1 Pesticides and agricultural development

Agriculture is now confronted with considerable pressure to increase production to feed a higher human population, expected to rise to 9 billion by 2050. In the Green Revolution of the late twentieth century, yields were increased by growing new crop varieties with more fertilizer and protected using pesticides. Growing concerns about the extensive use of pesticides has led to a policy, especially within Europe, of using pesticides only as a last resort in integrated pest management (IPM) programmes. IPM has been adopted initially in protected environments in which biocontrol and other non-chemical techniques have been effective on high-value fresh fruit and vegetable crops. This has to some extent been driven by consumers and supermarkets wanting produce without pesticide residues. In arable crops, the initial use of IPM has been with using economic thresholds to determine when to spray and promoting some biological control by management of field margins.

At present, farmers continue to regard pesticides as an essential tool to ensure that they can maintain production of crops of quality and quantity. Prior to the development of the modern pesticide industry, farmers had to rely very much on crop rotations and mechanical weed control with hoes, hoping for a good dry spell of weather so that the weeds dried and were not merely moved. They also hoped that insect pests and disease control could be ameliorated by choosing a good crop variety, which had some resistance to pest damage. When reconciling pesticide reduction with economic and environmental sustainability in arable farming in France, Lechenet et al. (2014) failed to detect any positive correlation between pesticide use intensity and both productivity (when organic farms were excluded) and profitability. This is not surprising as pesticides protect a crop from yield loss and do not increase the 'potential' yields, determined by soil fertility, rainfall and choice of crop variety.

Global estimates of crop losses due to insect pests, diseases caused by various pathogens and competition from weeds, vary depending on the crops involved and local variations in pest severity, but losses from 26 to 40% for major crops, with weeds causing the highest potential loss are

Pesticides: Health, Safety and the Environment, Second Edition. G.A. Matthews.

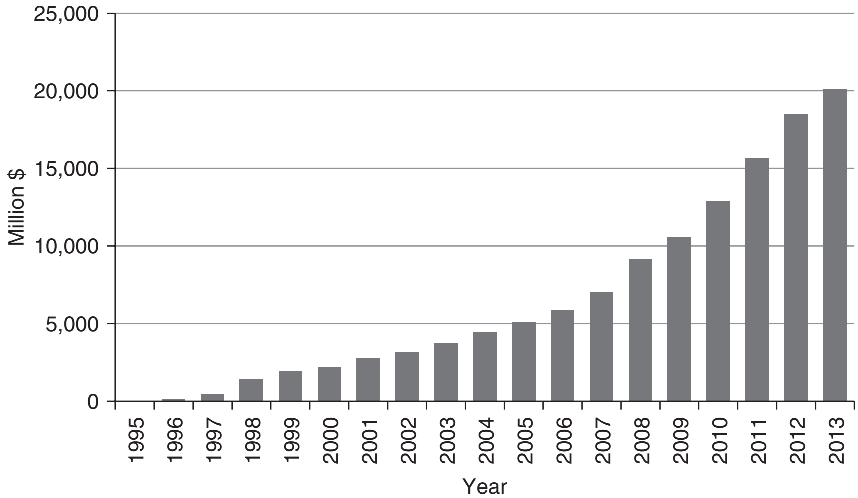


Fig. 1.1 Global market increase for GM seeds (Phillips McDougall, 2014).

reported (Oerke and Dehne, 2004). Some consumers have expressed a desire for ‘organic’ produce, but these usually are marketed at a higher price as farmers get lower yields and poorer quality without adequate crop protection. IPM has made considerable progress, especially within protected crops in which emphasis is given to cultural and biological control of pests, with minimal use of pesticides. Meanwhile the development of genetically modified crops has resulted in 18 million farmers growing biotech crops in 27 countries in 2013 covering 175.2 million hectares (Fig. 1.1). While insecticide use has reduced significantly on crops incorporating the Bt toxin effective against young larval instars of certain important pests, herbicide sprays continue to be needed with herbicide-tolerant crops.

Botanical insecticides, such as the pyrethrins, nicotine and rotenone (derris) were available prior to 1940, but they were not widely used, largely because they deteriorated rapidly in sunlight. A few inorganic chemicals, notably copper sulphate, lime sulphur and lead arsenate were also available. However, it was the development of synthetic organic pesticides during and following World War II that revolutionised the control of pests. Chemists had been looking for a cheap chemical with persistence in sunlight and low toxicity to man that would kill insect pests quickly, and in 1938 Muller showed that DDT would indeed fit this specification. Its availability during World War II led to initial use as a 10% dust on humans, for example in Naples, to suppress a typhus outbreak (Crauford-Benson, 1946). Soon afterwards it became available for agricultural use and began to be applied extensively on crops, such as cotton, at rates up to 4 kg ai/ha. Its use has had a major impact on vector control, being responsible, for example in India, for reducing the annual death rate due to malaria from 750,000 to 1,500 in

Table 1.1 Year of introduction of selected pesticides (Ware, 1986; MacBean, 2012 and web pages)

Year	Pesticide type	Pesticide
1850	Herbicide	Ferrous sulphate
1882	Fungicide	Bordeaux mixture
1930	Herbicide	DNOC
1931	Fungicide	Thiram
1939	Insecticide	DDT (commercialised 1944)
1942	Herbicide	2,4-D
1943	Fungicide	Zineb
1944	Insecticide	HCH (lindane)
1946	Insecticide	Parathion
1948	Insecticide	Aldrin, dieldrin
1949	Fungicide	Captan
1952	Insecticide	Diazinon
1953	Herbicide	Mecoprop
1955	Herbicide	Paraquat (commercialised 1962)
1956	Insecticide	Carbaryl
1965	Nematicide	Aldicarb
1968	Fungicide	Benomyl
1971	Herbicide	Glyphosate
1972	Insecticide	Diflubenzuron
1973	Insecticide	Permethrin
1990	Insecticide	Imidacloprid
	Fungicide	Azoxystrobin
	Insecticide	Spinosad
1994	Insecticide	Dicyclanil
	Fungicide	Ipconazole
1996	Insecticide	Pyriproxifen
1999	Fungicide	Ethaboxam
	Herbicide	Flucarbazone sodium
2001	Insecticide	Chlorfenapyr
2002	Insecticide	Pyridalyl
	Herbicide	Mesotrione
2003	Acaricide	Acequinocyl
2005	Insecticide	Flonicamid
	Insecticide	Spinetoram
	Insecticide	Spirodiclofen
2007	Insecticide	Chlorantraniliprole
	Insecticide	Flubendiamide
	Insecticide	Spirotetramat
	Herbicide	Pyraxosulfone
2012	Insecticide	Sulfoxaflor
	Insecticide	Flupyradifurone

the first eight years it was applied. Recognition of problems associated with the persistence of DDT in the environment were only realised later and highlighted by Rachel Carson in her book *Silent Spring* (Carson, 1962).

Parallel with the new insecticides, the development of 2,4-D as a herbicide controlling broadleaved weeds in cereal crops made a similar major impact on agriculture. While copper fungicides had been available since the end of the nineteenth century (Lodeman, 1896), further research has led to a greater range of more selective fungicides. These discoveries (Table 1.1) led to a rapid development of many other pesticides over the following decades. *The Pesticide Manual* (MacBean, 2012) is one important source of information on currently manufactured pesticides. Individual countries have lists of products that are registered for use. In the UK, this is published annually as *The UK Pesticide Guide*. Information can be obtained also from a number of Internet sites using a search engine such as Google. Information relevant to the UK is available through the Chemicals Regulation Directorate (CRD) web page, while the Environmental Protection Agency provides similar information in the USA. The Pesticide Action Network (PAN) and many universities also have web pages with pesticide information.

