THE CHALLENGE OF THE NEXT GENERATION OF WEED PROBLEMS

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Within the next generation world population is expected to rise from 4,000 m to 6,000-7,000m. Thus we will need to produce at least half as much food again during the next quarter century as we did in the last. This is the challenge of the next generation.

Our specific challenge in weed control will be to increase efficiency in agricultural production by reducing or eliminating weed competition without harm to the ecosystem. Although production of high-quality food will be our major mission, our role in maintaining and enhancing the environment will become increasingly important.

THE LAST TWENTY FIVE YEARS

Before facing up to the challenge of the next generation of weed problems, it will be helpful to look back at the progress and problems of the last 25 years. We have an excellent opportunity to follow changes since 1953 from the Proceedings of the first and subsequent British Weed Control Conferences. A comparison of the information contained in the 46 papers presented at the first conference with the knowledge we have today gives a picture of enormous progress. As a result my major difficulty in preparing this lecture has been my awareness of the actual extent of the changes that have occurred. These have been so fundamental that many of the conclusions we arrive at this week may well have little relevance in 25 years time.

In 1953 two herbicides, MCPA and 2,4-D, dominated the conference and many of the other herbicides discussed then, such as CMU, DCU, vaporising oil, gas oil, sulphuric acid and sodium arsenite, have virtually disappeared. The innovations during the last 25 years have been masked to some extent because the changes have been gradual. The very different conditions in 1953 are evident from many of the statements made by speakers at the first conference. Dr. E. Holmes in the Introductory Paper on "The cost of weeds and the potential value of herbicides in agriculture" reported that the average cost of weed control cultivations in sugar beet was £4.90/ha, operating costs for tractor spraying were £0.91/ha and ".....in many cases the weeding of peas is done by hand, often on the knees, at an estimated cost of £7.40-£13.40/ha"(Holmes 1953).

It would have been indeed a far-sighted or courageous man who would have predicted the rapid replacement of many of the promising herbicides of the time by chemicals with much greater physiological selectivity. Thus in sugar beet encouraging results were reported in 1953 with sodium pentachlorophenate, pentachlorophenol, endothal and sulphuric acid applied pre-emergence and with sodium chloride and sodium nitrate applied post-emergence. Potatoes were not mentioned in any of the papers, presumably because at that time cultural control measures were adequate and the potato was considered to be a cleaning crop.

Since the early 1950's our approach to many aspects of crop production has been influenced by the steady stream of new chemicals mainly from Europe and North America. The revolution in farming practice has, of course, not been due entirely to the impact of these herbicides. Many other important developments in technology including mechanisation and plant breeding have also occurred and the agricultural industry has been in a state of continual change. It is difficult therefore to know how much of the change is due to herbicides and how much to other developments. It is obvious, however, that herbicides have made a major impact on husbandry methods and that progress in many areas was dependent on efficient weed control.

Many economic, social and technical reasons account for the increase in herbicide usage and the expansion of the agrochemical industry during this period. These include the declining numbers and higher wages of agricultural workers and the need for greater efficiency and output per unit area in view of steadily increasing land prices and production costs.

Agriculture

Change has been particularly far-reaching with root crops, which in the 1950's had a high labour requirement. The acreage of sugar beet treated with herbicides in Britain has risen from 5% in 1961 to 98% in 1975 (Gunn 1977). This crop can now be grown without hand labour due in part to the introduction of pelleted monogerm seed and effective precision drills and harvesting equipment. But the full value of these developments was realised only by the introduction of effective herbicides.

Compared with most other agricultural crops the adoption of herbicides for potatoes has been less rapid, partly because the weed problem in this crop was not so acute and because of the better opportunities for post-planting mechanical treatments. Nevertheless, the acreage of main-crop potatoes treated with herbicides has risen from 1% in 1963 to about 70% in 1976 (Gunn 1977). In contrast to other crops the use of herbicides was already well established in cereals by 1953 but changes have occurred. The herbicides used are different, there is more winter sowing and increasingly cereals are grown in succession. There has also been a rapid increase in the acreage of crops direct-drilled without prior cultivation, the area treated in this way in the U.K. rising from 6,915 ha in 1971 to 51,895 ha in 1975 (Hughes 1978).

We now have answers to many of the questions asked about cereals by the first President of the British Weed Control Council in his Opening Address in 1953. Sir James A. Scott Watson speculated that there might be a danger that selective herbicides and the combine harvester taken together would lead to over-cropping with cereals. He also wondered how far we could replace the hoe by the sprayer and queried the long-term effects of a particular herbicide against *Sinapis arvensis*. He wondered if we would be faced with resistant strains and if so could we defeat them by ringing the changes or would other species usurp the place of *S. arvensis* in the absence of competition? We now know that this weed and other sensitive species such as *Papaver* spp have almost disappeared from cereal fields and that, as herbicide programmes changed, these weeds were replaced initially by the 2,4-D- and MCPA-resistant species *Galium aparine* and *Polygonum aviculare* and subsequently by grass weeds (Fryer and Chancellor 1970). These changes have been partly the result of herbicide usage but undoubtedly the decline in rotations has also contributed to the present situation.

