CHAPTER 5.VI

Plant Protection and Land Transformation

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5.VI.1 INTRODUCTION

Plant protection plays a significant role in optimizing the productivity of a given crop. Agricultural pests, which include all organisms such as fungi, bacteria, viruses, insects, mites, nematodes, weeds, rodents and grain-eating birds, that live on and/or compete with plants determine, to a varying degree, if crops can be grown economically in certain situations. Usually agricultural pests inflict considerable damage to crops and represent a significant production constraint. Effective plant protection thus becomes essential to minimize the losses caused and to ensure that full benefit is drawn from other production inputs.

Indirectly, agricultural pests and plant protection are therefore of importance to land transformation. They determine partially the productivity of the transformed land. Especially when effective chemical pest control measures were lacking, crop rotations and other agricultural practices—and thus the ways in which the land was used—were, to a large extent, aimed at reducing pest incidence. After the widespread introduction of pesticides in some parts of the world, such practices could be changed and a tremendous intensification of agricultural production could take place. Systems developed, such as mono- and multi-cropping, that would have been impossible without the new control measures. Certain crops could be grown in places where this would have been impossible without effective crop protection.

However, it should be stressed that the intensification process has also rendered most crops more susceptible to pest attack, and in fact crop losses continue to be very high. A new crop environment has been created. In addition, intensive use of pesticides in itself considerably affects the land and its biotic environment. Identification of the negative aspects of this type of transformation of the agro-ecosystem will in the future lead to a gradual change in plant production and protection practices. Within the framework of so-called integrated pest management systems renewed attention is given to
the significance of certain agricultural practices and crop varieties grown to reduce pest incidence.

5. VI.2 CHANGES IN CROP PROTECTION

Phytophagous organisms were present on this planet long before man appeared and started to use certain plants for his well-being, be it for food, shelter or clothing. The notion of plant pests only became applicable from the time that it was recognized that these organisms competed for the same materials that man considered as useful. However, pests are rarely very apparent in natural ecosystems, and the growing of crops as such has created much more favourable conditions for the development of pest organisms.

From recent studies on the perception of pests by traditional farmers, it may be concluded that a certain amount of damage caused by the so-called sedentary pests was, and often still is, considered an integral and unavoidable part of the traditional agricultural production process. These farmers seem to have a notion that the crop ecosystem should be rather diversified. For example, in certain African situations a small amount of food may be left on the field after harvest for the rodents, the latter being considered part of a ‘healthy’ ecosystem.

However, epidemics and plagues were certainly recognized in early times, and their threat must have had a strong impact on crop production. One of the oldest quoted examples is the locust plague which appeared at frequent intervals (about every 5–7 years) in large parts of Africa and Asia. Such plagues could cover enormous areas and, depending on the weather conditions, could last for a couple of years.

Thus, the struggle with plant pests has certainly taken place from the time that crops were grown deliberately, i.e. from about 8000 BC onwards. Only during a relatively short period of time has man felt totally confident that he could fully master certain pest organisms. This occurred during the period from roughly 1950 to 1970 when confidence in the newly available insecticides led some to believe that a permanent solution to certain insect problems had been found. Matters turned out to be more complex than foreseen, and only gradually are systems being developed to use these new powerful tools optimally, both from an economic and an ecological point of view.

Uncertainty about the effectiveness of pest control efforts has continuously led man to seek for improvements in plant protection. Three periods may be described. For each of these some aspects of particular relevance to land transformation will be discussed, although it should be stressed that these aspects are not necessarily the major characteristic of, or limited only to, the period concerned.

Until the 1940s certain agricultural practices were to a considerable extent aimed at the reduction of the impact of crop pests. These included matters
such as crop rotations and field clean-up after harvest. Most pests could not be directly controlled, or only inadequately so. In some cases, existing or newly introduced pests made it uneconomical to grow certain crops or crop varieties. This period clearly demonstrated the importance of the way in which the land is used (cultural practices) in reducing crop losses in a preventive manner.

The development and widespread use of synthetic organic pesticides drastically changed this approach. The idea gradually arose that plant and animal pests were of secondary importance. The effectiveness of these new control means made it possible to change land-use considerably. However, this period also revealed a succession of changes which had considerable ecological consequences. With respect to land transformation, it should be noted how the intensive use of pest control measures affected the agro-ecosystem.

During the last two decades the idea of integrated pest management has emerged. It aims at the combined use of pesticides and other control factors. Elements of this approach are gradually being introduced into current agricultural research and development activities. Emphasis is again placed on preventive measures, such as cultural practices, varietal resistance and maintenance of natural enemies. The importance of the crop condition to withstand pest outbreaks is highlighted again and the idea of plant health is gaining recognition. Thus a more stable agro-ecosystem is created, reducing the need for curative control measures.

However, before discussing certain aspects of these three periods in more detail, a general discussion of crop losses seems useful. This will place plant protection in proper perspective in relation to agricultural productivity.

5. VI. 3 CROP LOSSES

Spending any effort to reduce the impact of crop pests certainly requires a proper definition of the magnitude of the problem. Crop loss assessment serves this purpose and aids in evaluating progress resulting from control activities. But experience has clearly shown the difficulties in collecting data that are really useful. Recent efforts to systematically collect comprehensive crop-loss data on a global basis have produced few results, and there are no clear indications that much progress can, or will, be made in the near future. Crop-loss information must therefore continue to be collected from data that become available from various crop improvement experiments. In this respect, special attention can be drawn to the data generated by the International Agricultural Research Institutes, such as IRRI in the Philippines, CIAT in Columbia and IITA in Nigeria. An analysis of some of these data on damage caused by insect pests to major food crops clearly confirmed that estimates published by Cramer in 1967 still provide good order-of-magnitude estimates (Cramer, 1967), although for developing agriculture, Cramer's data are rather on the conservative side (Brader, 1982).
None the less, these estimates provide good insight into the overall magnitude of plant protection problems, and, as shown in the following, the loss figures are already such that there seems to be little need for additional efforts to prove the urgency of continued implementation of proper crop protection measures. The estimates of Cramer have been applied to the 1981 agricultural production figures given in the 1981 FAO Production Yearbook (FAO, 1982). Prices given in the same FAO publication have been used (Table 5.VI.1) to translate the losses into money values.

