODICARB—Larvicidal rates only

CHLORPYRIFOS—max of 2 **including mixtures**

PROFENOFOS—max of 3 **including mixtures**

TALSTAR®—max of 2, non consecutive, including heliothis sprays

DIFOCOL—Ground application ONLY
COMITE —Do not apply to pre-squaring cotton, full rate only
AGRIMEC
PEGASUS

1. Maximum of 2 applications per product
2. Non consecutive use of the same miticide, that is, **ROTATE CHEMISTRY**

Cultivate to destroy over-wintering pupae as soon as possible after picking and certainly by no later than the end of August

Fig. 1.3 Example of resistance management of insecticides on cotton in Australia.

Apart from the temporal control for pyrethroid insecticides, in Zimbabwe a spatial resistance management programme has been adopted for acaricides, whereby a particular type of acaricide may be used for only two seasons in one of three zones (Anon, 1998). The acaricides are rotated around the zones over a 6 year period (Fig. 1.4). In each of these resistance management programmes, the aim is to avoid a pest population being exposed too long to a particular pesticide. The alternative approach of using a mixture of pesticides, or adding a synergist such as piperonyl butoxide with pyrethroids, generally has limited value as insects are likely to become resistant to all the components

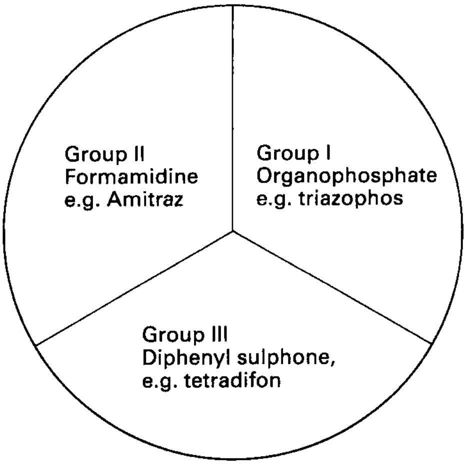


Fig. 1.4 Idealized acaricide rotation scheme based on system used in Zimbabwe (updated from Duncombe, 1973).

of the mixture. Whatever strategy is adopted, careful monitoring of levels of resistance in different localities is needed so that appropriate changes can be made to the strategy when needed.

Fungicide resistance

There is a similar problem with fungicides, in that if a chemical with a particular mode of action is used repeatedly, resistant strains of the fungi will be selected. Reduced dosages of fungicides showed significant selection for resistance to demethylation inhibitor (DMI) fungicides (Metcalfe *et al.*, 1998), and that the strength of selection varied with fungicide, position of infection in the crop canopy and position on individual leaves. Clearly, with variations in deposits within a canopy and degradation of deposits, fungi will be exposed to low dosages of fungicide. Thus selection needs to be minimised by better disease forecasting so that fewer applications are required and those needed can be timed more accurately. Making sure the optimum dosage reaches where the infection is within the canopy is clearly most important. Assays have been developed for use in sensitivity monitoring schemes to help decide on future treatments; thus, Cooke *et al.* (1998) used a zoospore motility assay to test sensitivity of fluazinam to isolates of potato blight (*Phytophthora infestans*).

Herbicide resistance

Changes in the weed species often follow frequent use of a herbicide in one particular area, as the species tolerant to the chemical can grow without competition. This has resulted in the need for different and often more expensive herbicides or a combination of herbicides. Resistance to a particular herbicide may become evident more slowly than to insecticides or fungicides, because the generations of weeds overlap due to dormant seeds and there are fewer generations each year, but development of resistance to certain herbicides is already evident (Heap, 1997). In particular, there is resistance to the triazines, acetolactate synthase- or actyl CoA carboxylase-inhibitors due to mutated target sites (Schmidt, 1997). Some grass weeds have multiple resistance to herbicides with different modes of action. As an example, resistance of black grass (*Alopecurus myosuroides*), first detected in 1982, now affects over 700 farms in the UK (Moss *et al.*, 1999). Similarly, resistant wild oats was found on 65 farms. The problem has shown up on farms with many years of continuous winter wheat production (Orson and Harris, 1997).