Horticulture

As yet in 1953 there was no hint of the role that herbicides were about to play in horticulture. Opening speakers on fruit and vegetables clearly failed to appreciate the revolution that was imminent. It was suggested that there was "no reason to expect the early discovery of ideally selective herbicides for use under bush fruits and strawberries". Twenty five years later there are nearly as many herbicides sold for strawberries as were discussed for all crops at the first conference and many growers are now producing this fruit in a virtually weed-free environment. Nor was the future for herbicides in vegetable crops considered any more favourably. Here also the phytotoxic effects of 2,4-D and MCPA in most horticultural crops encouraged the opening speaker on vegetables to suggest that "we cannot be very optimistic about the use of post-emergence sprays for many vegetables since, unlike cereals, most are very susceptible to the phytocidal effects of the established herbicides apart from those which I have already mentioned" (sulphuric acid, mineral oils and dinoseb). Today many vegetables can be kept substantially weed-free by a suitable rotation of herbicides. Some crops such as onions, which in 1953 were exceptionally difficult to grow in high rainfall areas partly because of the weed problem, can now be treated safely with a wide range of products and grown to maturity completely free from weed competition.

As well as controlling weeds, the use of herbicides has challenged some basic traditional principles of crop husbandry, in the course of their integration into production systems. In 1953 current practice in most crops was dictated by the need to cultivate to control weeds. Root, fruit and vegetable crops were grown in well-spaced rows and it was widely believed that cultivation, as well as controlling weeds, was necessary to develop a suitable environment for plant roots. It was thought that capping of the soil was harmful even to established plants. There is now much evidence from practical experience and from experiments that, in most soils, roots will obtain all the oxygen they require without the need for cultivation (Williams 1963). In perennial crops, capped, moss-covered and cracked soil surfaces, which were universally regarded as extremely harmful in the 1950's, are now looked on as beneficial on many soil types. Thus a faith in the value of well-tilled soil that has endured for millenia has been lost in one generation. The widespread adoption of non-cultivation systems of management by fruit growers during the 1960's was probably the first major advance in a practice of soil management that reaches back thousands of years.

Capped, slightly consolidated, herbicide-treated soil provides tractor passage without rutting on many soil types and the thick carpet of moss in high rainfall areas prevents soil erosion without providing any apparent competition to fruit crops. Even moderate soil cracking is regarded as beneficial by many fruit growers. Apart from helping to aerate the soil it is now known that soil cracks tend to be permanent, usually opening along the same lines each year. Plant roots grow preferentially along these cracks and consequently are well placed to use summer rainfall which penetrates more deeply where cracking occurs.

The development of effective herbicides for vegetables has changed dramatically the way these crops are grown. Now that cultivation equipment does not have to pass along every row we have much greater flexibility in plant spacing. Many vegetables such as onions and carrots are now grown in beds and all cultivation is done before sowing. The bed system of producing root crops has given growers much greater control over the proportions of their crop in the desired market grades. With these changed production systems it has been necessary to develop new machinery for drilling the crop at the required spacing and for harvesting. More specialised mechanisation has resulted in more efficient production. Higher plant populations have in turn necessitated higher fertiliser requirements and have resulted in higher yields. But again it was chemical weed control that provided the key to these developments. Herbicides therefore have done more than just controlled weeds; they are now an integral part of crop production and most agricultural and horticultural crops are treated with at least one application each year.

The last 25 years have seen a very large increase in the size of the total market for agro-chemicals in real terms and a considerable change in its composition. The table shows that the predominance of insecticides in the 1950's has been eroded and that the value of herbicides has increased 15-fold in real terms between 1953 and 1977. The chemical industry and weed scientists have made the last 25 years the 'age of the herbicide' and the agricultural industry in many countries has benefited as a result.

The pesticide market at end-user level for the world excluding Comecon countries ($m 1977 money)

	1957 Market Value	%	1977 Market Value	%
Insecticides	965	57	2630	34
Herbicides	225	13	3513	46
Fungicides	428	25	1196	16
Others	88	5	343	4
Total	1706	100	7682	100

Source: Shell International Chemical Company

There is, however, another side to the weed story in the last 25 years. Another reviewer might paint a different picture. He could see an agricultural industry based on high energy inputs in which farmers kill unwanted vegetation with plant poisons and are being forced continually to use more potent and increasingly costly chemicals because of new and resistant weeds. He could blame herbicides for the deterioration of the environment and even for the large number of people unemployed and could conclude that there had been regression instead of progress. This view arises partly because of increasing urbanisation and a lack of understanding of what is involved in food production today. Nevertheless these are some of the aspects that will increasingly involve those engaged in weed control during the next 25 years.

THE NEXT TWENTY FIVE YEARS

Energy

During the next quarter century the background against which agriculture and weed science will operate will be drastically altered. Within this period the demand for oil on a world basis will exceed its production. Much greater emphasis will therefore be necessary on energy conservation and all current uses of energy will be questioned much more critically than they are today. Farming uses moderate quantities of energy, not only directly, but also indirectly through the use of herbicides, other agrochemicals and machinery which all require energy for their manufacture. Blaxter (1978) estimates that U.K. farming accounts for about 4% of the nation's primary fuel consumption. But when the fuel used in food processing and distribution is included, this figure rises to 13%. Of the total energy consumption in primary agricultural production, crop protection, including both the chemicals and their application, accounts for only about 2%, (Green 1976). Although this figure is low, it would not be possible for energy inputs into U.K. agriculture to continue to increase annually at the pre-1974 rate.

Present day agriculture with its high productivity has resulted from the low cost of oil in the past. We are now faced with the difficulty of increasing food production at a time when fossil fuel is becoming scarce and more expensive. Even though herbicides represent only a small proportion of energy inputs into agriculture, the problem is highly relevant in weed science as the main chemical feedstocks for herbicides are hydrocarbons.