It can be seen in Table 5.VI.1 that the total annual cereal losses are of the order of 838 million tonnes, or the equivalent of about US$147 x 10^9. Total annual food crop losses would be almost 1400 million tonnes, worth more than US$300 x 10^9. Adding to this the non-food crops, the value of the total losses would be over US$348 x 10^9. It must be noted that post-harvest crop

| Table 5.VI.1 Amount of agricultural produce lost to pests in 1981 and its approximate money value |
|-------------------------------------------------|----------------------------------|-----------------|-----------------|-----------------|----------------|
| Actual production (kt) | Calculated losses (% of potential production) | Amount (kt) | Approximate price per t (US$) | Approximate value (US$ billion) |
| Wheat | 458 195 | 23.9 | 143 873 | 180 | 25.9 |
| Rice | 413 785 | 46.4 | 358 338 | 200 | 71.7 |
| Maize | 451 704 | 34.8 | 241 210 | 150 | 36.2 |
| Barley | 158 488 | 20.2 | 40 097 | 140 | 5.6 |
| Rest cereals | 181 656 | 23.1a | 54 497 | 140 | 7.6 |
| Total cereals | 1 663 828 | | 838 015 | | 147.0 |
| Potatoes | 256 978 | 32.3 | 122 578 | 120 | 14.7 |
| Other root crops | 304 589 | 23.1a | 91 377 | 100 | 9.1 |
| Pulses | 42 403 | 23.1a | 12 721 | 500 | 6.4 |
| Vegetables | 351 961 | 27.7 | 134 801 | 400 | 53.9 |
| Fruits | 282 526 | 23.1a | 84 758 | 400 | 33.9 |
| Oil crops (oil equiv.) | 52 984 | 32.5 | 25 485 | 500 | 12.7 |
| Sugar (raw) | 92 046 | 45.3 | 76 214 | 370 | 28.2 |
| Total food crops | 3 047 315 | | 1 389 008 | | 305.9 |
| Cocoa | 1 670 | 45.9 | 1 416 | 2 000 | 2.8 |
| Coffee | 5 846 | 44.4 | 4 665 | 2 500 | 11.7 |
| Tea | 1 845 | 32.2 | 874 | 1 500 | 1.3 |
| Cotton lint | 15 301 | 33.9 | 7 834 | 1 950 | 15.3 |
| Other fibres | 6 482 | 24.0 | 2 042 | 600 | 1.2 |
| Tobacco | 5 334 | 30.8 | 2 374 | 3 700 | 8.8 |
| Rubber | 3 807 | 25.0 | 1 268 | 1 100 | 1.4 |
| Total non-food crops | 40 285 | | 20 473 | | 42.5 |
| Overall totals | 3 087 600 | | 1 409 481 | | 348.5 |

a Estimates.
losses have not been included in the figures. They are certainly of significant importance, but reliable data to calculate these losses are not available. In addition, attention should be drawn to the significant losses that can be caused by various pest organisms in grasslands and forests.

It is quite evident that the magnitude of crop losses is enormous. The conclusion must be drawn that this extremely high level of wasted agricultural produce should be unacceptable to society as a whole, especially in view of recurring food shortages. Examples are given below of the impact of these losses, and efforts to reduce them, on land use. In fact, these examples also show that for virtually all categories of agricultural pest organisms, particularly in recent years, man has still not been able to reduce these losses significantly. Part of this failure is certainly due to the fact that inadequate recognition is given to the importance of cultural practices and the need to improve the overall plant health situation.

5. VI.4 PLANT PROTECTION UNTIL THE 1940s

Until the 1940s, as noted earlier, efforts to reduce crop losses were mainly based on the use of natural control practices in the broadest sense. From the middle of the nineteenth century these efforts were gradually complemented by pesticides of botanical and, in particular, inorganic origin. But plant protection maintained as its basis a complex of efforts aimed at the augmentation of the overall resistance of the agro-ecosystem to the development of pest organisms. Pest control strictly speaking (i.e. the deliberate control of specific pest organisms through pesticide applications) was of rather limited importance and mainly supplementary. With respect to land transformation, two matters are of particular relevance:

(1) large-scale outbreaks of pests which in certain cases resulted in the impossibility, at least temporarily, of growing specific crops or crop varieties and made agriculture in the region concerned permanently more difficult;
(2) the adoption of crop rotations to reduce pest carry-over from one crop to the other.

Both elements had, of course, significant impacts on agricultural practices in general. The spread of pests is still a major concern in current plant protection practices, but modern control measures generally allow the reduction of the overall impact, be it sometimes at very high cost. Pests continue to lead in a number of cases to restrictions on the growing of crops in certain regions.

5. VI.4.1 Spread and Outbreaks of Pest Organisms

The sudden spread of new pests is well known for most groups of pest organisms. Fungal diseases that can be easily spread by wind and water, and
for which the causal organisms can in certain cases survive for long periods in the absence of the host plant, are very well known in this respect. But the introduction of new weed species, as well as the spread of insects and nematodes, with or without their host plant, has also frequently occurred. The subsequent outbreak of pest organisms occur, in particular, in situations where agricultural crops have been introduced rather recently, such as in the USA and Australia.

