Fifty years of crop protection, 1950–2000

J.C. Zadoks

Herengracht 96-c, NL-1015 BS Amsterdam, The Netherlands (e-mail: jczadoks@euronet.nl)

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Introduction

The concept of 'crop protection' as a discipline in its own rights dates from the 19th century. In the Netherlands, Ritzema Bos was the proponent (Ritzema Bos, 1895) and literally the embodiment of this discipline (Schroevers, 1928). Nonetheless, crop protection never became what it should be, a discipline by itself (Zadoks, 1994). It has become an area of public and private activity, where many disciplines – old and new – meet with practical needs. Among the classic disciplines, entomology and phytopathology rank highly. New disciplines are molecular genetics and genomics. In addition, disciplines from the humanities such as economics, sociology, and communication science were called to help.

At the turn of the 20th century, several authors looked back on crop protection in general (Koeman & Zadoks, 1999) or on its contributing disciplines entomology (Chapman, 2000), phytopathology (Zadoks, 2001) and virology (Bos, 2000), to quote an arbitrary choice. They add information to older summaries[1] (e.g. Smith *et al.*, 1973; Zadoks & Koster, 1976; Zadoks, 1991). The 'Prefatory Chapters' and the chapters on 'Pioneer Leaders' in the Annual Review of Phytopathology are a treasure trove of personalized history. Bieleman (2001) discussed and Bain *et al.* (1995) admirably illustrated the farmer protecting his crop. In this paper some developments of the last half-century will be sketched following changes in world agriculture (Palti, 1981).

Intensification and extensification of agriculture

In the period under review, agricultural intensity has changed considerably, with strong intensification in developed countries, and zero to good intensification in devel-

1 See also Netherlands Journal of Plant Pathology 72 (2) 1966 issued to commemorate the 75th anniversary of the Netherlands Society of Plant Pathology.

oping countries, whereas vociferous pressure groups advocate de-intensification or extensification in affluent societies. Over the last 50 years, the world population roughly doubled and agricultural land per capita decreased from 0.25 ha to about half that value (Den Hartog, 2002). So yields must at least have doubled during the period of our study. Intensification was a must and has been a success. Higher outputs per unit area and unit labour have been attained world-wide. Empirical data indicate that during the last 3 to 4 decades of the 20th century agricultural production increased by 2.25% annually whereas real prices decreased by 2/3% (Kuyvenhoven, 2002). The use of land and labour increased by 0.5% and labour productivity by 2.5% per year. The amount, quality and diversity of agricultural products have improved considerably, and the processing and storage of perishable products have bettered. These impressive results were obtained by increasingly higher external inputs of knowledge and technology. It is hardly possible to de-aggregate the success over contributing disciplines. A common statement is that half of the success was due to improved varieties and the other half to improved cultivation practices. Crop protection definitely contributed to the overall success but to what degree?

Whereas a green evolution proceeded slowly but steadily in the developed countries over hundred years or more, the Green Revolution swept over the developing world though barely touching Africa. The Green Revolution was inspired in part by the Cold War antagonism of the 1960s, with the idea that relief from hunger and misery would keep suffering countries in the western camp or at least prevent them from turning to communism. Far-seeing Americans took the lead, not by direct government action but through charities such as the Rockefeller and Ford Foundations, with full diplomatic support from the USA government. The results were impressive since countries such as India and Vietnam became a net exporter of wheat and rice, respectively, and Indonesia became practically self-sufficient in rice, in spite of their high population growth rate. Key to the success were improved varieties, water management and pesticides.