Timing of spray application

One of the major problems of using pesticides is knowing in advance what pesticide and how much of it will be required during a season. To facilitate forward planning some farmers may prefer a prophylactic or fixed calendar schedule approach, but to minimise pesticide usage it is preferable to restrict treatments and only apply them when crop monitoring indicates a definite need. Forecasting pest incidence is an important means of improving the efficiency of timing applications, but is not always very accurate due to variations in weather conditions and survival of a pest population from the previous season. However, growers of sugarbeet in the UK have benefited from the virus yellows warning scheme (Dewar, 1994). Modelling of the incidence of virus yellows has shown that over the last decade, up to five severe epidemics could have occurred since the major epidemic in 1974 (Fig. 1.5) if improved pest management practices had not been adopted (Werker *et al.*, 1998). Short term prediction of the potential for a disease outbreak based on weather forecasts can be useful for some diseases, for example where the temperature has to exceed a certain minimum coincident with high humidity and/or leaf wetness. Mini-meteorological stations can be set up to measure the conditions in crops sensitive to certain pathogens.

Economic thresholds

Ideally conservation of natural enemies would reduce the need for farmers to use any insecticides, but where climatic conditions and cropping practices result in a build-up of pest populations, quick action is needed to prevent economic losses. The actual loss of a crop will depend on when the pest infestation occurs during crop development and its severity. Often a crop can sustain some pest damage if there is sufficient time for plants to respond and compensate for the damage. The problem for farmers is deciding when action

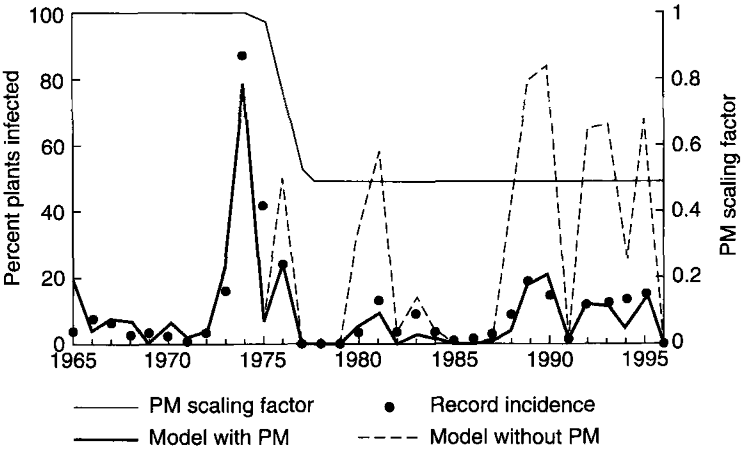
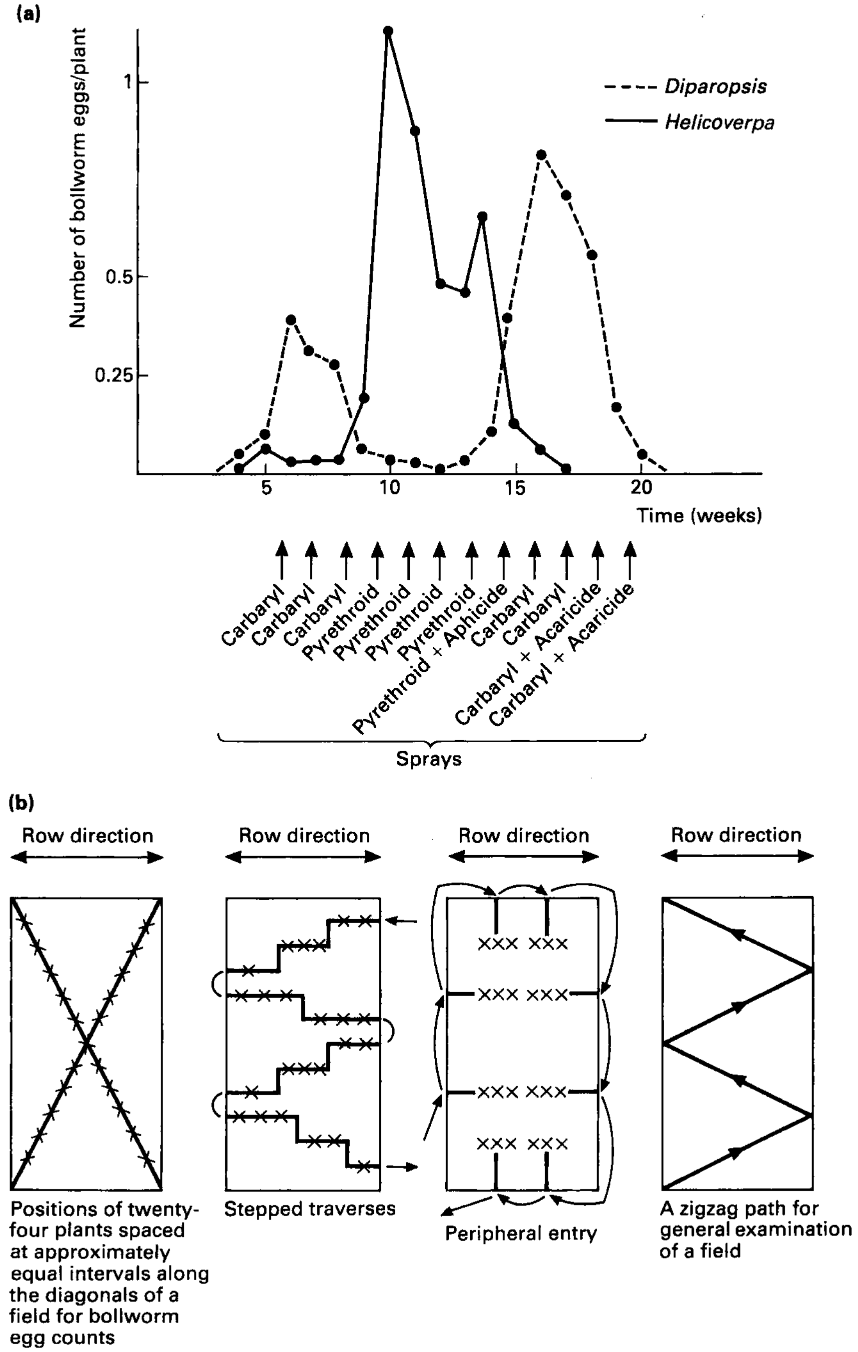