Ainsworth (1981) has given an overview of the major disease epidemics and their impact. The epidemic of the potato blight in Europe caused by *Phytophthora infestans*, which appeared in Europe for the first time in the 1840s, is certainly one of the most notable cases. It caused massive famine in Ireland and resulted in the migration of a large portion of the population to the USA. Coffee rust (*Hemileia vastatrix*) was accidentally introduced around 1869 in Sri Lanka and wiped out coffee production in that country. The crop was replaced by tea. The same disease organism spread accidentally to Brazil in the 1960s and is now considered the major threat to the coffee industry of Latin America.

The introduction of vine mildew (*Plasmopara viticola*) from North America into France in the 1870s threatened wine growing in that country for many years. The losses caused were overcome through the breeding of resistant varieties by hybridizing European stocks with American. Dutch elm disease was introduced into North America from Europe in 1931 and has since then been destroying American elms. The reintroduction of a more virulent strain of the same disease into England in 1970 is still devastating elm trees in that country. Chestnut blight (*Endothia parasitica*) was accidentally brought into the eastern USA in 1904 with nursery stocks from Asia. Within a few years it virtually eliminated the American chestnut.

Certain endemic diseases could reach epidemic proportions after, for example, periods of favourable weather conditions. Epidemics of ergot of rye (*Claviceps purpureum*), for example, had caused many human deaths until the nineteenth century. In recent years some disease epidemics have been created by the release of new varieties with augmented disease susceptibility, and considerable losses have sometimes occurred (Lupton, 1976). An example of this is leaf blight (*Bipolaris (Helminthosporium) maydis*) in hybrid maize production. This susceptibility came from the male sterile line and had been introduced to such an extent in commercial varieties that losses estimated at one billion dollars were suffered in the USA during the years 1971–73 before the cause was discovered and action could be taken. The same phenomenon occurred with the release of hybrid varieties of pearl millet in India that proved very susceptible to downy mildew (*Sclerospora graminicola*). As a result the national pearl millet yield in India was reduced by more than 50% in 1973.

The still ongoing efforts to contain the spread of pear fireblight in West
Europe caused by the bacteria *Erwinia amylovora*, including the destruction of various wild hosts, show the continued impact of disease epidemics in modern agricultural practice.

In discussing introductions of insect pests Simmonds and Greathead (1977) note that certain characteristics favour spread. Small insects, for example, can readily be transported on plant material or passively by air currents, and polyphagous species have more chances to survive in their new surroundings. But they also note that in many instances pests were distributed by man when he transported them together with their host plants into new surroundings.

The grape Phylloxera (*Viteus vitifoliae*) was introduced in the middle of the nineteenth century from North America into Europe and nearly destroyed the wine industry in France. This aphid attacks the roots and was estimated to have destroyed by 1884 the vines over an area of 1.2 million hectares. The total monetary loss at that time amounted to US$2 billion. In fact this has also become the classic example of the successful control of an insect by breeding resistant varieties. In this case resistant American rootstocks were used.

Until the end of the nineteenth century cotton had been grown in North America for about 100 years without suffering from significant insect damage. However, in 1892 the boll weevil (*Anthonomus grandis*) entered Texas from Mexico and has since rapidly spread over a large part of the American cotton belt. This has led to the disappearance of the slow-growing sea-island cotton varieties in the southern part of the USA. In addition the boll weevil became a permanent cotton pest that has dominated production practices until today. It is now considered the most costly insect in the USA. Moreover, control measures taken have led to a series of secondary effects, which have increased further the costs of cotton production.

The cottony cushion scale *Icerya purchasi* was introduced around 1870 into California and became such an important pest that in the 1880s it threatened the citrus industry in the western United States. The introduction of an effective predator of the scale, the ladybird beetle (*Rodolia cardinalis*) re-established a more balanced agro-ecosystem and reduced the pest to below economically significant levels. However, this pest has continued to be the determining factor in the citrus production practices of this area.

In certain instances locally occurring species have become pests of introduced crops. For example, the European corn borer *Ostrinia nubilalis* fed originally on *Artemisia* spp. before it became a pest on maize. It was later introduced into North America. The colorado beetle (*Leptinotarsa decemlineata*) provides a similar example. It became a pest of potatoes when the latter was introduced from South America into North America. Later the beetle was introduced into Europe where it is still considered a pest requiring specific plant quarantine measures.

Weeds constitute a major constraint to agriculture and they have been widely introduced into new areas with inherent economic damage. A study of
500 weeds of North America showed the following origin: native 39%, Europe 35%, Eurasia 13%, tropical America 3%, Asia 2%, undetermined 8% (Burnside, 1979). An excellent example of an introduced weed from Europe to the USA is St. John’s wort (*Hypericum perforatum*). In Europe this weed is not of economic significance, but in its new environment it became one of the worst grassland weeds. It was finally brought under control by the introduction of Chrysomelid beetles (*Chrysolina* spp.) that became very effective ‘pests’ of the weed.

Weeds were sometimes introduced as ornamentals or as fodder crops. As such, prickly pear (*Opuntia* spp.) became a major problem in Australia. By 1925 *Opuntia* had invaded about 25 million hectares, rendering them unsuitable for agriculture. It has also become one of the most outstanding examples of effective biological control of weeds. During the 1920s the deliberately introduced lepidoptera *Cactoblastis cactorum*, and some other biocontrol insects, succeeded in gradually reducing prickly pear to an insignificant weed.