Variety improvement

Varieties underwent drastic changes. Dwarfing genes were introduced in many cereal crops with the objective to improve the harvest index and to tolerate higher N inputs. The change in physical appearance of the crop had various consequences for crop protection. The tall varieties used so far suppressed weeds. This form of subconscious ecological weed control was replaced by chemical weed control. The shorter stature of the wheat varieties brought the vulnerable grain-producing heads nearer to the ground and some fungal pathogens profited from the shorter distance between their soil reservoir and the target ears. In north-west Europe in the 1950s, *Septoria nodorum* of wheat became much more conspicuous than it used to be (Becker, 1963). The shortened stature allowed for high N fertilizer dosages leading to changes in foliar physiology, which benefited biotrophic pathogens and sucking insects and disadvantaged perthotrophic pathogens. Biotrophs (e.g. rusts and mildews) and their look-alikes (e.g. *Pyricularia oryzae*) cause 'rich man's diseases' and perthotrophs (e.g. *Drechslera oryzae*) 'poor man's diseases'. Increased crop density (e.g. expressed as leaf area index) reduced airflow within the crop with unknown effects on the accessibility of target sites to pest propagules and on their escape from the crop. The increased humidity within the crop may have favoured many pests.

The Green Revolution's shock treatment of rice cultivation caused many a change. The early 'high-yielding varieties' were vulnerable to nearly every pest of the dictionary. Resistance had to be introduced to one pest after the other, beginning with resistance to *Pyricularia oryzae*. The International Rice Research Institute did a great job by producing multiple-resistance varieties.

Understanding the genetics of resistance made great progress but good resistance breeding is costly. At least two effects became visible. The use of dominant major genes for resistance allows rapid progress but at a penalty. These genes are often 'labile', i.e., their resistance is easily matched by new genes for virulence of the pest to be controlled. In the Netherlands, for example, yellow rust of wheat (*Puccinia striiformis*) produced on average one new race per year during a prolonged period (from about 1955 to1975). The interest in other genetic mechanisms of resistance gradually increased as expressed by terms such as 'horizontal resistance' and 'partial resistance'. Methods to exploit these forms of resistance at reasonable costs were developed (Jacobs & Parlevliet, 1993; Govers *et al.*, 2002).

Interspecific and intergeneric hybridization was developed before World War II and its products were marketed shortly after. Some resistances were successful but others were soon broken with dramatic consequences (Zadoks & Bouwman, 1985). Modern genetic modification overcomes the classical interspecific fertility barriers. In 2001, at world level over 50 million hectares were under genetically modified crops, almost all modified for crop protection purposes (Anon., 2002). Transgenic varieties have been a reasonable success producing extra benefits, which are said to be distributed over various stakeholders: farmers (40% or more), bioscience industry (10–30%), breeders (about 9%), and consumers (negligible) (Falck-Zepeda *et al.*, 2000). So far, transgenic varieties have had no adverse effects on human health. They have positive and negative ecological effects but our knowledge is not yet detailed enough for agricultural economists and ecologists to draw up the balance-sheat (Zadoks & Waibel, 2000).

Breeding companies can make money only if many farmers grow their seed. Whereas in the beginning of the period under review every European country had more or less its national seed supply with its national varieties, providing a varietal mosaic at the continental scale, the present situation is rather one of few varieties grown over large areas. So the risk of pest outbreaks has considerably increased, especially when new pathogenic strains appear. Chemical and genetical crop protection is, to some degree, interchangeable. No wonder that large pesticide companies bought up many comparatively small breeding companies and amalgamated into 'life science companies', selling pesticides and varieties, without or with genetic modification[2].

2 The then famous Dutch plant breeder Dr. W. Feekes already contemplated cashing by means of a combination of pesticides and varieties, semi-seriously, in the late 1950s.

Water management

Over the last 50 years, water management has improved considerably in many parts of the world but regress occurred too. The crop protection implications may be considerable. Where crops grow lush, the rich man's pests flourish. Where the expected water supply is either failing – with too much or too little, or lacking timeliness – new problems pop up.

In north-west Europe, water management improved considerably and the resulting regularity of crops in space over the field area, and in time throughout the growing season, has improved yields. In the Netherlands, dry winds from the east may retard potato growth in spring and overhead irrigation is applied, like during the 1976 drought. Such irrigation helps to reduce potato scab (*Streptomyces scabies*), but in recent years it promoted the spread of potato brown rot (*Ralstonia solanacearum*) when the irrigation water was infested (Van Elzas *et al.*, 2001). The consequences of excess rainfall – primarily in recent autumns – are not yet known in detail. Late-fall planting of cereals may have reduced the carry-over of inoculum from the preceding to the next crop, the 'green bridge' effect (Zadoks, 1984).