Fig. 1.5 Incidence of infected sugar beet and predicted levels as shown by model to indicate impact of integrated pest management.

has to be taken. One aspect of IPM is to use an economic threshold, defined as the population density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level. This economic injury level is the lowest population density that will cause economic damage (Stern, 1966; Onstad, 1987; Pedigo *et al.*, 1986). Changes in the market prices of crops make it very difficult to be precise about economic thresholds, so based on past experience farmers may have to follow a more pragmatic 'action threshold'. In some countries, farmers can employ independent crop consultants who will inspect fields and advise when chemical control is needed. However, in most situations it is the farmer who has to decide, so simple techniques of monitoring pest populations and/or damage are needed if the number of chemical treatments is to be minimised.

Timing of spray applications on cotton in relation to pest populations has been possible by using sequential sampling methods to reduce the time needed examining plants in the field (Fig. 1.6). The system allows a decision to spray if the population exceeds a set threshold even if the whole field has not been sampled, but generally requires sampling to continue if low populations are present. To simplify the crop monitoring, pegboards were developed (Beeden, 1972; Matthews, 1996a), the design of which has been adapted in different countries according to which pests are dominant and whether sampling considers the presence or absence of natural enemies. While it is important to avoid a spray treatment if large numbers of predators, such as lacewings, are present, natural enemies are generally less easy to detect.

In assessing whether to spray cotton, scouting for bollworm eggs (Fig. 1.7) has been advocated, as it is important to control first instar larvae, between the time eggs hatch and when larvae enter buds, to minimise the dosage of



Positions of twenty-four plants spaced at approximately equal intervals along the diagonals of a field for bollworm egg counts

Stepped traverses

Peripheral entry

A zigzag path for general examination of a field

Fig. 1.6 (a) Timing of spray treatments on cotton, based on crop monitoring of bollworm eggs in Central Africa (updated from Matthews and Tunstall, 1968). (b) Sampling schemes for eggs in a cotton crop.

Fig. 1.7 Pegboard for small scale cotton farmer to record insect pests.

insecticide required. Once bollworm larvae are inside buds or bolls they are well protected from insecticide deposits, and to kill larger larvae requires a much larger amount of chemical. This same principle applies to most pests that attack the fruit and stems of crop plants. However, those advocating biological control prefer a delay until larvae are seen, as some eggs may not be viable or could be parasitised. This dilemma, whether to spray or wait, emphasises the importance of research in a particular area to assess the extent of biological control at different stages of crop development. Generally, if the 'action threshold' has been set correctly, insecticide is applied only when a pest infestation is no longer checked by natural controls and intervention is essential to avoid crop loss.

Other sampling systems have been devised depending on the crop and pest. Pheromone traps provide a selective and effective way of sampling low pest densities to determine whether an infestation is likely. At higher pest populations the trap data are less reliable, but trap use only indicates when pests are active and crops need to be monitored. Similar sticky traps, or traps with a food attractant, may be more appropriate for certain pests. Some scientists have suggested timing of treatments based on crop damage assessments, but it is likely that it is too late to justify an insecticide treatment when damage is observable. As an example, control of an insect vector of a viral disease requires action at very low pest populations, before the symptoms of disease can be seen, although reduction of further spread of an infection may be checked by a late treatment.