Obviously food supplies must be maintained and it will be the responsibility of government to ensure that the means of producing food are safeguarded. Similarly it will be a major responsibility for weed technology to make more efficient use of energy inputs into agriculture through new techniques and skilful management. There will be scope for progress in a number of different areas such as the direct contribution of herbicides to more efficient agriculture and their indirect contribution in helping agriculture to produce more of its own energy through the growing of woody and oil-bearing plants. The increasing scarcity and rising cost of fossil fuel will also stimulate developments in the use of natural oils and carbohydrates from plants as substitutes for petrochemicals in industry.

The concept of energy budgeting at farm level will become more important. All operations will be increasingly scrutinised for their energy inputs and scientists will be more involved in the identification and adoption of energy saving techniques. Compared with many other agricultural operations weed control practices have a favourable energy input/output ratio, because of the large increases in crop yields possible as a result of weed control. There are, however, large differences in energy inputs for different cultural, mechanical and chemical methods of control (Nalewaja 1974). Rising energy costs will undoubtedly influence soil preparation and cultivation practices. Methods which eliminate or require less mechanical tillage are likely to use less total energy despite a greater usage of herbicides.

Results from several trials suggest that direct drilling and minimum tillage techniques save about 1.0 GJ/ha of total energy or about 30 l/ha of diesel fuel (Green and McCulloch 1976). Energy inputs will also be reduced by our increasing knowledge of the mode of action of herbicides and of the population dynamics of individual weed species. This will result in the more economical and skilful use of herbicides, better timed applications, the use of correct doses and better anticipation of weed problems.

Energy inputs into agriculture will also be reduced by improvements in spraying equipment. For example, the introduction of Controlled Droplet Application (CDA) has resulted in greatly reduced water volumes without undue risk of drift (Cussans and Taylor 1976). Just as herbicides were the key to many present practices such as the direct drilling of cereals, so CDA with its low spray volumes and low pay load requirements could be the key to a new concept of crop production involving low energy inputs.

Excellent weed control has been achieved in cereals at the Weed Research Organization with lightweight, low ground pressure vehicles travelling at 20 km/h applying herbicides in volumes of 60 l/ha. Autumn-sown cereals can be sprayed during October to March even when the soil surface is damp (Elliott 1978). Now that many farmers no longer cultivate the soil and the need for major traction has gone, large tractors with a high fuel consumption could become obsolete on many farms. While it is impossible to predict accurately the future of application equipment, the need to conserve fossil fuel and the low energy requirements of CDA spraying suggest that we will see many innovations in application technology and crop production methods during the next 25 years. One example of the scope there is for ingenuity in this area is the development in Nigeria of a solar energy light crop sprayer. In this CDA sprayer a solar energy collector about 33 cm square, carried as a "sun shade" above the head of the operator, provides the power for herbicide spraying (Wijewardene 1978).

Environment

Britain has been fortunate that emotions have not played as important a role in the procedures controlling the use of herbicides as they have in some other countries; we are not faced at present with the legislative overkill that is stifling progress of weed science in the U.S.A. Nevertheless, public pressure in recent years has been partly responsible for the more stringent regulatory requirements now in force in Western Europe. The already evident ground swell of public interest in the use of herbicides in agriculture will increase and environmental issues will be more to the fore politically during the next quarter century. The use of herbicides will be questioned more closely on a number of points such as their effect on the environment and on human wellbeing.

Man's activities have been influencing the appearance of the countryside for a very long time. Until recently farmers had the countryside largely to themselves and were widely regarded as its natural custodians. This view is being increasingly challenged in many countries. In the next quarter century there will be a significant reduction in the working week for urban dwellers; in addition, a greater appreciation of the environment, as a result of improved education, will strengthen their interest in and views on how the countryside should be managed. Conservation interests will be increasingly vocal in questioning the role of pesticides in extensive and marginal agriculture and their effect on the natural environment.

We know that the safety record of herbicides is good in relation to their direct effect on wild-life. Nevertheless they are reducing the diversity of species over large areas through their contribution to the intensification of agriculture on the better land (Moore 1971). The science of assessing environmental hazards from the direct and indirect effect of pesticides is still relatively primitive and there is a big challenge for governments, industry and academics to co-operate more closely in this area, to develop agreed methodologies and to assess more rigorously the possibilities of short- and long-term hazards. It is preferable that weed scientists should be the first to point to possible hazards with certain herbicides and we must be ready to make adjustments before these are forced on the industry by public opinion.

There will also be growing concern by the public about pesticide levels in foodstuffs and increasing fears about their effect on crop quality and on human health. Although most of the problems in the past have been with the indiscriminate use of insecticides and not with herbicides, the public will not differentiate closely between these two groups of agrochemicals. Results of a limited number of experiments and surveys on present herbicides used at normal agricultural doses are reassuring (Byerly 1968, Freeman and Bennett 1969 and Hance et al 1978).

The fears held by the public about the use of pesticides will require much greater efforts in education and publicity. Firstly it will be necessary to ensure that policy makers, administrators, teachers and the general public are better informed about the contribution of agriculture and chemicals to public welfare. The educational process should begin in schools and we will need to find ways to get these topics into school syllabi and to ensure that teachers are sufficiently well informed to be able to present a balanced viewpoint to their pupils.

Opponents of herbicides must be assured that many of the alleged problems are more imaginary than real. On the other hand, weed scientists have been too ready in the past to publicise the benefits of herbicides without discussing the risks. We have tended to minimise the problems that could result from misuse e.g. overdosing, misapplication or through improper handling or disposal of containers.