The water hyacinth (*Eichhornia crassipes*), which originates from Central and South America, has very nice flowers; this is one of the main reasons why it is now a major waterweed in North America and parts of Africa and it is still spreading further. It may completely block waterways and has caused enormous economic losses. In the course of the 1960s the weed *Parthenium hysterophorus* was probably introduced into India with food aid shipments. Since then it has spread continuously. Many other cases of pest introduction have been reported in the literature and many have certainly occurred unnoticed. The spread of various plant parasitic nematodes belongs to the latter category.

The spread of pest organisms continues to be of major concern even in today’s modern agriculture. It has not only been greatly facilitated by increased communication, but also by agriculture itself. Agricultural practices in general offer very favourable conditions for newly introduced pest organisms and augment their chances of reaching pest status. However, the major reason that newly introduced organisms often become more important pests than in their country of origin is the absence of effective natural control mechanisms. The result may be a much faster population build-up, unless biotic mortality factors are also introduced. The examples given of the prickly pear and St. John’s wort show that the agro-ecosystem can indeed be made more resistant to pest development. Similar examples exist for the biocontrol of introduced insects (e.g. the cottony cushion scale in citrus growing in the western USA mentioned above).

5. VI. 4.2 Crop Rotations

In the older literature crop rotations are often highlighted as useful plant protection measures, especially for the control of soil living organisms.
Wardle and Buckle (1923) note, while discussing crop rotations with respect to insect control, that traditionally crops have been and are grown in a particular order. They indicate that maintaining soil fertility is generally the major reason, but that there might also be some benefits for insect control; however, these authors do not give further details. Crop rotation is very briefly mentioned by Smith (1948), and he concludes that

Crop rotation in practice probably has little influence upon the degree of insect infestation over the whole area, chiefly because of the variation in crop rotation on different farms and because insect pests are rarely specific to one plant host and also have strong migratory powers.

This is probably correct with the exception of certain soil insects. For example, rotating corn with soy-beans is considered an effective measure for the control of corn rootworms.

Crop rotations are often mentioned in connection with the control of noxious weeds. Rotations using crops with different life histories will help to reduce weeds with life cycles that are not adapted to the cultural practice of the cultivated crops. Winter annual weeds, such as weed bromegrasses, will be of little importance under cultural practices normally applied to summer annual row crops, such as corn. Many summer annual weeds will not thrive under the cultural practices of autumn planted cereals (Koch, 1970). For example, wild oats (*Avena fatua*), a summer weed, is abundantly present in a continuous succession of summer cereals, while its population does not increase in a cycle where the summer cereal is grown only once every four years.

The significance of crop rotations has been studied in particular for soil-living disease organisms, including nematodes. A detailed review has been published by Curl (1963), from which a number of examples are drawn here. He notes that crop rotation as a control measure has been directed chiefly, and with the greatest success, towards control of root diseases, many of which cannot yet be economically reduced by fungicidal treatment. It would be applicable, in particular, to the so-called root-inhabiting fungi that are regarded as specialized parasites, and normally do not survive long in an active state in the absence of living host plants.

Studies on the control of different foot and root rots of wheat in the USA led to the conclusion that the impact of these diseases may be reduced through crop rotation. But in that case wheat should be preceded for 3–6 years by non-susceptible crops. Maize root rots, caused primarily by species of *Pythium*, *Helminthosporium* and *Fusarium*, have been reduced by crop rotation in many places in the USA. Similarly crop rotations have been used with success to obtain profitable yields with peas in spite of fungi that caused pea root rot.

Various rotation experiments have been carried out to control *verticillium*
wilt (*Verticillium albo-atrum*) of potatoes. Based on numbers of infested tubers, it was demonstrated that 3- and 4-year rotations gave practically complete control. The reduction of *Plasmodiophora brassicae*, the cabbage club root fungus, requires a host-free period exceeding four years. Such a long period is needed as resting spores survive for quite a long time in the soil.

Of the various measures recommended to control nematodes, crop rotation has been and often still is one of the most satisfactory. The best known examples in this respect are the sugar beet nematode (*Globodera schachtii*) and the potato root eelworm (*Globodera rostochiensis*). In Great Britain the sugar-beet eelworm Order of 1943 allowed the enforcement of crop rotation on infested and non-infested land; and although it was quite difficult to apply the same rules with good results to various situations, this legislative procedure served to draw attention to the value of rotation in reducing the rate of spread of the parasite and subsequently preventing serious crop losses.

Comparable rules have been established for potato-growing in Western Europe for the control of the root eelworm. For example, in the Netherlands the following regulations are currently enforced. Susceptible potatoes may only be grown in those fields where (i) for the last three years no potatoes have been grown; or (ii) for the last time, three years ago, susceptible potatoes have been grown and a soil disinfection has been carried out and notification given to the plant protection service; (iii) for the last time, three years ago, resistant potatoes have been grown; or (iv) for the last time, two years ago, a resistant potato variety has been grown and the field has been disinfected before or after the growing season and has been notified to the plant protection service. Resistant potatoes may be grown on fields where (a) for the last two years no potatoes have been grown, or (b) for the last time, two years ago, potatoes have been grown and a soil disinfection has been carried out and the plant protection service notified.

Crop rotation is seldom included in recommendations for controlling diseases caused by viruses, particularly where the virus has a wide host range. The best evidence of virus control by rotation is found in studies with tobacco mosaic and wheat mosaic viruses. It was found in field experiments in Illinois that cropping with non-susceptible crops may reduce damage from wheat mosaic, but rotation was not considered entirely adequate as a control measure. The incidence of virus diseases of Brassica crops in Great Britain was reduced by omitting one crop for a short period.