In Western Europe and North America the availability of herbicides was a major breakthrough at a time when shortages of labour due to the world war, industrialisation and urbanisation all played a part in necessitating a change in weed management on farms. Spraying fields with a herbicide allowed the crop seeds to germinate and develop without competition from weeds, thus increasing the harvested yield that could then also benefit from fertilizer applications. The discovery of paraquat, a herbicide that killed all weeds enabled a new concept of minimum or zero-tillage to reduce the need for ploughing fields every year and thus reduce the risk of soil erosion in many areas of the world. Subsequently glyphosate has dominated the weed control market with the advent of herbicide-tolerant genetically modified crops. Tolerance to other herbicides is now becoming available as overuse of one herbicide has led to weeds resistant to glyphosate.

The global market for pesticides has continued to grow despite the withdrawal of many of the older and more toxic pesticides, especially in Europe. Total global sales of pesticides had increased to approximately $54 million per annum in 2013, from $26.7 million in 2003. Growth of 9.8% per annum was recorded between 2007 and 2013 (Fig. 1.2a and b).

Data for 2013 shows that 43.7% of the global market was for the herbicide, plant growth regulator and sprout suppressants, with 27.5% for insecticides, 25.8% fungicides and 3.0% for other chemicals. North America was no longer the largest market, with Latin America, Asia and Europe all taking about 25% of the market (Fig. 1.3). Countries in Africa and the Middle East have not invested in increasing crop protection so yields remain low and crop protection has involved few pesticides and sowing genetically modified crops has barely started in these areas.

Few countries have survey data on the actual usage of pesticides. Thomas (2000) described the system operated in the UK to obtain accurate and timely information to satisfy government legislation. The data are also helpful in relation to the registration process and review of approved products.

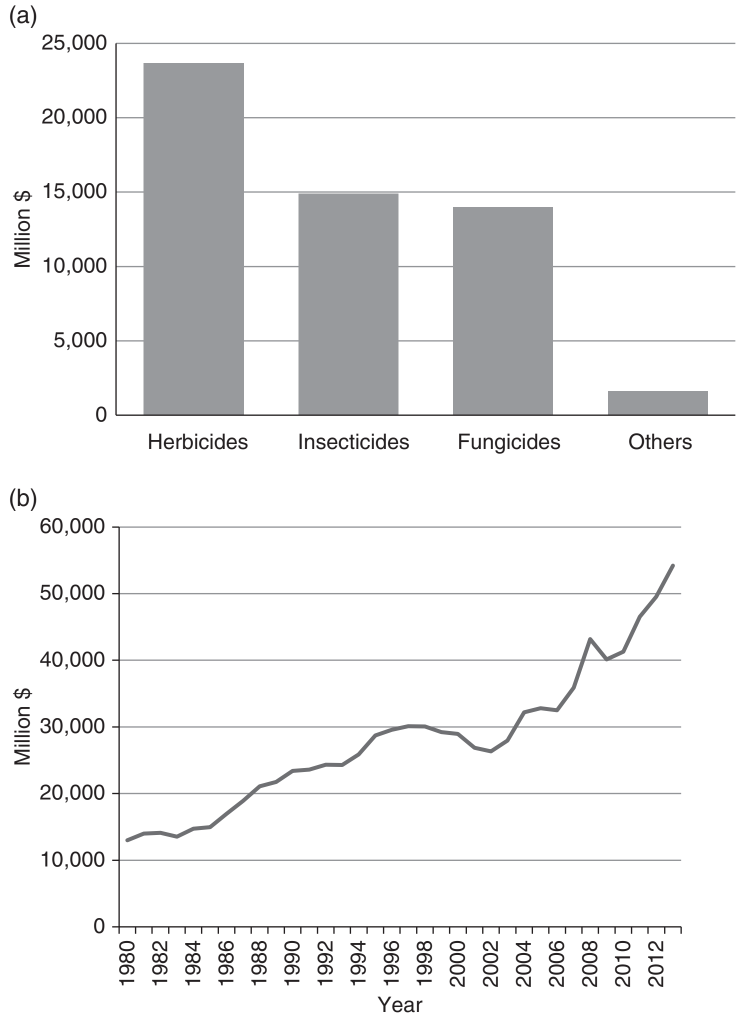


Fig. 1.2 (a) Global market of pesticides 2013 (Phillips McDougall, 2015). (b) Increase in global market of pesticides 1980–2013 (Phillips McDougall, 2015).

Principal pesticides

The following sections provide a brief account of some of the pesticides now available. World Health Organization (WHO) provides a classification of pesticides by hazard (WHO, 2010). Many of the pesticides which are extremely hazardous to use are no longer registered. This is particularly important in countries where protective clothing is uncomfortable to wear due to a hot climate. Poisoning due to pesticides is included in a classification of acute poisoning (Thundiyil et al., 2008). A major concern is that many more pesticides will be withdrawn in Europe when they are

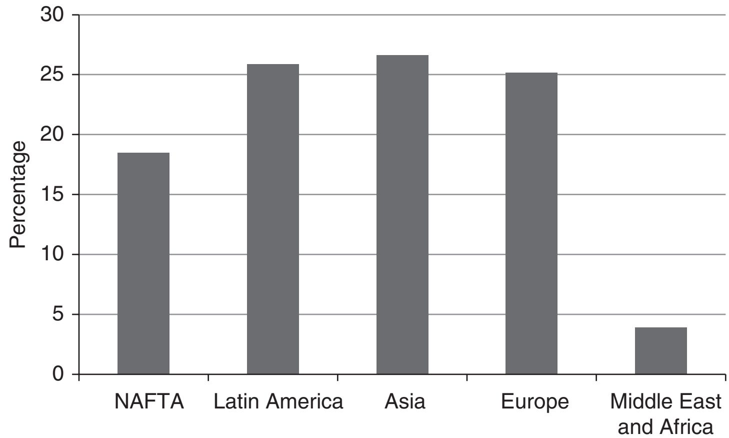


Fig. 1.3 Global market of pesticides by region 2013 (Phillips McDougall, 2015).

re-assessed with the hazard assessment due to other legislation such as the water directive. One report has predicted that a loss of certain pesticides, mainly on the basis of being perceived to be endocrine disruptors or the impact of the Water Framework Directive and greater reliance on mechanical and hand weeding, will among other consequences increase the cost of food at a time when agricultural output should be optimised (The Andersons Centre, 2014).

Insecticides

Initially the two main types of insecticides were the organochlorine (OC) and organophosphates (OPs), both being neurotoxins. The OC insecticides, including DDT, dieldrin and endrin had one main advantage, namely their persistence that enabled farmers to achieve control over a long period. However, plant growth and rainfall reduced the effectiveness of deposits on foliage. Later it was realised that this attribute led to residues remaining in the environment and being accumulated in some animals at the end of food chains. In consequence, these chemicals can be found everywhere, although their use has now been banned. The use of DDT for indoor residual spraying in vector control has been permitted on a limited scale.

OP insecticides are a diverse group (Anon and Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment, 1999), some of which are extremely toxic, for example parathion, methidathion and monocrotophos, while others, such as temephos, malathion and trichlorfon are much less hazardous to use. When used in place of the OC insecticides, more people suffered acute poisoning, as the need for protective clothing had not been adequately recognised in many countries. Many people now consider that those classified as the most hazardous to use (see later), should also be banned. In the UK most of these chemicals were not approved, although a few, such as chlorfenvinphos, were registered for control of specific pests. Other OPs such as diazinon were used extensively in sheep dips. Karalliedde et al. (2001) provide a critical review of OPs and their impact on health.

Another group with a similar mode of action is the carbamates that also vary very much in their toxicity. The most toxic examples, including aldicarb and carbofuran, were only allowed registration in the UK as granules, applied directly into soil, and not as sprays. The less-toxic carbaryl has been very widely used as a broad-spectrum insecticide. Newer groups are the pyrethroids, neonicotinoids and ryanodine insecticides.