Application sites and placement

A key issue is the risk of 'spray drift' beyond the field boundary, especially if there is another crop susceptible to a herbicide, there is surface water or a ditch which could be contaminated by the pesticide (Croxford, 1998), or there are bees downwind of insecticide-treated fields. Protection of hedgerows around fields is also of crucial importance to avoid contaminating the habitat of important populations of natural enemies. Field boundaries are also important habitats for game birds and conservation of other wildlife (Oliver-Bellasis and Southerton, 1986; Forster and Rothert, 1998; Boatman, 1998) (Fig. 1.8). To minimise the risk of drift, some countries now have a legal requirement for a 'no-spray' or 'buffer' zone around fields or at least along the downwind edge of a field and to protect surface water (Van de Zande *et al.*, 2000) (Fig. 1.9). The width of the untreated buffer zone really depends on the spray droplet spectra, the height of release of the spray and wind conditions. To simplify the procedure some countries have fixed distances downwind from the field boundary; thus in the UK the unsprayed buffer zone (UBZ) has been set at 5 metres between the side of a ditch or watercourse and the edge of an arable crop, and 18 metres in orchards. However, following concern about the

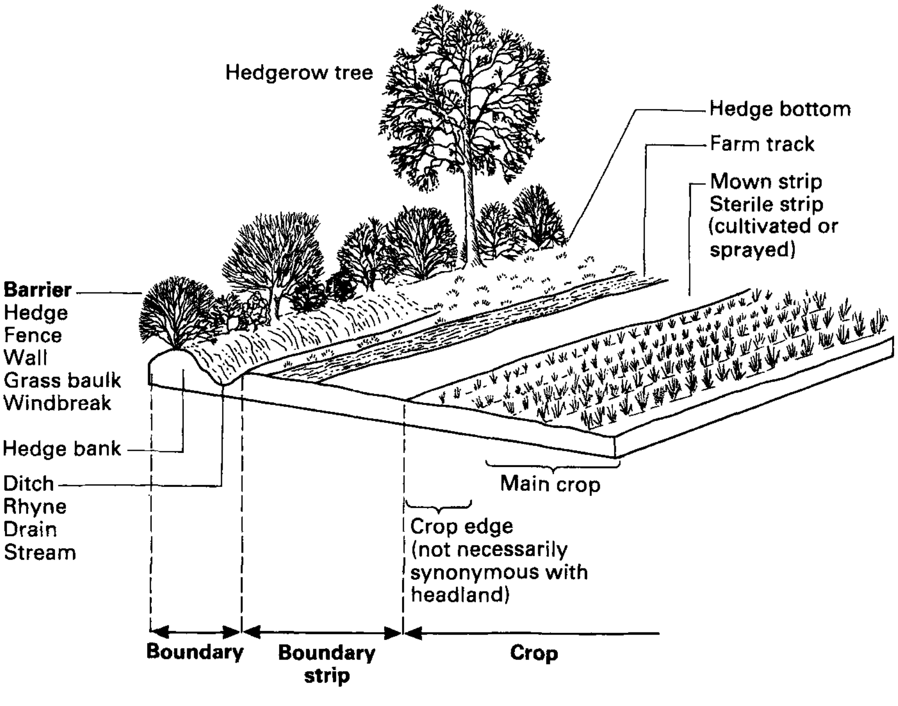


Fig. 1.8 Principal components of arable field margin (from Greaves and Marshall, 1987).