Overhead irrigation increases moisture retention in the canopy, causes splash dispersal and promotes diseases (Rotem & Palti, 1969; Palti, 1981). The introduction of drip irrigation and fertigation drastically improved the situation. Furrow irrigation is known to spread diseases. Similarly, the flooding of tropical rice fields can spread diseases such as bacterial leaf blight (*Xanthomonas campestris* pv *oryzae*). The first half of the 50 years under review saw the construction of large irrigation schemes, which brought higher productivity but also increased risks due to lack of water or at least timely water. Water supply may be out of season and as a result rice pests may appear, especially rice borers but also *Pyricularia*. Many irrigation systems are in poor repair, with leaching water creating wet patches where pests flourish and survive through seasons that would normally destroy them. Excess water at the head end and lack of water at the tail end of the system lead to disturbances of the agro-ecosystem. Floods resulting from the combination of neglect and excess precipitation can cause havoc; they contributed to the rapid spread of the once imported golden apple snail (*Pomacea canaliculata*) ravaging rice in the Philippines (Ketelaar, 1993).

Irrigation was part of the Green Revolution incantation. Transplanted irrigated rice in the humid tropics is relatively well protected from weeds, *Pyricularia* and several other pests, but in the 1990s in South East Asia water became scarce and labour expensive. Poor and irregular water supply favours weeds and various other pests, and lack of labour makes transplanting costly. One response was direct seeding, which created its own set of new problems. The Green Revolution credo has it to grow two to three rice crops per year, thus building the perfect 'green bridge' with serious crop protection implications. One is an intensified carry-over of pests from one crop to the next, as exemplified in Indonesia by rats in rice.

Pesticide management

The pesticide wave

Plant protection went through several episodes differing in their leading paradigm. From the 'pre-scientific' via the 'pathogenetist' and the 'chemotherapeutant' to the present 'new environmentalist' episode (Zadoks, 1991). The last half-century, coinciding roughly with the chemotherapeutant episode (Zadoks, 1991), saw the surge of the phenomenon 'pesticides'. The chemical industry eagerly seized the opportunity to invent and sell pesticides, and farmers were quite ready to buy and use them. The extension services of most countries were willing to recommend pesticides, often covering their own risk or ensuring their own income by advising more treatments than necessary. The first to ring the alarm bell were the ecologists (see Koeman & Zadoks, 1999), and their laments were expertly voiced by Rachel Carson (1962). Her case is exceptional because a single, well-documented person really made a difference for millions of people over several decades.

Governments responded by adjusting their pesticide laws, initially intended to protect farmers from malpractice of pesticide salesmen, in order to protect the consumer, the environment and the user. Around 2000, regulation in the European Union has become so strict that a scarcity of suitable pesticides threatens crop continuity in some areas. The strictness of the regulation has increased the costs to the degree that many chemical companies were forced to abandon their efforts in crop protection or to merge. A recent pulse of mergers reduced the number of research-based pesticide companies alarmingly (to 10 at best) and the danger exists that agriculture will experience a scarcity of new 'molecules' in the near future.

Developments in the tropics were stormy. In some countries no regulation existed and in other countries the existing regulations could not be enforced. In the 1960s until the 1980s, many stories circulated about unethical methods of pesticide companies to push their products. Alternatively, our concept of business ethics changed. Companies based in the developing countries want to profit from the pesticide wave. As they hardly have the capacity to develop new molecules they rather invest in 'generics', pesticides with patents expired. These are cheap to produce but often dangerous to man and environment (Oudejans, 1999). Will we see a second pesticide wave in developing countries with a burgeoning pesticide industry? In the West, the pesticide wave is over the top for a variety of reasons, among which restrictive legislation, meagre profits, and consumer pressure.