Natural pyrethrins had been known for centuries as a potent insecticide, but they were rapidly inactivated, when exposed to sunlight. Research at Rothamsted in the UK led to the development of the synthetic photostable pyrethroids, permethrin, cypermethrin and deltamethrin (Elliott et al., 1973, 1978). Other pyrethroids have been developed, so this group became a very popular broad-spectrum insecticide group.

Similarly, but following the botanical insecticide nicotine, the neonicotinoids, notably imidacloprid, have been developed and rapidly accepted, especially where insects are resistant to the earlier types of insecticide. There are four groups of neonicotinoid insecticide, based on their chemistry: chloropyridyl (e.g. imidacloprid), thiazolyl (e.g. thiamethoxam), furanyl (e.g. dinotefuran) and sulphoximine (e.g. sulfoxaflor).

Neonicotinoids are active at extremely low dosages and have been used as seed treatments as they are absorbed by the plants which are protected over a long period. However, their use in Europe has been limited due to concerns that very low doses are detrimental to bees. In contrast, the authorities in Australia allowed continued use of the neonicotinoids as pollinator declines reported in some parts of the world were likely to be caused by multiple interacting pressures including habitat loss and disappearance of floral resources, honeybee nutrition, climate change, bee pests and pathogens, and miticides and other chemicals intentionally in hives to control varroa mites (Anon, 2014a). However, more favourable weather during the winter of 2013–2014 allowed overwintering bee mortality assessed in 31 countries to drop below 10%, despite neonicotinoid-based crop protection products being still in common use throughout Europe. In the USA, the *Center for Regulatory Effectiveness* (Anon, 2014b) consulted widely and reported that *Varroa destructor* mites are, by far, the greatest threat to feral and managed bees around the world, and secondly that neonicotinoids pose little or no threat to pollinators when used in accordance with regulatory requirements. They also concluded that studies which blame neonicotinoids for contributing to bee health decline are poorly designed and rely on massively overdosing sample bee populations, indicating that the main problems for bee keepers were not the use of the neonicotinoids. This was later confirmed by a study over 3 years to assess chronic sublethal effects on whole honey bee colonies-fed supplemental pollen diet containing imidacloprid at 5, 20 and 100 μg/kg over multiple brood cycles, which showed that field doses relevant for seed-treated crops (5 μg/kg) had negligible effects on colony health (Dively et al., 2015).

A new systemic insecticide flupyradifurone from the butenolide chemical class is effective against sucking pests and could replace imidacloprid, although it has a similar mode of action, but it has a different chemistry. Its development has followed studies of stemofoline alkaloids from a small group of flowering plants (*Stemonacea* family) native to various regions of Southeast Asia, as herbal extracts from these plants have been used for centuries as pesticides and to treat respiratory diseases.

Other new insecticides effective at a low dosages are fipronil, a phenylpyrazole, developed initially as it was extremely effective against locusts, and chlorantraniliprole (Rynaxypyr), very effective against lepidopteran pests. This is the first insecticide from the anthranilic diamide class of chemistry. It affects the ryanodine receptor and muscle function is disrupted, so insects stop feeding, as with the botanical insecticide, ryania. It is an important development as it is effective against insects resistant to older products with a different mode of action.

In contrast to the nerve poisons, insect growth regulators, such as diflubenzuron, affect insect development, mostly by adversely affecting chitin synthesis so the insect fails to complete a moult from one larval stage to the next. Another novel, insecticide, tebufenozide causes larvae to form precocious adults; that is, they attempt to moult into an adult before sufficient larval development has taken place.

Spinosad was the first insecticide using spinosyns A and D. A second-generation insecticide spinetoram, with a mixture of chemically modified spinosyns J and L, has been developed from a fermentation process in which *Saccharopolyspora spinosa* colonies were grown using natural materials such as soybean and cottonseed meal as feedstocks. Another insecticide chlorfenapyr, derived from microbially produced compounds known as halogenated pyrroles, is metabolised into active substance after it is in the pest. It is therefore slow acting compared with other insecticides.

There is now considerable interest in the development of natural organisms such as the fungus *Metarhizium acridum* as a biopesticide, which is very effective against locusts and other acridids. One advantage of mycoinsecticides is that they are selective, but this presents difficulties in marketing a product that is effective against a limited number of pests. Entomopathogenic nematodes have also increased in importance to control certain pests that attack plant roots such as the vine weevil. Biopesticides also tend to be slower acting, but they do integrate well with other biological control agents.

Herbicides

Herbicides are the most extensively used group of pesticides. Already their use is a crucial part of mechanised farming in North America, Europe and Australia. Specific herbicides, such as glyphosate, are linked to genetically modified herbicide-tolerant crops. This has led to their excessive use and increasing problems due to weeds becoming resistant to the herbicide. Herbicides have not been adopted on many small farms which have relied on manual weeding, but the situation is changing as the number of people available for weeding has declined with migration to cities and where disease such as HIV/Aids has increased problems of coping with weed control at the critical stages of early crop establishment. There is still the problem of whether to apply a herbicide if rainfall is erratic and crop establishment uncertain.

Herbicides can act on *contact* with a plant or are *translocated* within the plant. Good spray coverage is needed with contact herbicides. Sometimes only part of the foliage is affected, so some weeds although adversely affected, will survive. Translocated herbicides are particularly important for controlling perennial weeds, such as some of the key grass weeds. An example of a translocated herbicide is glyphosate, which will move down into the rhizomes of grasses, rather than only affect the foliage above ground. As the herbicide is distributed within the plant, good coverage is slightly less important.

Herbicides can also be classified according to the time of application. Weed control may be by means of a *pre-planting* application. This is usually a soil treatment that affects weed seeds before the crop is sown. After the crop has been sown, a *pre-emergence* herbicide will selectively affect the weed species without interfering with the germination and growth of the crop. When farmers have to contend with erratic rainfall and are not sure if a crop can be established, they may opt for a *post-emergence* herbicide applied later to the weeds. The herbicide may be applied to the whole of the crop area, or in the case of post-emergence herbicides, the spray can be applied as a band in the inter-row, or in some cases along the intra-row, using mechanical cultivation of the inter-row. This method is useful with crops that have been genetically modified to be resistant to particular herbicides that can be sprayed over the crop. In contrast, where a crop may be very sensitive to the herbicide, sprays need to be directed to avoid contact with the crop. Individual clumps of weeds can be spot treated, or if certain weeds are confined to specific areas of a field, the farmer can do patch spraying.

Herbicides may be broad spectrum, affecting all types of weeds, or they may be selective. In most cases, selectivity is between monocotyledon weeds, for example grasses and dicotyledons, the broadleaved plants. There are many different groups of herbicides, based on their chemical structure.

The Weed Science Society of America has provided a classification of herbicides (Mallory-Smith and Retzinger, 2003). Most have a very low mammalian toxicity. Most concern of human toxicity has been directed at paraquat, as it is lethal if the concentrate reaches the lungs.

Many different types of herbicides are now available. The following notes refer only to a selected number of different chemical groups.

Amide. Flucarbazone sodium is a relatively new post-emergence herbicide for application on wheat.

Aryloxyphenoxy propionates. These have good activity against grass weeds in broadleaved crops as a post-emergent translocated herbicide. One example is fluazifop-butyl.

Benzoylcyclohexanedione. Mesotrione is a synthetic analog of leptospermone developed to mimic the effects of this natural phytotoxin, obtained from the Californian bottlebrush plant. It is a selective pre- and post-emergence herbicide effective against a range of broadleaved and grass weeds.