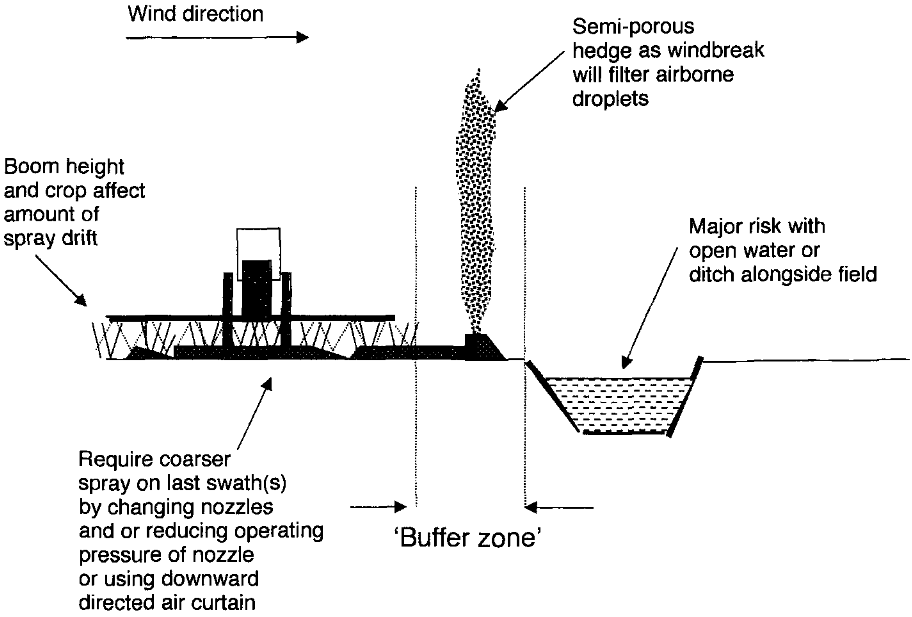


Fig. 1.9 Untreated buffer zone.

amount of crop area affected in the UK (Orson, 1998), this system has been modified by the introduction of a Local Environmental Risk Assessment for Pesticides (LERAP) where the UBZ can be reduced for ground based arable spray equipment from 5 metres to effectvely 1 metre from the top of the bank of a ditch if the spray method and equipment meets LERAP approval (Gilbert, 2000) (see also Chapters 4, 5 and 7). Longley and Southerton (1997) and Longley *et al.* (1997) examined the extent of drift into field boundaries and hedgerows and Miller *et al.* (2000) showed that differences in the plant structure will affect the extent of drift at field margins (Fig. 1.10). An established vegetative strip will significantly decrease drift compared with a cut stubble due to the filtration of the droplets (Miller, 1999). A grassed buffer strip, especially if sown perpendicular to the slope, will also restrict run-off of pesticide (Patty *et al.*, 1997). Heijne (2000) reported the use of artificial netting as an alternative to a hedge, which will take time to get established. The height and porosity of the netting determines the extent to which drift is reduced.

Crop monitoring for a pest may indicate a particular focus of infestation in a crop, and permit localised treatment to reduce the spread of the pest and avoid the cost of a treatment to the whole area. Some infestations may be initially at the edges of fields, e.g. pink bollworm may spread from villages if stalks have been stored for fuel. Many windborne insects collect on the lee side of hedges (Lewis, 1965) or other topographical feature. An isolated tree in a field can affect the initial distribution of red spider mites due to its effect on air

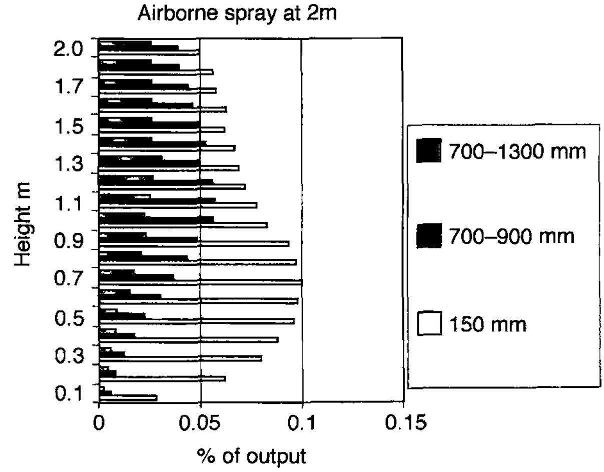


Fig. 1.10 Effect of vegetation in filtering spray droplets at field margin. Airborne drift at 2 m downwind recorded at different heights showing reduction if vegetation is 700 mm or higher.

movement across a field. If detected early, the initial patches of infestation can be treated with a knapsack sprayer to avoid treating the whole field.

Spatial differences within a field or crop canopy can also be exploited by using localised treatments to allow greater survival of natural enemies. Discrete droplets leaving areas untreated are generally more favourable than high volume treatments where all surfaces get wetted, when natural enemies inevitably are exposed to pesticides. Theoretically, some treatments can be localised by using an electrostatically charged spray, particularly to avoid pesticide fall-out on the soil and adversely affecting soil-inhabiting predators. However, this approach has not been exploited. Soil application of a systemic insecticide as granules or seed treatment will generally control sucking pests with less risk of direct effects on their natural enemies.

Conservation of natural enemies is especially important in perennial crops, so pesticide treatments may need to be separated in time. Thus, treatment of strips through an orchard with a non-persistent insecticide provides control of the pest, and natural enemies can re-establish from the untreated sections of the orchard which are treated several days later.

The importance of restricting pesticides as far as possible to the actual target is fundamental to good pest management and is considered in more detail in subsequent chapters.