The public is often misinformed about herbicides because we are not sufficiently active in providing adequate information. Greater publicity should be given to the absence of adverse effects of herbicides on humans, wildlife and microorganisms when used at normal agricultural rates. At the same time more emphasis should be given to the development of better techniques for the safe disposal of unused herbicides and containers and to more effective training for operators. The importance of this is evident from a survey conducted by ADAS which showed that 57% of sprayer operators on commercial farms were untrained (ADAS 1976).

Protagonists of herbicides must accept that, if misused, agrochemicals are a potential threat to the environment. Our challenge here is to obtain knowledge and present it in a manner that will prevent any polarisation of attitudes that would stifle objective discussion on courses of action.

It seems likely that the possibility of using biological methods of controlling weeds, alone or as part of an integrated programme, will be pushed forward more strongly by governments and environmentalists in the near future. This is an area where strong pressure from an uninformed public could militate against successful weed control. Interest in such methods is rising, however, on a world-wide basis for a number of reasons. These include the growing resistance of insects to broad spectrum insecticides and the complete resistance of some insects to current chemicals (Adkisson 1971), the widespread and often unfounded criticism that pesticides are adversely affecting the environment (Carson 1962), fears that fossil fuel reserves, especially oil, required for the manufacture of pesticides are rapidly diminishing and concern that the increasing cost of developing new chemicals may reduce the number of compounds becoming available.

There is no doubt that some spectacular successes have been achieved such as the control of prickly pear cacti (Opuntia spp) by the moth Cactoblastis cactorum. However, with a few exceptions biological control has been successful against introduced weeds that have become dominant over large areas of range land or relatively undisturbed areas. Biological control is usually only appropriate where benefits can be obtained from controlling a single species in a plant community. While the theoretical advantages of using a self-perpetuating, inexpensive, non-polluting method of weed control are very attractive, problems involved in developing satisfactory methods for controlling mixed populations of native weed species without harming crop species are very great.

As discussed by Cussans (1974), the prerequisites of success for biological control of weeds are:

1) the economic dominance of a single species;

2) crops must be tolerant of a continuous low weed infestation and

3) the weed status of the target plant must be maintained in all situations.

While there are examples in Britain where these prerequisites might be met e.g. bracken (Pteridium aquilinum) and docks (Rumex spp) in grassland and wild oats (Avena fatua and A. ludoviciana) in arable land, the situations where biological control is likely to be successful on both technical and economic grounds seem to be extremely limited at least in the short-term. Moreover in the U.K. there is at present no organisation set up to explore and develop the possibilities of biological control of weeds.

It will be necessary to keep an open mind on biological methods, especially in view of their undoubted value against insect pests in integrated control systems. Indeed their use in Britain against certain specific weeds is possible during the next generation. Compared with insecticides, herbicides have not been beset to the same extent by problems such as resistant species, build up in food chains and toxicity to animals. Thus the main pressures of our attack on weeds in the next generation must continue to be with chemical methods.

Employment

As scientific progress and economic pressure further reduce the number of workers required on farms and in factories and public services, the use of pesticides will be blamed, along with many other aspects of modern technology, for exacerbating the unemployment problem. Pleas such as those made by Schumacher (1973) for the return to more simple ways will be heard increasingly, for a move back to the "good old days" pre-herbicides, when hard manual work was a cure for incipient psychiatric problems. Certainly using labour for weed control would help to reduce the unemployment problems in western Europe if workers could be obtained in the rural areas where they are needed and if they could be persuaded to do the monotonous, back-breaking task of weeding in all weather conditions at a price the farmers could afford to pay. Obviously such calls are extremely unrealistic but they will be made. The public must be informed more clearly of the fall in living standards that would result and the greater proportion of take-home pay that would have to be spent on food by any return to a "primitive" agriculture. It must be informed more directly that the only way living standards can be safeguarded is through the maintenance of agriculture in an efficient and profitable condition.

Efficient agriculture does not necessarily mean increasingly large-scale agriculture. The growing strength of labour unions could increase the relative profitability of smaller units. New technologies including simpler methods of land preparation, seed sowing and crop protection, including weed control with herbicides could make small-scale and part-time farming more attractive for many rural and urban dwellers.

Technical problems

While the major problems of the next 25 years, such as environmental issues, are likely to come from outside agriculture, numerous technical problems within agriculture will require solution e.g. resistant and new weed species, crops as weeds and light infestations of weeds. There is also a growing need for safer herbicides and for more information on the effects of sequential treatments and tank mixes.

Resistant species

We have been fortunate that during the last 25 years there has been little indication of the evolution of genetically resistant weed species, despite the evidence that there is considerable intra-specific variation in susceptibility to herbicides. In 1977, more than 300 insect species had developed some type of resistance to insecticides in some part of the world (Brown 1977). In contrast Parker (1977) lists only nine weed species in which acquired genetic resistance due to herbicide application has been reported. However, it is inevitable that this number will increase since the regular use of herbicides provides a strong selection pressure.

While there is little room for complacency the risk of a devastating resistance problem with weeds is less likely than with insects or diseases. Relatively few British weed species produce more than one generation each year so that the time during which herbicide resistance can develop is likely to be longer than with insecticides. There is therefore greater opportunity to deal with the problem and farmers have already acquired considerable experience in dealing with species that have flourished because of their inherent tolerance of a herbicide. Nevertheless, the inevitability of the evolution of further resistant species must be more widely publicised to agronomists, growers and weed scientists, and a sequence of different herbicides used as far as is practicable to minimise this risk. If resistant populations do appear drastic efforts will be justified to bring them under control. This will be a recurring challenge in the next quarter century.