Bipyridyliums. Paraquat is the most important in this group. It damages foliage quickly on contact, but is ineffective once the herbicide reaches the soil as it very strongly adsorbed on soil particles. The rapid wilting and desiccation of foliage within hours has enabled effective weed control to be achieved in many crops, where the spray is directed away from the actual crop. It has been extensively used in tree crops such as rubber plantations.

Dinitroanilines. Trifluralin is used as pre-planting soil-incorporated herbicide to reduce the impact of grass weeds in a broadleaved crop. Low water solubility minimises leaching and movement within the soil, but being volatile they must be covered by the soil. Due to its volatility and toxicity to fish and other aquatic organisms, its use is now banned in Europe.

Phenoxy or 'hormone' herbicides such as 2,4-D and MCPA are highly selective for broadleaved weeds, being translocated throughout the plant, affecting cellular division.

Phosphono amino acids, such as glyphosate and glufosinate, are foliar-applied translocated herbicides that interfere with normal plant amino acid synthesis. They are non-selective, but more effective against grasses than broadleaved weeds. There is no soil activity. They are formulated to improve uptake by the plants as rainfall shortly after application can reduce effectiveness.

Pyrazole herbicides (including benzoylpyrazole and phenylpyrazole). This is a new class of herbicides and includes pyroxasulfone, a pre- and post-emergence herbicide with long residual activity. Topramezone is used as a post emergence herbicide. The main target is annual grasses and broad leaves in corn crops, but is recommended for a range of other crops.

Substituted ureas. Most of these, such as isoproturon, flumeturon, diuron and linuron are non-selective, pre-emergence herbicides, which are absorbed in the soil and then taken up by roots. Some are active as foliar-applied post-emergence herbicides. Isoproturon has been widely used, especially to control black grass in winter wheat crops, but its extensive use had led black grass becoming resistant to it. However concern was raised about a risk to aquatic organisms by its movement into surface water courses due 'run-off' and via land drains. No risk management methods could be identified and its registration was withdrawn in the UK.

Sulfonylureas. This is a large group that is used mainly to control broad-leaved weeds by inhibiting meristematic growth. Metsulfuron-methyl. and others in the group have both foliar and soil activity and are active at extremely low application rates – a few grams per hectare. Rimsulfuran has been used to control glyphosate-resistant weeds such as rye grass. It may be used pre-emergence in maize, but with a safener (e.g. isoxadifen) has been used post-emergence. If small amounts of these herbicides remain in the soil too long, the following crop may be affected.

Triazines. This group includes one of the most commonly used herbicides, atrazine, which was very effective as a post-emergence spray in maize. However, it has been implicated in environmental problems, as it has been claimed that very low doses in water have an endocrine disruption effect that has resulted in a decline in frog populations, so its use has been curtailed.

Fungicides

The use of sulphur to protect vines dates back to ancient Greek civilisations, and with Bordeaux mixture since the end of the nineteenth century, most developments of fungicides have occurred only in the last few decades. Apart from the contact, protectant fungicides, such as copper fungicides and mancozeb, a number of systemic fungicides (Table 1.2) with different modes of action have been developed, most recently the stobilurins. Unfortunately, pathogens that are susceptible to a particular type of fungicide often become less sensitive. Thus great care is needed to avoid selection of pathogens resistant to a fungicide, by only applying those with a particular mode of action for a short period before using another one with a different mode of action in rotation. Manufacturers have also recommended mixtures as a means of delaying selection of resistant strains. Fungicidal seed treatments are important to protect young seedlings. Among the new fungicides isopyrazam, a pyrazole carboxamide is used to control black sigatoka disease on bananas. Benzovindiflupyr is being introduced to control Asian soybean rust (*Phakopsora pachyrhizi*).

Oliver and Hewitt (2014) provide an updates on the emergence of the strobilurins and succinate-dehydrogenase inhibitors (SDHIs) and the

Table 1.2 Some examples of fungicides

Type of fungicide	Example
Triazoles	propiconazole
	metconazole
	tebuconazole
Benzenoid	mefenoxam
Morpholines	fenpropimorph
Anilinopyrimidines	cyprodinil, pyrimethanil
Benzimidazoles	carbendazim
Carboxamides	isopyrazam
SDHI	boscalid
	fluxapyroxad
	penthiopyrad
Strobilurins	azoxystrobin
Ethylbenzamide	fluopyram (also marketed as a nematicide)
Host Plant Defence Induction; Group P1	acibenzolar-S-methyl
Others	chlorothanil

increased incidence of fungicide resistance. They also discuss legislative requirements to reduce fungicide applications in IPM programmes to minimise selection of resistance.

Rodenticides

Significant crop losses can be caused by rodents, both in the field and in stores. Rats are also a major problem in cities and other areas where they can get food. Various poisons have been set out in baits, usually inside traps to prevent other mammals, especially dogs from gaining access to the poison. Following the use of the anti-coagulant warfarin, to which rats have become resistant, other rodenticides such as bromadiolone and difenacoum have been introduced. There is particular concern that predatory birds can be affected by eating rodents that have consumed a poisoned bait, but have not yet died.

Crop distribution

The distribution of pesticide use is illustrated in Figures 1.2–1.4. Public concern is directed mainly at the amounts of insecticides and fungicides used on food crops, especially those that are eaten without further processing. IPM was developed to reduce pesticide use by encouraging farmers to combine different control techniques. IPM is now adopted as requirement in Europe aimed at using pesticides only as a last resort. While consumers may prefer to have produce without any pesticide residue, the lower yields

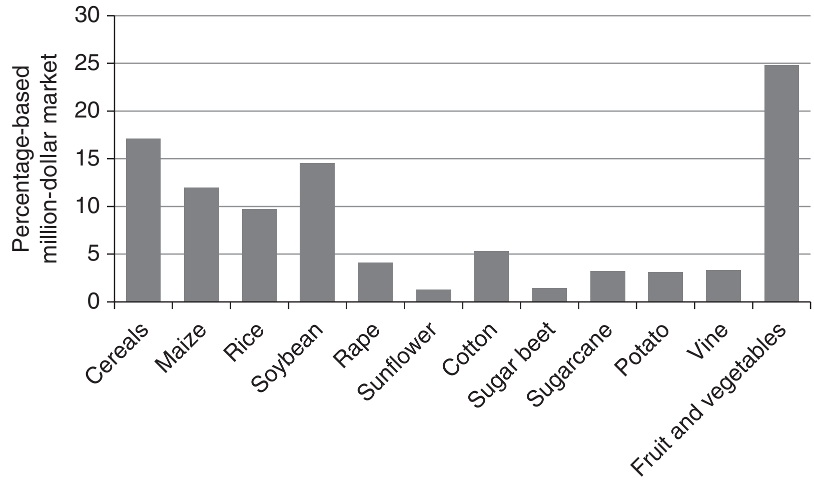


Fig. 1.4 Global sales of pesticides by major crops (Phillips McDougall, 2018).

and cost of 'organic' crop production indicates that some pesticides will be needed for rapid action against pests affecting yield and quality of produce. Where GM crops have been accepted, those with a Bt gene are grown can reduce insecticide use against some pests. In contrast the development of herbicide-resistant crops will see an expansion of the use of certain herbicides. Newer, less-toxic pesticides, including biopesticides are being developed and will also be crucial in maintaining high yields of crops.

Major crops

The application of pesticides has been an important component of changes in agricultural practices, including new crop varieties that have enabled yields of major crops to be increased. While they have not increased the yield potential, they have enabled farmers to realise a higher proportion of the potential yields by reducing the losses due to pests and pathogens and from weed competition. In addition improved quality of the harvested produce has allowed longer storage under suitable conditions that enables marketing of the crop to be extended. A few examples of the higher yields harvested are shown for the following selected crops.