In a recent publication (Palti, 1981) the various reasons for applying crop rotations were listed in the following way:

1. General agronomy: better use of nutrients and desirable effects on soil texture, with deep-rooted crops alternating with crops with shallow roots; water economy, in particular conservation of water in years of fallow.
2. Weed control: row crops in which in-growth tillage for weed control
could be practised alternated with crops sown by broadcasting, crops likely to stifle by their rapid growth and dense foliage (beets, potatoes) alternated with crops making slow and sparser growth (onions).

(3) Soil-born pathogens were held to be amenable to ‘starving out’ by depriving them of their hosts for several years in succession.

The same author also cites the example that:

The Incas passed a law that potatoes must not be grown on the same land more than once in seven years. It so happens that this is the period required for nematode populations to diminish to a level which makes it possible to produce another potato crop. The Spanish conquerors of Peru, contemptuous of a law that to them seemed senseless, repealed it with disastrous results.

However, the economic need to further augment agricultural productivity has in the last 40 years strongly decreased the reliance on crop rotations as a way to reduce pest impact. The availability of relatively cheap and effective synthetic organic pesticides has favoured this development considerably.

5. VI.5 WIDESPREAD USE OF SYNTHETIC ORGANIC PESTICIDES

The rapid development of the synthetic organic pesticides since the 1940s runs parallel with the strong increase in agricultural productivity. It would be incorrect to conclude that the latter was determined by the former, but the availability of these new protection measures certainly made the very rapid changes in agriculture easier. Various cultural practices could be changed without significant increases in pest problems. The increased percentage of mono-cropping of large areas is, of course, the best example where the use of pesticides has relegated pest problems to a secondary position in planning decisions. Economic requirements and technological developments were the major forces behind these changes.

In view of man’s continued struggle to become more independent of agricultural and other pests, the confidence placed in these new tools was well justified, although it can now be easily argued that mistakes were made. But, with the knowledge originally available it would have been impossible to advise how plant protection matters could have been better solved. Consequently, it was not surprising that within plant protection the emphasis shifted from the use of a number of crop improvement measures, to the control of individual pest species through the intensive use of pesticides. This occurred particularly for those groups of pest organisms for which effective pesticides became available (i.e. insects and weeds). Thus, pesticides have contributed enormously to the way in which land use has changed in modern agriculture.

This contribution can probably best be appreciated by briefly reviewing the developments in pesticide usage. The statistics for this are generally expressed on the basis of the money value of the annual purchases. The best information
is available from the US market, and the USA also best illustrates shifts of usages in modern agriculture. Some global figures however, provide a useful introduction (Woodburn, 1983).

The 1982 global market in crop protection chemicals amounted to an end-user value of US$13.3 billion. Of this, herbicides represented 39.5%, insecticides 32.7%, fungicides 21.9% and others 5.9%. Over 70% of the herbicides are used in North America and Western Europe. Insecticides are used in particular on crops in tropical and sub-tropical regions, while fungicides are mainly used in high-value crops. An overview of the usage on some major crops is given in Table 5.VI.2.

Table 5.VI.2 shows the significant use of pesticides on fruit and vegetables, including vines. The latter crop is, of course, the main reason for the fact that this group covers over 40% of the world fungicide market. Maize, soy-beans and wheat are together responsible for over 50% of the herbicide market, while fruit and vegetables and cotton each consume about one-quarter of the insecticides sold. Over the recent years the market share of herbicides has been growing considerably, in particular at the expense of insecticides.

The average annual real increase in the world pesticide market since 1970 has been around 4.5%. This growth rate was substantially higher at the beginning of the period; since 1978 the annual growth rate has been about 4%. In particular, the use of non-selective herbicides has increased in recent years and is directly related to the extension of reduced tillage practices in agriculture. A continued growth of pesticide usage is expected, at about 5% per annum. Towards 1990 the total agricultural pesticide market is expected to amount to US$20 billion (in 1982 $ terms). The geographical spread of pesticide consumption will not change significantly from today's figures, as shown in Table 5.VI.3.

The use of pesticides in US agriculture has been reviewed by Eichers (1982). The US farmers' expenditure on pesticides increased from less than US$200 million in 1951 to nearly US$2 billion in 1976. Use on a constant

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<tr>
<th>Crop</th>
<th>Herbicides</th>
<th>Insecticides</th>
<th>Fungicides</th>
<th>Totals</th>
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</thead>
<tbody>
<tr>
<td>Fruit and Vegetables (including vines)</td>
<td>425</td>
<td>1160</td>
<td>1300</td>
<td>2885</td>
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<tr>
<td>Maize</td>
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dollar basis increased about 5.5 times over these 25 years. By 1976 the farmers used annually an average of about 2.75 kg of pesticide for each hectare of agricultural land treated. In 1982 herbicides represented 57% of total agricultural pesticide use in the USA, insecticides 30% and fungicides 13%. It must be noted that pesticides are practically not used on pasture or range land.

Over the period 1966 to 1976 insecticide use increased by about 17%, fungicide use was up by about 43%, while herbicide use almost quadrupled. The latter figure demonstrates the gradual change in use and treatment of arable land—for example, the extension of no-tillage practices. Such changes would not have been possible without the availability of non-selective herbicides. From 1966 to 1976 the area treated with herbicides in the USA doubled from 40 to 80 million hectares, while the quantity of active ingredient used per hectare rose from 3 kg to 5.4 kg. Leading products in 1976 were atrazine and alachlor, which together accounted for about one-half of the market, while the third-ranking 2,4-D had dropped from its leading place in 1966 when it represented 35% of all herbicides used.

The total area treated with insecticides increased between 1966 and 1976 from 17 to 30 million hectares, but the amount of active ingredient applied per hectare decreased from 9 kg to 6.2 kg. They were applied to 76% of the tobacco, 60% of the cotton, 55% of the peanuts and 38% of the maize grown in the USA in 1976. Because of problems with insecticide resistance and restrictions on use due to persistence in soil and water, the share of organochlorine insecticides diminished from 60% in 1966 to 25% in 1976. Organophosphates increased from 27% to 50%, and the other major group, the carbamates, increased from 9% to 19% of total insecticide use.