New weeds

Although weeds with acquired genetic resistance to herbicides are still rare, new weeds resulting from inter-specific selection by herbicides are very common. For example *Viola arvensis* and *Lithospermum arvense*, which were formerly of little importance, have become widespread in winter wheat as a result of repeated treatments with urea-based, blackgrass herbicides.

Hypericum humifusum, classified as rather rare (Webb 1953) has become dominant in some apple plantations in Ireland because of its resistance to simazine and paraquat. Techniques introduced during the last 25 years, e.g. direct drilling of cereals and bed systems for vegetables, have increased our dependence on herbicides. The widespread development of a weed flora resistant to the current herbicide programme emphasises again the need for an agroecological approach. If we cannot rotate crops, we must rotate herbicides on crops in a management system that includes where practicable mechanical, cultural, ecological and possibly biological methods as well as combination herbicide treatments and sequential treatments (Shaw 1978).

Crops as weeds

There is also the increasing problem of crops as weeds which was considered in some depth at the 12th British Weed Control Conference (Hughes 1974, Lumkes 1974) and receives further attention at this Conference. Modern technology and present farming methods are blamed for causing this problem. However, in many cases as crop production systems are made more suitable for the crop, the weeds best able to exploit the new conditions are the plant propagules themselves. In addition the change from manual harvesting to rapid but less efficient mechanical methods and a series of mild winters have been largely responsible for the increase in volunteer potatoes. Genetic contamination along with chemical and mechanised advances in beet growing have encouraged weed beet and no longer are such plants chopped out by hand during hoeing.

Reduced cultivation and non-ploughing have aggravated the problems with volunteer barley and several pasture grasses including ryegrass have become serious weeds of cereals and other crops. The telescoping of rotations has increased all of these difficulties without necessarily being the prime cause. Experience obtained since the problem of weed crops was highlighted has also served to show the difficulties involved in obtaining solutions. The problems could be greatly reduced with more attention to rotations but with farmers geared increasingly to close cropping there is a tendency to look to chemical methods for a solution.

Just as no single cause can be held responsible, so the remedy is unlikely to come from a single source. Solutions will require the attention of scientists in a number of disciplines. For example, plant breeders will be required to produce cereal cultivars that are resistant to shedding or to imposed dormancy. Weed biologists and agronomists will need to produce more precise recommendations for the optimum treatment of land from which crops have been harvested so that propagules remaining from the previous crop can be more easily destroyed by cultural and chemical means or by frost. Better equipment to ensure more complete harvesting, more specific herbicides, new concepts in application equipment to enable non-selective herbicides to be used selectively and more effective antidotes to increase crop tolerance can also be expected to reduce the extent of the problem.

Light weed infestations

After a period of routine spraying with herbicides a situation can arise in extensive crops in which the weed infestation may appear to be too light to justify the cost of chemical treatment but is too high to be rogued or the weed species may not be roguable - the so-called grey areas of weed infestation. In this situation there is a temptation for farmers, possibly after years of routine treatment, to decide not to spray, thus allowing the weed populations to rise again. There is considerable scope for expansion of the work already underway at the Weed Research Organization and other centres on the use of reduced, and therefore more economical doses on light weed infestations. As more is learned about the population dynamics of weeds and the effects of herbicides on specific weeds, we will be able to adjust doses to affect seed production and so populations can be forced into decline. In extensive cropping we should concentrate less on controlling weeds in a single crop in a single year, and give more consideration to weed control on the total farm over a period of years.

There is still much to be learned about the use of reduced doses when herbicides are used in sequence. In the long-term this will be seen to be the right approach both by the farmer and also by the herbicide manufacturer. It will be better for farming and ultimately more profitable for the chemical industry that farmers should use herbicides, albeit at reduced doses, to control light infestations rather than that full doses should be used on a restricted acreage only.

Sequential treatments and tank mixes

Because of the strong selection pressure exerted by a herbicide on a mixed weed population and as changes in crop production methods increase our dependence on effective control with chemicals, so the use of herbicides as sequential treatments and tank mixes will continue to expand. This will be further encouraged by the trend towards safer, more selective but more specific herbicides, requiring rotational or combined treatments to control a broad weed spectrum. Some of the problems that can and are arising from these practices have been reviewed by Scarr (1977) and Long (1977). There is an urgent need for regulatory procedures which are sufficiently flexible not to place unnecessary restrictions on such practices.

Risks of damage through synergistic or accumulative effects of a series of herbicide treatments are present but have not occurred to any extent in practice. Nevertheless the need for more information on sequential treatments and on the compatibility of tank mixes is urgent and suggests a greater need for closer liaison and joint research between manufacturers along with state organisations. Industry can be justifiably proud of its service to agriculture. If this record is to stand the problems of compatibility of products used in sequences and in tank mixes must be tackled urgently and thoroughly by the companies marketing the components aided by the public sector. We are approaching an age of prescription weed control when specific weed problems will require specific recommendations. There is a need for a large number of accredited specialist weed advisers, who would work closely with the regulatory agencies and who would be qualified to prescribe mixtures and systems of weed control to deal with specific problems.

Increasing cost of developing new herbicides and systems of weed control

The discovery, development and registration of new herbicides for both major and minor crops will be an increasingly costly task for industry in the future. In 1976 it was estimated that the cost of doing the necessary toxicological studies to get clearance would be in the order of £2-4 m and the total cost of developing a product would be about £10 m. The number of new compounds being introduced is now falling, the number introduced in each decade since 1920 being:- 1930's - 3, 1940's - 8, 1950's - 46, 1960's - 75 and 1970 to 1977 - 43 (Pesticide Handbook 5th Edition). This problem could be exacerbated by the decline in patent protection as fewer firms will have the benefit of earlier successful patents to finance present and future searches for new compounds. Governments in a number of countries could help to reduce the crippling costs of developing and marketing new herbicides by harmonising registration requirements. The Draft Directive relating to EEC acceptance of pesticides could be a useful initial step in this direction. In my opinion the herbicide industry can be developed most effectively by the private sector. But state support may be needed if chemical firms can no longer afford to provide agriculture's herbicide requirements.