The pesticide profit

Pesticides were cheap and easy to apply, saved labour and relieved growers from worry so that they could sleep well, the 'sleeping pill' effect. Application of pesticides showed growers how much yield could be saved. Still, pesticides had a price. The notion grew that good timing and prospective calculation of costs and benefits could pay off. The Dutch EPIPRE system for pest control in wheat, which peaked around 1980, based its recommendations on a calculation of the costs and benefits of pesticide treatments

(Zadoks, 1989). In most cases it was financially attractive to reduce pesticide treatments but in some cases the farmers were recommended to treat more. Another example is the '40 days rule' in rice. Whereas pesticide salesmen in South East Asia pressed farmers to start treatments very early in the season, the International Rice Research Institute advocated the rule that insecticide treatments during the first 40 days of the rice crop never paid (see e.g. Heong *et al.*, 1994).

In the beginning, pesticides were regarded as production factors and Headley (1968) calculated that every dollar invested in pesticides yielded four dollars in return; too good to be true. Zadoks & Schein (1979) indicated that pesticides could do no more than increase 'actual yield' to 'attainable yield'. In other words, pesticides restrain 'yield-reducing factors' but cannot undo 'yield-limiting factors' (Rabbinge, 1993). Economists created the term 'damage abatement factors' and produced improved equations to calculate return on investment of pesticides (Lichtenberg & Zilberman, 1986).

The foregoing examples referred to costs and benefits at crop level. However, pesticides have important external effects. They arrive at distant places that were never treated, such as Antarctica and the high Rocky Mountains. As less than 5% of the pesticides applied reach target, the other 95% is environmental pollution, which affects not only the treated field but also the field's surroundings, air and water, and the pollution may carry far and stay for long. The external effects of pesticides are many, affecting the health of humans, cattle and environment. The cost of these external effects is difficult to calculate. Modest estimates in the USA (Pimentel *et al.*, 1993) and Germany (Waibel & Fleischer, 1998) indicate that if external effects of pesticides and their social costs are brought to bear, a dollar invested may yield up to 1.5 dollar in return. With a firmer grip on social costs that figure might go down to 1 or even less. As we cannot avoid all pests at all times, insurance may be a much better way to maintain the growers' income than pesticides. Insurance against pest damage exists in several countries but, unfortunately, its merits are seldom discussed in the crop protection literature.

Twice the chemical industry attempted to estimate the world-wide losses due to pests. Cramer's (1967) attempt was a surprise, loudly praised. Oerke *et al.* (1994) made a second attempt. Policy makers tend to use their figures as a world standard, but we should be sceptical because of flaws in the assumptions (Zadoks, 2001). In actual fact, pests are subject to so many 'checks and balances' that large-scale losses are often rather limited though local damages may be severe. Savary *et al.* (2000) carried out a regional survey on pest losses in rice and found them to be remarkably low. One explanation may be that they studied rice agro-ecosystems in South East Asia, which had centuries to millennia to equilibrate crops, pests and beneficial organisms. In contrast, introduced pests can cause tremendous losses until a new equilibrium is established. A classic scenario is the epidemic of coffee leaf rust (*Hemileia vastatrix*) in South East Asia that began around 1869, re-enacted in Latin America from 1970 onwards (Bowden *et al.*, 1971).

Integrated Pest Management and Plant Health

From the beginning, pesticides met with criticism and environmental concern and alternatives were actively sought for. In North America as well as in Europe biological control in orchards was studied already before the 1950s. When pesticide treatment failed because of resistance in target pests against pesticides, Californian entomologists developed a sequence of ideas which ultimately led to Integrated Pest Management (IPM, Stern *et al.*, 1959). IPM was developed in universities and research institutes and the approach was typically top down, the growers being told what to do. In developed countries *anno* 2000, IPM is well established in many greenhouse districts, and beneficials for biological control are widely used. However, apart from orchards, in open crops IPM is not yet widely accepted.

In the tropics developments followed a different pattern. Non-chemical crop protection, which today we would call IPM, was well developed in the colonies (Oudejans, 1999). When these became politically independent they were economically recolonized by pesticide companies. Official services stimulated the use of pesticides, often for their own purposes, and credit for pesticide purchases was always available. Often, farmers were forced into package deals including seed of high-yielding varieties, fertilizers and pesticides (e.g. Brazil, Philippines). Farmers were financially squeezed and at times they protested fiercely, as in Manila in 1987, when farmers formed a picket line in front of the XIth International Congress of Plant Protection[3].