The area treated with fungicides increased between 1966 and 1976 from 1.9 to 4.3 million hectares, while the amount of active material used per hectare decreased from 20 kg to 11 kg. Over that period there have been relatively few changes in the types of fungicides used.

Eichers emphasizes the significant increase in agricultural productivity achieved through pesticide use, and he concludes:
The reasons for farmers' increased use of pesticides are rather clear: to reduce the labour required for production, to increase the amount of food available while using less land, to reduce waste and maintain or create a quality of food preferred by consumers, and to reduce the risk of crop failure.

It is estimated that in 1982 about 22% of all pesticides were used in developing countries; the Latin-American region showed the fastest growth rate. Pesticides are mostly used on so-called 'cash crops' in developing countries. For example, the high figures given above for maize mostly relate to the production in the USA. Maize produced for food by the small farmer receives very little, or no, crop-protection inputs, notwithstanding the potentially high losses caused by various pests.

While considering the above figures on pesticide use, it should be born in mind that currently the major tasks in tropical agriculture are the production and distribution of enough food for the rapidly expanding world population, plus the improvement of small farmers' welfare through a gradual increase in their earnings. The most important tropical food crops—such as rice, maize, sorghum, millet, pulses, roots and tubers—are almost exclusively grown by small farmers; thus the requisite increases in food production have to be realized by this group.

However, during recent decades the development of pest control technology has been determined mainly by the needs of highly capital-intensive agriculture in the Western world. Since the 1940s the change from an emphasis on the use of cultural practices and resistant varieties to reduce pest incidence, to chemical pest control, was economically justified in this system and was generally adopted. This technology was then widely introduced into tropical agriculture to protect cash crops.

The tendency now is to apply the same approach to small farmers' food crops in an attempt to achieve the required food production increases. Before doing so, however, adequate attention should be paid to various specific aspects of current agricultural production, to ensure that permanent beneficial results are achieved. The criterion to be used to evaluate the results should be real progress in the plant health situation. In other words, an agricultural production system must be established where the minimum of plant protection inputs and efforts are needed to achieve the healthiest product. This goal can be achieved, but only if both the useful characteristics as well as the limitations of pesticides are well understood.

In this respect, we must draw on the experience gained so far and strive for well-balanced changes in land use in the developing countries. However, it should at the same time be stressed that these countries do not yet take adequate advantage of the benefits that could be obtained through the proper use of these useful tools. For example, limited and well-adapted use of herbicides would not only reduce the current enormous losses caused by weeds, but would also help to overcome the shortage of hand-labour in critical growing periods, as well as part of the drudgery of hand-weeding.
Thus, over a period of 40 years synthetic organic pesticides have become an integral part of modern agriculture. They have directly contributed to a more productive use of farmland and have allowed the maximum benefit to be derived from the investments made in other production factors. However, their intensive use has also revealed a number of shortcomings which led to negative changes in the agro-ecosystem. As a consequence, the use of certain products has decreased, and the use pattern of pesticides has and will gradually be further changed in the future. More details of these developments are discussed in the following section.

5.VI.6 INTEGRATED PEST MANAGEMENT

Regular use of pesticides may result in a number of unforeseen side-effects, which reduce the benefits to be gained. The study of these side-effects has indicated that pesticides can be used most effectively in reducing pest populations, when proper consideration is given to other crop production and protection factors. In fact, we should return to the concept of the period before 1940 that the total plant protection situation needs to be considered in order to optimize control results. If a specific pest is controlled, then it should be known how these activities affect the overall system. The integration of chemical control with other control measures is needed, and integrated pest management has emerged as a new phase in crop protection.

The side-effects referred to above concern negative changes in the agro-ecosystem that reduce its capacity for plant production. In the context of plant protection and land transformation they require further discussion. Side-effects include:

(1) the emergence of pesticide-resistant strains of pest organisms;
(2) effects on the balance of organisms in the agro-ecosystem and the subsequent emergence of new pest problems;
(3) the pollution of the environment by pesticides.

Pesticide resistance occurs in all groups of pest organisms (CAST, 1983). Surveys have revealed that among arthropods (insects, mites and ticks) at least 428 species had developed resistance to one or more insecticides that were once effective against them. In particular in cotton growing, where insecticides are used very extensively, this has led to situations where the major pest could not be adequately controlled during certain periods—for example, in Peru and Mexico. In other situations, such as in Central America and Sudan, the cost of cotton production has increased enormously. Similar problems have occurred in other crop situations where pesticides were frequently used. In Central America, Turkey and Sudan, an additional effect was found as malaria-transmitting mosquitoes also became resistant to the products commonly used in treating cotton. This in turn entailed considerable costs and difficulties for malaria control. Of the above reported 428 species of
arthropods, about 60% are of agricultural importance. Resistance has been reported in more than 90 species of plant pathogens, 36 species of weeds and 2 species of nematodes.

Pesticide-resisting strains occur as a result of the selection of resistant individuals within the existing population. The speed of development of resistance depends on many factors, the major ones being the selection pressure exerted by the pesticide and the development rate of the pest organism concerned. This rate is generally higher under tropical conditions, and widespread application of certain pesticides can therefore lead to the appearance of pesticide-resistant populations within a period of only 2–3 years. The situation is further complicated by the phenomenon of cross resistance, i.e. resistance to a specific pesticide entails simultaneous resistance to related pesticides. The speed of occurrence of pesticide-resistant strains can only be reduced by more selective and reduced use of the pesticides concerned. The lesson to be derived from this is that excessive use of pesticides should be avoided, and that they should only be applied when the pest situation really warrants it.