Moreover industry cannot undertake much of the research needed to improve application techniques to maximise herbicide performance; nor can it readily develop long-term systems of weed control involving a range of products.

While empirical research by individual agronomists was adequate to solve many of our earlier weed problems, the more difficult issues of the next 25 years can only be tackled by well-trained teams of scientists of different disciplines including, chemistry, plant physiology, engineering and agronomy. The base of support for weed science must expand and more government-financed research departments and centres like the Weed Research Organization devoted specifically to weed control are required in different countries.

The problem of obtaining clearance and approval for the use of herbicides in minor crops will be particularly acute (Makepeace 1977). Because of the high cost of toxicological studies a herbicide to succeed will need to have wide use on a major crop. At present herbicides recommended for fruit and vegetables were cleared when costs were reasonable and it has been possible for manufacturers to extend clearance to many field vegetables from major arable crops at little extra cost. But the situation in future may be different when it will be unprofitable for a company to seek clearance for new herbicides on minor crops.

The system introduced by the Agricultural Chemical Approval Scheme with the help of ADAS and the British Agrochemical Association involving provisional acceptance by ACAS has helped manufacturers to get minor use recommendations on labels and subsequently to obtain full approval. If the full potential of minor crops is to be realised it will be essential that suitable herbicides are made available speedily to growers. It may be necessary for government to consider undertaking, or at least subsidising, the cost of obtaining clearance for minor crop use.

ADVANCES IN TECHNOLOGY

The agricultural and chemical industries, therefore, are facing many problems which did not exist 25 years ago. Fortunately advances in many other disciplines and a closer involvement of scientists and technologists from these disciplines with weed problems will result in improved methods of control in the next quarter century. There are many areas where we can confidently expect significant advances such as herbicide technology, engineering research, plant breeding, the manipulation of sward constituents in grassland and computerised information.

Herbicide technology

In view of the large investments that have been made on a worldwide scale in herbicide research, it is surprising that many of our chemicals are still discovered by routine screening of compounds. With present progress towards a better understanding of the physiological and biochemical mechanisms of plant growth we can expect a change in the method of developing new herbicides. We will have increasing opportunities to design specific herbicides to utilise small biochemical differences between crop and weed.

The challenge presented by the need for safer herbicides both environmentally and for crops is likely to be met in several ways. Screening methods used to find new herbicides will become more sophisticated (Hess 1978, 1979). The traditional pre- and post-emergence greenhouse screen will be supplemented with carefully controlled laboratory tests. These tests will include a number of experimental procedures to reveal any intrinsic chemical activity. The test material will probably consist of single cell algae or cell cultures from higher plants grown on artificial media in controlled environmental chambers, thereby providing uniform test material throughout the year. Evaluation procedures will include assays for all the common modes of action including photosynthetic inhibition, membrane disruption, growth inhibition, mitotic disruption or inhibition and metabolic inhibition. These tests will have many advantages over the tradtional glasshouse screen. They will be rapid, inexpensive, set up and harvest will be done quickly and many of the bioassay steps will be automated. Such tests will be used to provide objective evaluation of the effects of large numbers of chemicals on specific plant processes.

The computer will also be used extensively as a powerful research tool for identifying chemical structures associated with biological activity. Pharmaceutical chemists have adopted computer approaches to improve understanding of drug mechanisms and to design model compounds. So far progress has been limited but it has been possible to predict the activity of certain compounds within related series and to determine by prior calculation whether a proposed synthesis is justified (Anon. 1976). Computer technology is developing rapidly and as our data base expands, its potential for helping scientists design better herbicides is very great.

With both traditional and new approaches less phytotoxic compounds will be forthcoming. Antidotes e.g. 1,8-naphthalic anhydride and N-diallyl 2 2-dichloroacetimide have significantly increased the selectivity of a number of herbicides in several crops (Blair and Dean 1976). Although these antidotes have not yet been used extensively in the U.K. and their mode of action is not yet fully understood it seems reasonable to assume that other substances will be developed so that this principle of protection will be extended to a wider range of crops. In particular herbicide antidotes will be valuable for overcoming the very difficult problem of freeing crops from closely related wild species.

The need for herbicides, safer to the environment, is well recognised by the chemical industry and research and development programmes have been moving in this direction. From an environmental viewpoint a herbicide should suppress the target weeds, be non-toxic to non-target organisms, degrade to ecologically acceptable products at the appropriate time, stay at the site of application and should not accumulate in other organisms. We need more precise control over the persistence of herbicides in the environment. Kearney (1977) has presented evidence to show that herbicides such as atrazine can be modified to reduce their persistence. It seems likely that a greater understanding of the bio-degradability of linkages in herbicides during the next few decades will give users greater control over their persistence in the soil.