Responding to the outcry following the publication of 'Silent Spring' (Carson, 1962), the Food and Agriculture Organization of the United Nations (FAO) created a Panel[4] on integrated pest control, which functioned from 1968 to 1994. With the support from the Panel, FAO introduced IPM in South East Asian rice cultivation by way of a project[5] largely funded by the Netherlands and Australia. Though the introduction of IPM was again top down, the approach was completely different from that in the West. Methods borrowed from 'adult education' were applied in 'Farmer Field Schools'. Farmer groups were trained during a full growing season to do field observations, to deliberate together, and to make their own decisions accordingly (e.g. Van De Fliert, 1993). The results were remarkable; the money saved on pesticides was used to buy nitrogen fertilizer and to send the children to school[6]. Yields increased. The programme was very successful in Indonesia, Vietnam and elsewhere. Around 2000, the concept of Farmer Field Schools is being applied to other crops than rice, primarily in rice based cropping systems, and to other areas, among which China and Africa.

3 The author conversed with several pickets, rice farmers who neatly explained the circumstances leading to their presence.

4 The Food and Agriculture Organization/United Nations Environment Programme (FAO/UNEP) Panel of Experts on Integrated Pest Control was an advisory body to the Director General of FAO. It consisted of experts, about half of them from developed and half from developing countries, of various disciplines. The Panel convened about once every 2 to 4 years, usually in Rome.

5 FAO/UNEP Inter-country Program for the Development and Application of Integrated Pest Control in Rice in South and South East Asia. Dr. Peter Kenmore was the project leader.

6 Author's observations.

The message may extend beyond crop protection to crop husbandry.

What began as a crop protection programme often developed into a participatory rural development programme, as in Zanzibar (Bruin & Meerman, 2001). A similar development occurred in participatory plant breeding. Neither crop protection nor plant breeding will be successful without considering the local agro-ecosystem as a whole, with all the local constraints and challenges. The adage 'think globally and act locally' is now being implemented in many developing countries. How different is this from the original idea behind pesticides, where ideally one pesticide formulation was to be applicable to many crops at many places in the world, thinking locally at headquarters and acting globally.

Biological control of insect pests has a high visibility. In fungal, bacterial and viral pests biological control is not obvious at first glance. Hence, phytopathologists usually manifested a different attitude to crop protection than entomologists. The American Phytopathological Society developed the concept of 'Plant Health' (Cook, 2000), which is claimed to be wider than the IPM concept because prevention is emphasized more heavily and crop husbandry is brought in. Old ideas such as crop rotation and healthy seed receive renewed interest. Direct biological control of fungal and bacterial diseases and also of weeds is gradually being developed into a practical proposition financially acceptable to farmers.

The role of economics and politics

Institutional changes

In Europe, the food scarcity caused by World War II, made such an imprint that politicians said 'never again'. The present European Union stimulated the production of major commodities such as wheat by offering a fixed price well above the world market price, a policy leading to high yields in kilograms per hectare. These many kilograms necessitated high inputs of fertilizers and pesticides. Initially, pollution and health aspects were ignored. Now that agriculture and industry are completely set to this high external input agriculture, change is difficult and transition costs are high. With the pending expansion of the European Union to the East the high level of agricultural subsidies cannot be maintained and a different agriculture will emerge applying less external inputs on larger farms.

From various sources a radically different movement sprang into being, legalized as 'organic agriculture'. It refuses to use inorganic fertilizers, synthetic pesticides and – recently – genetically modified crops. Organic agriculture does or did use large amounts of processed, non-synthetic pesticides such as free copper, sulphur, and botanicals, and may apply flaming for weed control and potato haulm destruction. So the pollution effects of organic agriculture have been considerable but progress in research and development gradually reduces these undesirable side effects.