Wheat

Yields of wheat worldwide average only 2.6 t/ha, although the potential is much higher as shown by the improvement in yields achieved in the UK (Table 1.3), although yields have reached a plateau. For higher yields,

Table 1.3 Area and yield of wheat in the UK

Year	ca. 1932	1969–1971	1971–1981	1988–1990	1999	2003	2013
Area harvested (1000 ha)		980	1434	1994	1847	1837	1510
Yield (mt/ha)	2.1	4.2	5.6	8.8	8.0	7.8	7.8

Table 1.4 Yields of rice (t/ha rough rice) from http://www.irri.org/science/ricestat/pdfs and http://ricestat.irri.org:8080/wrs2/entrypoint.htm

Year	Global	China	India	Japan
1962	1.89	2.08	1.54	5.14
1972	2.32	3.25	1.60	5.85
1982	2.98	4.89	1.85	5.69
1992	3.59	5.90	2.61	6.28
2002	3.92	6.27	2.91	6.63
2012	4.40	6.74	3.52	6.74

research has been initiated to increase the potential yield from 8 to 20 t/ha with new varieties. Much of the yield benefit in the UK has been due to efficient weed management following the introduction of herbicides. A return to the days of manual weeding is unthinkable as the cost of labour would be too high. In the UK, with organic agriculture, the estimate for casual labour for some vegetable crops can be as much as 40 days per hectare at £5.70 per hour, although mechanical hoeing would be done where possible to avoid manual weeding. In the USA, a state law was enacted to ban weeding crops with short-handled hoes as the work was excessively arduous, but the use of long-handled hoes was considered to cause some crop damage.

Rice

Success with breeding new high-yielding varieties of the 'Green Revolution' in Asia led to higher yields and production (Table 1.4), but also increased pest problems. The use of insecticides is generally blamed for the outbreaks of the brown planthopper, *Nilapavata lugens*, as insecticides were promoted in some areas as if they were like fertilizers and increased yields. In practice, poorly applied broad-spectrum insecticides made the planthopper problem worse as little spray reached the lower part of the stem favoured by the nymphs. The pest problem was also due to the overlapping of two or more rice crops with little attention given to a closed season between harvesting and sowing a second crop. Improvements in variety selection, enabling farmers to sow resistant varieties reduced the planthopper problem and by avoiding any insecticide use in the first six weeks of plant development, natural enemies have been able to exert adequate control of most pests (Way and Heong, 1994). Farmer field schools have been more effective in lowland irrigated rice areas as the system was based on extensive research at the International Rice Research Institute (Matteson, 2000). One of the problems in adopting IPM is getting farmers to accept that crop losses are not always as high as they perceive (Escalada and Heong, 2004).

However, rice farmers also have to contend with weeds as the increased cost of labour has resulted in changes from the transplanting of seedlings to more extensive use of direct seeding. Yield losses as high as 46% caused by weeds have been reported, so in some areas, farmer adoption of herbicides has increased rapidly in the last decade, although alternative crop establishment methods have also been adopted to reduce weed problems. Crops may need to be sprayed with fungicide in some areas due to diseases, such as rice blast.

Cotton

Insecticide use on cotton was considerable as insect pests have been a major constraint on production. Before the discovery of DDT, yields were generally less than 500 kg seed cotton per hectare obtained on 'organic cotton' but even small- scale farmers in Africa could expect to get yields of over 1000 kg/ha (Tunstall and Matthews, 1966; Gower and Matthews, 1971). This has changed with the development of GM cotton incorporating genes encoding toxin crystals in the Cry group of endotoxin of *Bacillus thuringiensis*. The *Cry1Ac* gene was used initially and its effectiveness has been improved by the addition of the *Cry2Ab* gene. The success of this development is due to

Fig. 1.5 Contrast between untreated cotton with many insects and sprayed crop ready for harvesting in Malawi. Similar effect now between Bt cotton and untreated plants with severe bollworm infestation (Photograph by Graham Matthews).

the first-instar bollworm larvae contacting the toxin as soon as they start to feed. This enables growers to achieve high yields without multiple sprays during a season to control the bollworms and other lepidopteran pests. The toxin is not effective against sucking pests, such as aphids, so some sprays may be required unless in the absence of the bollworm spray programme, natural enemies will control sucking pests. Where Bt cotton is not grown, farmers have to continue to monitor their crop and spray when necessary according to action thresholds. As with other insecticides, prolonged use of Bt cotton will result in a key pest becoming resistant to the Bt toxin. In contrast to the USA where a resistance management policy was implemented, resistance of the pink bollworm (*Pectinophora gossypiella*) to Bt cotton has been recorded in India (Fabrick et al., 2014).

Maize

Pesticide use on maize is also changing with GM Bt-maize incorporating the *Cry1Ab* gene to give resistance to corn root worm and corn earworm. Weed management is simplified with herbicide-tolerant maize. Yields of over 9 t/ha are achieved, whereas farmers in many areas of Africa barely produce 0.5 t/ha. Their major problem is initially weeds, which are highly competitive with young seedlings during the first 3 weeks after seed germination. In parts of Africa, the parasitic weed *Striga* has continued to be a major problem with crop losses over 50% under moderate to severe infestations (Parker,

Fig. 1.6 Manual weeding of maize. Greater use of herbicides is now likely in areas where labour is not so readily available (Photograph by Graham Matthews).

Fig. 1.7 Maize damaged by stem borer (Photograph by Graham Matthews).

Fig. 1.8 Simple granule treatment where Bt maize is not yet grown (Photograph by Graham Matthews).

2012). Sowing seeds of a maize-tolerant variety treated with imidazolinone herbicide can be very effective, when soil moisture is suitable (De Groot et al., 2008, Kabambe et al., 2008). Progress has also been made with new varieties resistant to *Striga* by the International Institute for Tropical Agriculture.

Traditionally African farmers have hoed their crops, but the amount of time and effort needed often results in part of the sown area being abandoned. Attention is now being directed in Africa to conservation farming which will introduce more herbicide usage. Locusts can also decimate young maize crops, but these can be controlled using a biopesticide – *Metarhizium acridum*. Without GM maize, stem borers can be controlled by a relative small amount of insecticide, provided it is in the whorl of leaves of the young plants. Crop protection is again crucial when the grain is harvested.

Fruit

Bananas

A major disease of the 'Cavendish' variety (about 10% of global production) of bananas, Sigotoka, has resulted in growers resorting to fungicide applications, usually applied by aircraft on large estates. A new form of the disease, black sigatoka and a new strain of fusarium wilt, also known as Panama disease, is causing particular concern, as this disease is far less easy to control. Bananas, with plantains, are widely grown on small farms in Africa, largely for local consumption, but a major drop in production in Uganda occurred due to failure of disease control in 1980, plus damage due to nematodes and banana weevils. Some farmers are now growing new resistant varieties imported from Central America. Meanwhile a major effort is underway to develop new disease resistant varieties.

Apples

Apart from a number of insect pests, such as the codling moth, apple orchards can suffer from mildew and scab diseases. For insect control, where insecticides are used the trend has been to apply insect growth regulators such as pyriproxyfen and tebufenozide, although indoxacarb and spinosad are also recommended. Much emphasis has been put on controlling insects with pheromone traps and encouraging natural enemies, but several fungicides sprays may be needed during the season. In the UK research is aimed at endeavouring to control the pathogen late in the season after harvesting to reduce the carryover of infection to the following season. Fewer early season fungicide sprays should then control the disease and also reduce the likelihood of any pesticide residues in the apples.

Fig. 1.9 Cocoa farmers need apply fungicides to protect pods from black pod disease (Photograph by Roy Bateman). (*See insert for color representation of the figure*.)