Many other developments will enable us to use existing herbicides more effectively and with less risk to the environment. With soil-acting herbicides we want to control weeds over a long period, yet prolonged chemical stability is environmentally undesirable. Controlled release formulations will eventually enable us to achieve season-long control of many weeds as after application the chemical would be released gradually into the environment at a rate matching the requirement. Biodegradable, starch encapsulated, controlled release formulations of several herbicides have improved the overall performance, residual weed control and safety to crops of several chemicals. Although the initial cost of a controlled released formulation is higher than that of the raw chemicals, this added cost could be more than repaid through the need for lower dosages and fewer applications (Baker and Lonsdale 1978). Controlled release formulations could make useful some compounds that never passed beyond early screening trials because they were too transient. It seems possible that some of these chemicals will be re-assessed because of improvements in screening methods and advances in controlled release formulations.

Engineering research

Current research in many countries indicates that there are many possibilities for significantly improving equipment for mechanical, physical and chemical control of weeds. New concepts for the mechanical removal of tall growing weeds in crops will be developed and electronic controls will improve the precision of row cultivators. During this Conference Diprose et al (1978) will discuss the scope for the use of electric energy as an addition to more conventional weed management practices. New herbicides will stimulate the production of novel application equipment and new applicators will encourage the development of new formulations of herbicides. We can expect the introduction of many types of applicators designed to enable non-selective herbicides, such as glyphosate, to be applied selectively and economically. Examples of new types of applicators are the recirculating sprayer (McWhorter 1977), the carpet applicator, the rope-wick applicator (McWhorter 1978) and the Stoneville wiper (Chandler 1978). Concurrent with the development of CDA we can expect marked improvements in conventional sprayers. The need for highly efficient application equipment will become more evident as herbicides increase in price and must be used with maximum efficiency.

Rutherford (1977) has described a machine for the next decade. It will be a special purpose, self-propelled applicator with an air-conditioned cab in which the operators will have no direct contact with the chemical. Herbicides will be supplied in standardised containers. When clipped to the machine these containers will be pierced automatically and flow rates will be controlled to give any pre-set solution selected by the operator. Instrumentation will give the driver constant reading of his application rate per unit area and warn of nozzle blockages or machine malfunction.

In the longer term, but before the end of the next generation, mini-computers in cabs pre-programmed with all relevant information on a range of chemicals will enable herbicides to be applied more precisely and with much greater safety. Much spraying will be done automatically initially from the ground and eventually from the air.

Plant breeding

The presence of genetic variation for tolerance to certain herbicides is widespread in many crops and has led to the selection of strains of crops resistant to specific herbicides e.g. *Lolium perenne* to paraquat (Faulkner 1976). Just as we will see herbicides designed to suit major crop plants, we should see greater activity in selecting cultivars to suit wide spectrum herbicides. If the increasing cost of development severely affects the number of new chemicals becoming available we will need to assess more thoroughly the potential of existing herbicides with their known toxicology. For certain weed problems it will probably be cheaper to breed a cultivar resistant to an existing herbicide than to attempt to develop a new herbicide for existing cultivars. For example simazine is a useful herbicide for strawberries, being cheap and effective against most annual weeds. It cannot, however, be used on newly planted runners or in the spring when a high standard of weed control is most desirable. Genetic variation between strawberry cultivars to simazine is known (Caseley 1960) and it should be possible to select lines with greater genetic tolerance.

Holliday et al (1977) point out that there could be an inherent danger in such an approach since when a crop is dependent on one particular herbicide for effective weed control, conditions may occur favouring parallel evolution of resistance in weed populations. This emphasises again the need for a rotation of herbicides even when a highly satisfactory, wide spectrum herbicide is available for a specific crop.

In the past cultivars of many crop plants have been selected which provided vigorous vegetative growth to enable them to compete with weeds for light and nutrients and to survive the harmful effects of soil disturbance. As we move towards a weed-free situation for certain crops where all the moisture and nutrients in the soil and all the space around each plant are available for its sole benefit and where its roots are not subjected to periodic pruning, crop plants may now be excessively vigorous. There will be a growing need for new cultivars to exploit more effectively these changed conditions.

Plant breeders have successfully incorporated both insect and disease resistance into cultivars of many crops. Might it not be possible to breed crops with allelopathic characters i.e. that can compete more successfully with weeds, by inhibiting their growth by toxins secreted from their roots? As allelopathy occurs in natural plant communities, Putnam and Duke (1974) hypothesised that the wild predecessors of many crops possessed allelopathic substances which allowed them to compete efficiently in their native plant community and that this character may have been lost through breeding. They showed that with Cucumis sativus there are accessions capable of severely inhibiting the growth of certain weed species. Obviously it will be difficult to incorporate into commercial cultivars competitive ability against major weeds. Nevertheless the demand for greater emphasis on biological methods is likely to result in increased world-wide interest in such methods.

Advances in tissue culture and genetic engineering could stimulate the development of herbicide-resistant cultivars. Cultures of a crop plant could be treated chemically or with radiation to induce maximum variation. The cultures could then be grown in a medium containing the herbicide and survivors propagated and tested for agronomic qualities. Protoplasmic hybridisation provides the possibility for creating new plants by fusing the different nuclei of two species within the same cell membrane (Bajaj 1974). If the difficulty of growing fused nuclei can be overcome this technique could open up possibilities for the development of a wide range of new plants incorporating many desired characteristics such as increased protein, higher yields, nitrogen fixation, herbicide tolerance and weed resistance. As more is learned about the genetic control of resistance to herbicides, it may be possible to produce herbicide-tolerant plants by transferring the gene or genes which control resistance to a crop plant using genetic engineering techniques.

Manipulation of sward constituents

In spite of the rapid advances in the use of herbicides in many crops their use in grassland remained at a low level during the 1950's and 1960's. Single applications of MCPA and 2,4-D often suppressed clover and treatment with herbicides seldom gave lasting control of broadleaved weeds unless coupled with marked changes in husbandry. In addition there was a lack of convincing evidence to show the potential benefits to animal production of the removal of specific weed species (Haggar and Squires 1978). In 1977 less than 10% of grassland in the U.K. was treated with herbicides (BAA 1977).