Great effort has been made in finding a middle course between the high-input agriculture of the early period, say 1950–1975, and organic agriculture. Results were offered under various labels such as 'alternative agriculture' (e.g. Anon., 1989), 'geïntegreerde landbouw' (= 'integrated agriculture'; Van Der Weijden *et al.*, 1984), 'Integrierter Landbau' (Diercks & Heitefuss, 1994), 'agriculture raisonnée' in France (Bouron, 1998) and 'integrated crop production' (e.g. Anon., 2001). The term 'current agriculture' originally used to indicate the high external input agriculture indicated above, is shifting its meaning towards 'moderate external input agriculture'. 'Moderate' here refers to moderation in the use of inorganic fertilizers and pesticides, but with much increased use of knowledge and know-how. Here we see a confluence of tendencies in developed and developing countries, where politics stimulated over-application of pesticides in some instances and lack of purchasing power caused under-application of pesticides in other instances.

Pesticides have been improved tremendously and are still being improved to meet modern health and environment requirements, becoming selective and degradable (Casida & Quistad, 1998). Mankind will need such pesticides dearly to feed the world population, to meet the growing requirement of animal protein food, to do this without expanding the agricultural area at the cost of natural resources and to avoid any risk to health and environment. Slowly, agriculture turns in this new direction since the supply market of 1950 has changed into the demand market of 2000. Consumers, at least in the West, take the availability of food for granted, demand high external quality standards (though it takes lots of pesticides to attain these standards), and worry about food safety including freedom from pesticides. The large retailer companies translate these worries into 'product and production' requirements, as e.g. stated in Euro-Retailer Produce Working Group/Good Agricultural Practice (EUREP/GAP) agreements, which apply to producers in both developed and developing countries. A grower who wants to stay in business should follow the instructions of the retailers, who have the market power and the means to check the products and to supervise the production process. In a way, the private institutions bypass the public institutions in the race for the consumer's favour.

In developing countries primarily the many growers who produce for western markets are feeling the effect. In the big cities a change in consumer demand becomes visible among the more affluent part of the population and this change will undoubtedly spread. The going will be slow because of the lack of purchasing and market power of the masses and the lack of institutional strength in most developing countries.

The public-private balance

After World War II, the state took responsibility for everything, including crop protection, at least in many countries in north-west Europe. Around 2000, the opposite is favoured, with deregulation and privatization. The state has ceded much of its power to supernational organizations, primarily the European Union, and to sub-national organizations of a different feather (Meester *et al.*, 1999). This change has its good and its bad sides. Good but not easy is the 'Europeanization' of regulations on pesticides, quarantine, genetic modification and agricultural pollution. Nonetheless, public action has not yet been very successful in reducing the pollution load by agro-chemicals. With the market power shifting from producers to consumers things may change for the better. Retailers now dictate the crop protection methods, and their commercial requirements often reach further than the legal requirements. Many growers placed more trust in advisers of pesticide companies than in those of the government. More recently, independent private advisers have golden times, primarily in the USA but increasingly in other developed countries. In the 1990s, several small companies became active in IPM using meteorological instruments and computer-based decision support systems to control *Phytophthora infestans* in potatoes. Companies selling beneficials for biological control do well especially if they also provide instruction and advice.

So far, privatization seems to be favourable. In the long run, however, the unfavourable effects become apparent. Political pressure is exerted on agricultural universities and research institutions – in the Netherlands and elsewhere – to make money by privatizing knowledge. Molecular biology allows patenting of inventions and even of genes but crop protection matters such as IPM and the underlying knowledge cannot be privatized. So under the present circumstances they tend to disappear from the research agendas of agricultural institutes and the curricula of the universities, an alarming prospect. Insight into outdoor phenomena, such as crops and pests, their interaction and environment, are rapidly disappearing behind the computer screens on the desks of researchers, teachers and students.

What's new?

New is the strong interdisciplinary exchange of information that enabled rapid application of technologies across disciplines, among them genetic engineering, genomics, computer science, mathematics and electron microscopy. New is the globalization, not of science, which was global already, but of scientists who travel far and frequently, and of plants and pests that are shipped all over the world. New are the impressive gain of depth in science, the development of narrow specializations in conjunction with lively competition among scientists, and the loss of general knowledge. New is the widening gap between science and practice in agriculture and crop protection. Around 2000, many changes occur in society, in agriculture and in crop protection. These are exciting times even when crop protectionists must plead for the protection of crop protection.

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