Vegetables

Potatoes

Commercial yields of potatoes vary from around 18 to over 45 t/ha depending on the variety and soil type, but also on protection from nematodes, late blight and insect pests. In the UK, the average yield is about 45 t/ha. If untreated, late blight, which was the cause of the Irish famine (1846–1850), can spread very rapidly with as much as 75% of foliage destroyed in less than 10 days. In fungicide trials yield increases of up to 30 t/ha have been reported. A GM potato with blight resistance has been developed but not yet commercialised. Similar devastating crop damage can also be inflicted by the Colorado beetle (*Leptinotarsa decemlineata*), which has spread from the USA across Europe to Asia. Yield loss due to viruses transmitted by aphids is usually low in the year in which the crop acquires infection, but if those tubers are used as seed potatoes, the yield will decline rapidly. Thus farmers obtain certified seed potatoes from areas with low aphid infestations. However, aphids may still need to be controlled if populations build up rapidly. Ideally crop rotation is used to minimise nematode damage, but nematicides are still required where potatoes are grown one year in four on the same land.

Tomatoes

In the tropics tomatoes are grown in fields, but in Mediterranean and temperate climates the crop is in plastic or glasshouses. Yields as high as 200 t/ha have been harvested, but protection from pests and diseases is essential. In a more controlled environment, the trend has been away from using insecticides to greater reliance on biological control, but protection from several diseases is still essential.

Forests

Certain insect pests can cause major defoliation of large areas of forests. In North America the spruce budworm (*Choristoneura fumiferana*) and the gypsy moth (*Lymantria dispar*) are among the key pests that have led authorities to spray large areas with insecticides. In the early days of these programmes broad-spectrum insecticides were used, but currently *Bacillus thuringiensis* and other more ecological acceptable products are sprayed. In Poland control of the nun moth (*Lymantria monacha*) was achieved over 2.5 million hectares using aerially applied Bt and the chitin inhibitor, diflubenzuron in 1994–1997. Thus control operations are crucial in some years to preserve forests.

Tillage

Farmers have for centuries used crop rotation and traditional tillage by ploughing and hoeing to manage weeds in the fields. However, in some parts of the world, ploughing may adversely affect earthworms and the loosening of the soil makes it prone to erosion. There is, therefore, awareness that for some crops reducing tillage, usually referred to as conservation tillage, has advantages. The aim is to protect the soil from the damaging effects of rain splash by leaving 30–50% stover on the soil surface to retain more rain on the fields. Various techniques have been developed to sow and plant the crop, for example by using a narrow furrow or just individual planting holes. Most of the land is undisturbed, but with the lack of burying weed seeds, conservation tillage does depend on careful use of herbicides to avoid weed competition.

Amenity areas and home gardens

Significant quantities of pesticides are now used by local authorities, for example in keeping pathways and gutters free of weeds. More emphasis has been given to non-chemical methods where these are effective, but cost-effective treatments are required. A limited number of pesticides are now marketed for home and garden use, notably for controlling insect pests on tomatoes, roses and lawns. In the UK, only those considered to be safe to use without professional training and do not require protective clothing are permitted. Many of these products have been sold in ready to use in small plastic containers incorporating a trigger-operated nozzle. In some countries the use of pesticides on turf and in gardens has been prohibited by local bye-laws, but in these areas where serious pest damage occurs, professional pest control companies may be employed.

Nuisance pests and vector control

The control of ants and cockroaches in dwellings was often done by applying a low concentration dust, to areas where the insects are known to live. The alternative has been to use pressure packs, known more usually as aerosol cans. Professional operators controlling nuisance pests in restaurants, hospitals, aircraft and other locations use a range of different spray equipment.

In more tropical climates vectors of malaria, dengue and other diseases need to be controlled. Insecticide-treated bed nets have become widely available and reduce illness and mortality of those who remain under the bed net while the vectors are active. Indoor residual spraying has also given good control of mosquitoes that enter houses, but in some situations an area-wide space treatment is needed. Urban areas can be treated with vehicle-mounted cold fogging equipment or aircraft may be used to apply insecticide at the flight time of the mosquitoes. Mosquito control units are present in most counties throughout the USA and these have been particularly active following the outbreak of West Nile Virus. Reduction in larval breeding sites by drainage may require follow up treatment of areas without drainage by applying larvicides.

Legislation

Legislation on the registration and use of pesticides has been primarily by national governments. In Europe Directive 91/414/EEC initiated harmonisation of the registration procures, and has been followed by the Sustainable Use Directive (SUD) new legislation in the form of a Regulation (EC Regulation 1107/2009), which came into force in June 2011 and requires compliance by all EU countries. The aim has been to minimise risks of environmental pollution based on data obtained from manufacturers and to exclude the most hazardous compounds. This is important as other parts of the world, especially in areas where protective clothing is either not available or considered too uncomfortable to wear, may follow and no longer register many highly toxic pesticides. Apart from registration of the pesticides, the regulation also brings in requirements for pesticide packaging with more emphasis on recycling of cleaned pesticide containers to increase safety. The number of pesticides that can be marketed in Europe has already been significantly reduced as a result of this legislation and has also affected countries exporting crops to Europe as these must also comply with regulations on maximum residue levels (MRLs).

At the same time, the Machinery Directive 2006/42/EC, has been amended and requires new pesticide application equipment to meet set standards prior to being marketed. Equipment now requires regular checks and spray operators must receive training to improve the precision of pesticide application, both in terms of placement and when an application is needed to minimise the amount of pesticide used in the environment. In Europe each country must develop national plans which promote the use of alternative controls with the application of any pesticide regarded as a last resort as part of IPM.

Requirements for registration are discussed in Chapter 2. In the international sphere, the Food and Agriculture Organisation (FAO) has sought to achieve harmonisation of the data requirements since the *Ad Hoc* Government Consultation on Pesticides in Agriculture and Public Health (FAO, 1975). Following this meeting, FAO published a Code of Conduct on the Distribution and Use of Pesticides, which has been subsequently amended and is now the FAO Code of Conduct on Pesticide Management (FAO, 2012). It includes requirements for Prior Informed Consent (PIC) aimed at assisting the less developed countries without the resources to administer a full registration system to decide whether it should allow the import of certain pesticides. FAO has also published a number of guidelines in support of the Code (see http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/list-guide-new/en/). Under the Rotterdam Convention, exporters of pesticides have to inform importers in developing countries about the toxicity and hazards associated with the use of products included on the PIC list and receive their authority before the products can be exported.

The FAO Code is voluntary, but the requirements for PIC have been included in a European Community regulation applicable by law in the Member States. A PIC database is maintained at the International Register of Potentially Toxic Chemicals held at Geneva, where the International Programme on Chemical Safety (IPCS) is located. Under the Stockholm Convention a number of pesticides are included in the list of persistent organic pollutants (POPs) and their use is now banned, although there is a derogation for DDT used only for indoor residual spraying to control mosquitoes.

WHO has published a classification system (WHO, 2010) (Table 1.5) for pesticides, based on the acute toxicity of the formulation. Class I pesticides are the most hazardous to use, whereas those in the unclassified category are the least toxic to mammals. The examples in Table 1.6 show that Class I are mostly the older types on insecticides. The Codex Alimentarius Commission of the United Nations is responsible for harmonisation of

Table 1.5 WHO classification (http://www.who.int/ipcs/publications/en/pesticides_hazard.pdf)

		Oral toxicity[#]		Dermal toxicity[#]	
Class	Hazard level	Solids*	Liquids*	Solids*	Liquids*
Ia	Extremely hazardous	<5	<20	<10	<40
Ib	Highly hazardous	5–50	20–200	10–100	40–400
II	Moderately hazardous	50–500	200–2000	100–1000	400–4000
III	Slightly hazardous	>500	>2000	>1000	>4000
U	Unclassified				

[#]Based on LD_{50} for the rat (mg/kg body weight).
*The terms 'solids' and 'liquids' refer to the physical state of the product or formulation being classified.

standards related to the international food trade and by collaboration with the Joint meetings of a FAO Working Party and a WHO Expert Committee, the Codex Committee on Pesticide Residues sets international standards. The International Union of Pure and Applied Chemistry (IUPAC) also has a role in setting specifications for each pesticide.