Pesticides are chemical compounds deliberately released into an ecosystem (usually an agro-ecosystem) for the purpose of eliminating or significantly reducing specific organisms (pests) that adversely affect crop productivity, or animal and human health. These pest organisms are part of an intricate ecological system and are often a food source for, or provide shelter to, a multitude of insects, fungi, bacteria etc. It is useful to note, however, that of the insects encountered, only a very small percentage of the species feed on higher plants. By far the majority live on other insects or detritus.

Experience has taught us that the application of a pesticide, in addition to the effect on the pest to be controlled, will almost always simultaneously affect many of the so-called non-target organisms. This in turn will have a destabilizing effect on the ecosystem, and as a consequence may negate part of the objective of the pesticide application (i.e. an improvement of the plant health situation).

Cotton growing in Sudan provides a good example of the potential ecotoxic effect of pesticides. Currently the cotton whitefly *Bemisia tabaci* is the most important cotton pest in the Gezira in the Sudan, causing every year severe damage associated with very heavy pest populations in late season. This contrasts strongly with the situation before the large-scale application of the pesticides. Then, the whitefly was only an occasional pest and infestations were limited to early and mid-season. A combination of factors is certainly responsible for this change; but there is now clear evidence that the reduction of the natural biological control agents has been the major cause for the increased pest incidence. The development of pesticide-resistant pest populations has further worsened the situation. Following introduction of the boll weevil into the USA, mentioned earlier, application of extensive control
measures has led to the emergence of the bollworm (*Heliothis virescens*) as a new major pest, due to the elimination of natural control agents.

Spider mites are the most typical man-made pests in apple orchards; the best-known species in Western Europe is the fruit-tree red spider mite, *Panonychus ulmi*. From a number of experiments it could be concluded that the absence of predatory mites was the major cause for the abundance of the spider mites in modern apple orchards. However, only when it became evident that certain fungicides used for the control of diseases were toxic to these predators could this knowledge be used for practical purposes.

With respect to disease control the situation seems to be different to the extent that only a limited number of comparable examples have been studied. Bollen (1982), in discussing the microbial balance, notes that in the natural environment suppression of sensitive species will soon result in an increase of resistant species competing for the same substrates. He also notes that pathogenic fungi are often parasitized by other fungi and that fungicides may effect this parasitism. Reference is made to the high level of white mould damage caused by *Sclerotium rolfsii* in peanuts sprayed with benomyl. This has probably resulted from the inhibition of the effective parasite *Trichoderma viride*.

The use of herbicides definitely leads to shifts in weed problems. Weed species less susceptible to the herbicide most commonly used will gradually dominate the specific agro-ecosystem. Parker (1977) notes that 'interspecific selection by herbicides is now by far the most important factor resulting in changes of weed problems'. He cites the example of herbicide use in small grain cereals in the United Kingdom, where first *Stellaria media* and *Galium aparine* emerged as new weed problems. After a change in the herbicide used *Polygonium* spp. emerged, and this was followed by the dominance of mayweeds (*Matricaria* and *Tripleurospermum* spp.). Meanwhile there was a continuous increase of wild oats (*Avena fatua*), requiring the use of specific herbicides, while for the grassweed *Alopecurus myosuroides* other new control measures were needed. In maize in the USA there have been corresponding changes resulting in increases again in annual grass weeds, particularly *Digitaria sanguinalis*, *Setaria* spp. and *Panicum dichotomiflorum*.

The examples cited clearly demonstrate that the use of pesticides, although primarily aimed at solving one or more specific pest problems, in many cases will have additional effects. These effects vary considerably depending on the type of pesticide used and the composition and functioning of the agro-ecosystem concerned. With insecticides and fungicides the impact on parasites and predators has to be considered in control operations, in weed control the relative effectiveness of the herbicides *vis-à-vis* the various plant species determines shifts in dominance.

The overall effect is that the agro-ecosystem tends to become more resistant towards the chemical control measures commonly applied. In other
words, the system has been made somewhat less suitable for current agricultural practices and, in that sense, the land use possibilities have been changed, however slightly.

The impact of pesticides on the environment has been discussed in many fora and has been the strongest factor leading to gradual changes in plant-protection practices. Although numerous studies have been published, the exact cause–effect relationships, short and long term, have rarely been demonstrated.

It has become clear that the environmental impact of a pesticide is determined by, in addition to its toxicity, the persistence of the compound in the environment, and its ability to accumulate in living organisms. Many organochlorine insecticides show a high degree of persistence and are lipid soluble, and thus were detected in soil, water and various organisms at unexpectedly high levels. Various observations have shown that these types of compounds can persist in the soil for many years.

Accumulation in living organisms can be exacerbated in the terrestrial environment by the so-called food-chain effect: lower organisms being eaten by higher organisms, and the latter thus accumulating increased dosages of the compounds concerned. For example, various studies have been carried out on the impairment of reproduction of raptorial birds as a result of eggshell-thinning. It has now been accepted that metabolites of DDT, and in particular DDE, are the most likely cause of shell-thinning. As the current most widely used pesticides do break down quite rapidly, such chronic effects are unlikely to occur. However, the possibility of a direct impact on the environment cannot be excluded, and this aspect is, and must be given careful consideration in the development of new compounds.