Some countries still do not have adequate legislation or trained staff to register pesticides and ensure that only registered pesticides are available to farmers. This lack of regulation is of great concern due to the risk of human health problems, associated with the most toxic insecticides being used by illiterate farmers, usually without training or adequate protection during their application (Matthews et al., 2011; van den Berg et al., 2011).

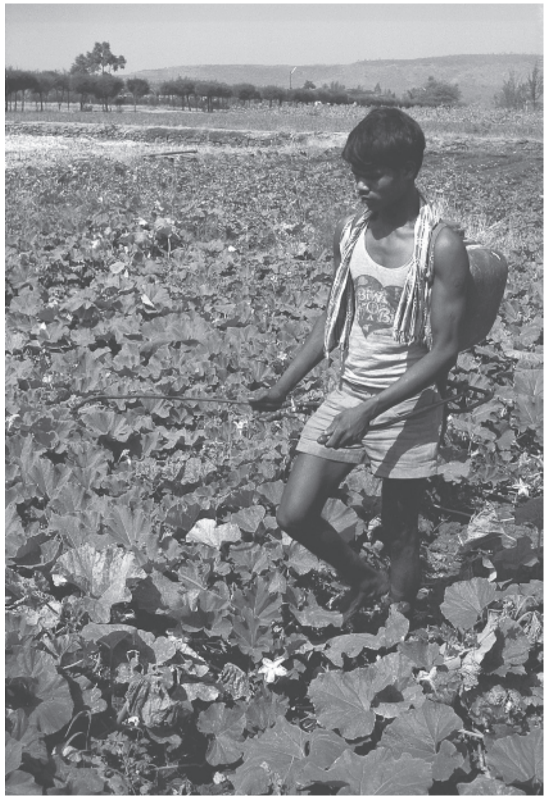
Estimates of poisoning cases are not easy in many countries with a poor infrastructure. In some countries, many affected by poisoning may not see a doctor and only a small proportion reach a hospital for proper treatment. In 2006, the WHO estimated global pesticide poisoning at 3 million cases, although the estimate may not represent the all cases of illness and death due to misdiagnosis or non-hospitalized cases (Mancini et al., 2009). In developed countries Thundiyil et al. (2008) indicated a rate of acute pesticide poisoning among agricultural workers was 18.2/10,000 full time workers and 7.4 per million among schoolchildren.

The most horrific number of deaths was at Bhopal in India in 1984, when a chemical methyl isocyanate (MIC) used at a factory making the carbamate insecticide carbaryl (Sevin) was contaminated with water. The reaction led to an extremely toxic gas escaping and this killed nearly four thousand people in the following hours. Regrettably, vast numbers had been allowed to live in slums close to the factory and with no contingency plans; these people were not protected from the toxic gas. Even more, further away from the factory were affected by the gas and suffered severe health problems. Some estimates indicate as many as 15,000 died later, with many more continuing to suffer from chronic symptoms. In 2006, the government confirmed that the leak had caused 558,125 injuries including 38,478 temporary partial injuries and approximately 3,900 severely and permanently disabling

Table 1.6 Examples of pesticides according to WHO classification in relation to mammalian toxicity for the active substance. The type and concentration of the formulation will adjust the ranking, thus pyrethroid insecticides are used at a low concentration, and are considered less hazardous

Class	Insecticide	Fungicide	Herbicide	Rodenticide
Ia	aldicarb	captafol		brodifacoum
	mevinphos			
	parathion			
	phorate			
	phosphamidon			
Ib	azinphosmethyl			warfarin
	carbofuran			
	dichlovos			
	formetanate			
	methamidophos			
	methomyl			
	monocrotophos			
	nicotine			
	triazophos			
II	bendiocarb	azaconazole	2,4-D	
	carbosulfan	copper sulphate	paraquat	
	chlorpyrifos	fentin hydroxide		
	cypermethrn	tetraconazole		
	deltamethrin			
	dimethoate			
	fenitrothion			
	fenthion			
	fipronil			
	imidacloprid			
	lambda-cyhalothrin			
	rotenone			
	thiodicarb			
III	acephate	copper hydroxide	ametryn	
	amitraz	copper oxychloride	bentazone	
	malathion	metalaxyl	dicamba	
	spinosad	thiram	dichlorprop	
	spirotetramat			
	resmethrin		glufosinate	
	trichlorfon		isoproturon	
			linuron	
			MCPA	
			mecoprop	
			propanil	
Unclassified	phenothrin	axoxystrobin	atrazine	
	spinetoram	benomyl	pyraxosulfone	
	temephos	carbendazim	simazine	
		iprodione	trifluralin	
		mancozeb		
		sulphur		

(a)



(b)

Fig. 1.10 Contrasts in protective clothing while using a lever-operated knapsack sprayer (a) India (Photograph by Graham Matthews), (b) Pakistan (Photograph by Graham Matthews), (c) the UK (Photograph courtesy of Hardi International) and (d) manually carried lance in southern Europe (Photograph by Richard Glass).

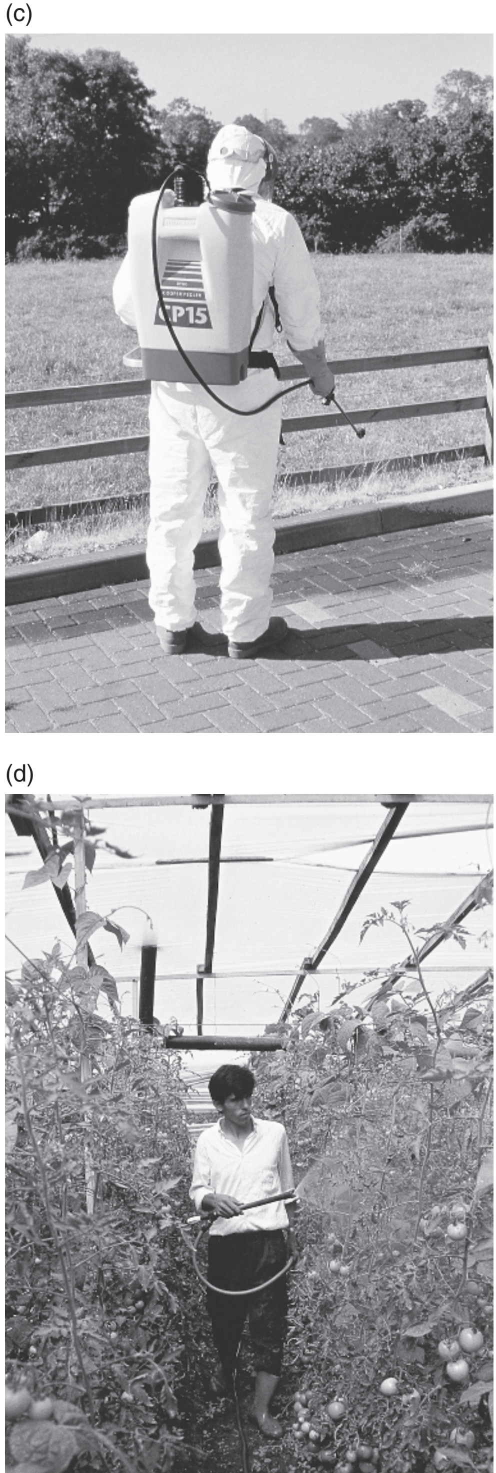


Fig. 1.10 (*Continued*)

injuries. Subsequently an Indian court sentenced seven ex-employees in 2010 to 2 years imprisonment and a fine of about $2,000 each, for causing death by negligence.