The total impact of the continuous efforts to reduce the effect of pest organisms in agriculture can best be evaluated by studying crop loss data. Such data are available from the USA and are summarized in Table 5.VI.4. The figures indicate that the relative importance of crop losses has not decreased since the 1940s. On the contrary, an increase is noted in insect and disease damage, while only in the case of weeds has a significant reduction occurred. It is rather difficult to explain these trends in detail. They certainly confirm that synthetic organic pesticides alone, in the way they have been

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<th>1942–51</th>
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<td>7.1</td>
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<td>Diseases</td>
<td>10.5</td>
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<td>Weeds</td>
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<td>Total losses</td>
<td>31.4</td>
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used so far, have not enabled us to reduce pests to insignificant levels. This is, in fact, rather surprising as it can be readily shown in well-planned experiments that most organisms that are amenable to chemical control can generally be very well reduced to very low levels.

However, this is only a short-term effect and, in most cases, inadequate attention has been paid to the long-term effects. The build-up of pest resistance is one adverse phenomenon, but probably more important is the elimination of natural control organisms in the case of insects, mites and fungi. To a certain extent the opposite of what is aimed at is achieved: pests are controlled in such a way that simultaneously their reproduction possibilities are increased by reducing the effect of natural control factors (Brader, 1980). It should also be realized that important groups of organisms such as viruses and bacteria cannot be controlled by chemical means, while effective control of various soil organisms is always difficult to achieve. Moreover, as mentioned in the introduction, intensification of various agricultural practices has made crops more conducive to pest development.

The newly developed integrated pest management (IPM) programmes have been designed to avoid the above-mentioned shortcomings. Within IPM two types of control measures are applied:

(1) crop-protection measures that have a long-term effect and render the agro-ecosystem more resistant to pest development;
(2) short-term measures that are applied when the pest reaches the so-called economic damage threshold (i.e. the level at which the crop losses caused equal the cost of the control measure).

The long-term measures concern modified cultural practices and, in particular, the introduction of pest-resistant crop varieties. The cultural practices may include matters such as changed sowing dates, modified fertilizer use, clean-up of crop left-overs and appropriate rotations. IPM requires regular monitoring of pest populations to ensure that control measures are only applied when really needed. In addition, when control measures are applied maximum care is taken that the activity of the so-called natural enemies (parasites and predators that usually destroy a large portion of the pest organisms) is reduced as little as possible. This can be partly achieved by the choice of the pesticides used and the timing of their application. In addition, increased progress is made on the production of selective control means (for example, mass-reared parasites and predators).

IPM programmes are increasingly applied in a multitude of crops, including cotton, rice, soy-beans and various orchard and glasshouse crops. Their introduction into practice has shown that pesticide usage can usually be reduced by at least 50%, while maintaining or even improving production results. Indeed these programmes clearly provide a model for making the best use of pesticides.
5.VI.7 SUMMARY AND CONCLUSIONS

In traditional agriculture production practices have evolved that rendered the crops rather resistant to pest attack. This, along with other factors, led to the implementation of well-adapted cropping systems and rotations. Under such conditions certain losses occurred, but these were considered unavoidable. The occurrence of pest epidemics as a result of weather patterns or the introduction of new pest organisms has from time to time upset this system and caused major catastrophies. But, in general, these systems were rather stable. Gradually pesticides have been developed that allow better control and have, in particular, reduced the significance of agricultural pest epidemics. Originally pesticides were extracted mainly from plants or were of inorganic chemical origin. Since the 1940s the synthetic organic pesticides have become the major control measures. The introduction of these new tools has permitted considerable change in agricultural practice.

However, the widespread use of pesticides has also revealed a number of shortcomings. These include the emergence of new pest problems, the development of pesticide-resistant pest populations, and pollution of the environment. Combined with the intensification of agriculture, which has generally rendered the crops more susceptible to pest attack, these effects have resulted in a situation where crop losses continue to be high. In some cases, where the same crop varieties are grown on a large scale, for example the so called High Yielding Varieties, the results, temporarily, may be real pest epidemics.

Recognition and analysis of the potential shortcomings of pesticide use has also led to a much better understanding of the functioning of agro-ecosystems. The emergence of new pest problems was due to the elimination of so-called natural enemies, parasites and predators that to a large extent proved to control the development of the population of pest species. It has thus become clear that every effort should be made to safeguard these useful organisms. Pesticide resistance results from the selection of resistant specimens within the existing pest populations under the continuous pressure of large-scale and intensive use of the same type of pesticides. Reduction of use and eventually changing the types of pesticides may considerably alleviate the development of resistant strains. The environmental impact of certain pesticides is mainly due to the combined fact that the compounds degrade very slowly and can accumulate in body tissues. Consequently, products with different physico-chemical properties are now widely used.

In addition to these factors directly related to pesticides, more attention is being given to the resistance of the crop as a whole to pest development. The important criterion to be considered is the need to maintain the economic viability of crop production. For example, increased fertilizer and water use augments the susceptibility to pest attack. But, as these factors are so essential
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for crop production, they cannot be changed for the sake of plant protection alone. The same holds for current cropping practices which allow for the optimal use of farm machinery. On the other hand, matters such as the genetic susceptibility of the varieties grown offer excellent opportunities to reduce pest incidence. Breeding of pest-resistant varieties has thus become of major importance in recent years.

In traditional agriculture a combination of practices were willingly or unwillingly used to render the crop less prone to pest attack. Modern pest-control measures were initially so effective that the major attention could be shifted to the acute pest control problems and the overall susceptibility of the production system to pest attack did not require special concern. Other production factors largely determined the way in which agriculture has been developed in recent decennia. However, new experience and knowledge have shown the existence of limitations, and it has become clear that a permanently healthy production system requires an integration of various plant-protection practices. Thus a healthier and more stable agro-ecosystem will be established in which optimum use can also be made of modern pest-control measures through which maximum benefit can be drawn from land transformation efforts and other production inputs.

5.VI.8 REFERENCES