In the Soviet Union, the use of pesticides had expanded so much that by the 1980s the USSR was one of the world leaders in pesticide use in terms of per hectare and per capita. Unfortunately their pesticides were often of inferior quality, packaged in large containers, poorly stored and inefficiently applied, often by aircraft. This led to vast numbers of people being poisoned, with for example the average daily concentration of OPs such as demeton over 0.1 mg/m^3 in air, 500–1000 m from cotton fields (Fedorov and Yablokov, 2004). This extensive poisoning in Uzbekistan led to a switch to biological control with the setting up of biofactories to produce parasitoids, a practice still adopted in the country.

Globally, the cause and symptoms of poisoning vary between chemicals and countries (Harris, 2000). In some cases, where deaths have occurred, it is undoubtedly due to application of pesticides classified by WHO as Ia or Ib pesticides with no protective clothing being worn. Some of these organo-phosphorus insecticides, such as parathion, methamidophos and monocrotophos, were used because farmers perceived that these killed their pests quickly. In some countries deliberate drinking of pesticides in suicide attempts has been the main cause of death, rather than occupational exposure.

In Sri Lanka, the total national number of admissions due to poisoning doubled between 1986 and 2000, with an over 50% increase in admissions due to pesticide poisoning, but the number of deaths fell. In particular the number of deaths due to the organo-phosphate insecticides, monocrotophos and methamidophos fell from 72% of pesticide-induced deaths as the import was restricted and eventually banned in 1995. However the use of these insecticides was replaced by endosulfan (WHO Class II) and this led to a rise in deaths from 1 in 1994 to 50 in 1998 when this insecticide was also banned. Over the decade the number of deaths due to pesticide poisoning had not changed significantly with WHO Class II OP insecticides becoming a major factor. The switching from one pesticide to another, especially in relation to self-poisoning needs further attention and although legislation on pesticides had an effect, the emphasis now must be on other strategies to reduce the availability of the most hazardous chemicals (Konradsen et al., 2003; Roberts et al., 2003). One strategy is for pesticides to be kept in special locked containers to reduce access to the poisons (Gunnell et al., 2007).

In South Africa early indications are that small-holders, who adopted the growing of Bt cotton had a reduced incidence of skin disorders, feeling generally unwell and other health effects that had been associated with spraying for bollworm. It has been suggested that if all farmers grew Bt cotton, the number of poisonings would decrease to just two per season, compared to 51 reported cases in the 1997/1998 season (Bennett, 2003). Similar reports come from China (Hossain et al., 2004).

Various non-governmental organisations (NGOs) have lobbied for pesticide reduction policies, including the PAN, which has sought to eliminate the hazards of pesticides, reduce dependence on them and prevent unnecessary expansion of their use, while increasing sustainable and ecological alternatives to chemical pest control.

Unfortunately in contrast to demands for banning of many pesticides, less attention has been given to equipment leaving it to farmers to choose and maintain their sprayers. In consequence, often cheap and poorly maintained sprayers are used and this has frequently resulted in prolonged exposure to pesticides, especially by those who have poor facilities to wash after work. This is likely the cause of many cases of poisoning, especially with insecticide sprays. In order to prevent leakage of pesticide from the sprayer tank over the operator's body or leakage over unprotected hands, FAO has published minimum standards for pesticide application equipment (Anon, 2001).

Compared to tropical areas, relatively few cases of acute poisoning are reported in temperate climates, where protective clothing is available and worn. In the UK, the extremely hazardous pesticides, such as aldicarb, applied as solid granules to soil for nematode control have been withdrawn, together with other pesticides, either because the commercial company did not consider sales justified the cost of the additional test data needed to meet the current requirements of the EU, or additional data and evaluation has led to revocation of registration.

The National Poisons Information Service (NPIS) in the UK has identified cases that required health care (Perry et al., 2014) and shown that from 2004 to 2013, 7,804 cases of pesticide exposure were identified out of 34,092 enquiries. Eighty-seven per cent were unintentional acute and 9.7% as acute, deliberate self-harm, while the remainder were unintentional but chronic exposures. Of the 38 deaths recorded, most were due to either paraquat or diquat (14) or aluminium phosphide (12). Most of the unintentional exposures were due to children having access to bait-type products for rodent or ant control. NPIS found that the minimum incidence of pesticide exposure requiring health care contact was 2.0 cases/100,000 population per year. This was higher than that reported by other toxicovigilance schemes such, the Pesticides Incidents Appraisal Panel (PIAP), essentially covering agricultural use, which has reported a decrease in the number of acute 'health incidents' per annum.

Another concern has been the presence of pesticide residues in food. Regulatory authorities analyse food samples (see Chapter 7) to determine whether the residues exceed the maximum residue level (MRL) that may occur following good agricultural practice. Approximately 1% of samples of food grown in the UK examined for pesticides residues in 2012 exceeded the maximum residue level compared with 7% for produce imported from outside the EU. In many countries, this concern has led to a policy to reduce the amount of pesticide or number of applications in a season. It is quite easy to reduce the quantity applied when a more active molecule, applied at a few grams per hectare can be applied instead of an older product. Reducing dosage of an application may be possible if it is correctly formulated and applied at the optimum time, but this is not always possible due to weather conditions. However, the policy encouraged the need for research into alternative strategies of pest control and in emphasising a need for integrating different control tactics has led to the mandatory IPM policy.

While some governments considered adding a tax on pesticides to reduce their use, in the UK in response to this threat, the Crop Protection Association introduced a voluntary initiative (VI) aimed at improving the standards of pesticide use through research, training, stewardship and communication (see www.voluntaryinitiative.org.uk/). This initiative has been highly successful with over 20,000 spray operators now registered on the National Register of Sprayer Operators (NRoSo) and over 90% of sprayed areas are treated with equipment that has been tested.

In 1978 a scheme, known as BASIS, was established in the UK by the pesticide industry to develop standards for the safe storage and transport of agricultural and horticultural pesticides and to provide a recognised means of assessing the competence of staff working in the sector. BASIS provides the training for staff in companies marketing pesticides, including those providing products used for amenity areas.

In the UK in 1996, another group, the 'Pesticide Forum' was set up to bring together a wide range of organisations representing those who make, use or advise on pesticides as well as environmental, conservation and consumer interests. The forum continues to provide a mechanism for exchanging ideas and for encouraging joint initiatives to address particular issues. It also provides advice to Government on pesticide usage matters. It reports progress annually on a number of indicators covering economic, environmental and social issues including compliance on water quality (a 30% reduction in the frequency of detection of individual pesticides in untreated surface water at levels above 0.5 and 0.1 ppb), and benefits to biodiversity by adoption of crop protection management, now IPM programmes and changes in the behaviour of farmers through training (see http://www.pesticides.gov.uk/guidance/industries/pesticides/advisory-groups/pesticides-forum/pesticides-forum-annual-reports).

Although many of the foods and beverages we consume contain natural pesticides to defend plants from pest attack, many people have a preference for 'organic' produce, completely free of farmer-applied chemicals. The aim of organic farming is to develop good soil with healthy crops that have natural resistance to pests and diseases, and to use crop rotations to encourage natural predators. However, organic standards allow seven pesticides that are either of natural origin (e.g. soft soap) or simple chemical products – copper compounds and sulphur, which occur naturally in the soil.

This chapter has shown that there have been many changes in pesticide regulation in the last decade in response to concerns about their use. IPM is now a policy within the European Union. Nevertheless, farmers continue to need to apply pesticides to maintain high yields to feed a growing global population. In the following chapters, the way in which governments regulate their use is described and ways in which we can protect people.

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