Recent research at the Weed Research Organization has demonstrated the possibilities that now exist for altering sward composition in any one of a large number of different directions. For example Poa annua can be suppressed in Lolium perenne, trends towards Agrostis dominance can be reversed, Holcus lanatus can be selectively controlled and clover can be stimulated. A wide range of herbicides has been used to manipulate sward constituents including ethofumesate, methabenzthiazuron, paraquat, dalapon, asulam, difenzoquat, propyzamide, carbetamide and linuron.

Herbicides combined with new seeding equipment have also helped to reduce the cost of grass renewal by re-seeding of pastures. Haggar and Squires (1978) have discussed the merits of direct drilling, overdrilling and slot-seeding. They suggest that based on the flexible use of partial reseeding techniques and selective herbicides, the composition of permanent swards could be regulated at will to meet the needs of different livestock and utilisation systems. The scope for increases in grassland productivity is large and the full development of herbicides as management tools will be a major feature of the next few decades.

Computerised information

As well as helping in the search for new herbicides computer technology will have significant impact on the way specialist advisers and farmers receive their information in the future. It is now possible for a scientist to research several million abstracts of technical literature in a few minutes and to print out those on which information is required. The same techniques will be used extensively in the future for getting reliable information quickly to farmers.

Weed control practices at farm level are influenced by many factors - by research findings, weather conditions, soil type, government regulations and the cost of alternative treatments. So much information is now available in many areas of weed control that the integration of these variables into specific recommendations becomes more difficult every year. It should be possible to design a computerised data bank and an operating system so that when the variables mentioned are typed in, the system will deliver recommendations on weed control alternatives.

In addition to coping with the mass of information that could scarcely be handled in any other way, a computerised data bank has the advantage that it can deal with information, such as prices, that change rapidly. While it is useless to publish data as a tool of reference if they are going to be out of date in a short time, changing figures such as prices can be revised easily in a computerised data bank.

Shortly with the availability of cheap computer terminals in home and farm office it should be possible to communicate directly with a large central computer. It should be feasible for the computer to consider a particular weed flora in a specific crop cultivar, the growth stage of crop and weeds, the soil type, existing weather conditions and the result of relevant experiments. On receiving teletyped questions, the computer could combine this information with models of weed response and give, in a teletyped reply, recommendations for the best control alternatives.

The challenge of this potentially significant advance in advisory methods is not the technology of information retrieval, which is already widely used and efficient, but rather in collecting the data and in keeping it up to date. Data collection will require a different philosophy in research and advisory work. Researchers will need to co-ordinate the planning of experiments more closely so that all the relevant information can be assembled in a single computer programme. Specialised advisers will transmit information on ambient weather conditions and on particular weed problems to the central computer and will obtain and distribute recommendations from the computer.

Development with information retrieval from data banks is now proceeding so rapidly that it is not possible at present to envisage the numerous ways computers will be able to aid the research worker, adviser, chemical manufacturer and farmer by the year 2,000.

TOWARDS A WEED FREE ENVIRONMENT

In the 1950's Sir John Russell wrote "It is not likely that it will ever be possible to grow crops completely free from weeds" (Russell 1958). While this statement is still essentially true, many crops which can stand the cost of sequential treatment including black currants, raspberries, apples, onions, bulbs and nursery stock are now being grown in a virtually weed-free condition in some areas. Total weed control in these crops has been achieved in many cases by chemicals alone, sometimes supplemented by a small amount of hand work to deal mainly with weeds disseminated by wind or birds. Control has been achieved because the high value of the crop made it possible to apply sequential treatments adjusted to the specific weed problem; in addition the morphology of the crop plants was often very different from that of the weeds so that a range of suitable herbicides was available.

The results with overall herbicides and virtually complete weed control in horticultural crops has been encouraging. There is evidence that yields have increased in the absence of cultivation (Robinson 1964, Robinson and O'Kennedy 1978), soil structure has improved (Jelley et al 1974) and soil organic matter has not fallen on completely weed-free, non-cultivated soil over a 13-year period (Jelley 1978).

The fact that we can achieve virtual weed freedom in some crops is significant. It shows that we don't have to take weeds for granted and look on them as an inevitable part of crop production. For too long we have tended to regard complacently the genetic diversity that exists in our weed species and the selective pressures put on a population of weeds when a herbicide programme giving incomplete control is applied. But if we suppress weeds completely then resistance cannot evolve. Certainly in intensive areas there will be much in favour of attempting to achieve a weed-free environment even if this requires a period of what is apparently cosmetic weed control. Growers will need to develop a different philosophy of weed control. They will need to think more about long-term strategies for reducing the weed seed population in the soil by chemical, cultural and other means. Spot treatment either with liquid formulations or granules is used with a high degree of success by some growers but is not yet as widely accepted as it should be. As improved methods of weed control and better application equipment in the next 25 years reduce weed populations to low levels in many more crops, the scope for spot applications will increase e.g. in sugar beet.

Paradoxically the aim of weed freedom in crops where annual soil disturbance is unnecessary, is likely to result in less and not more herbicide usage over a period of years. Experience shows that once perennial weeds have been controlled in fruit crops, herbicide doses can be reduced to a low level. The concept of "complete weed control" will be of greatest value when it can be applied to whole farms and regions and not just to individual crops. It cannot be applied at present to many extensively grown agricultural crops where herbicides available are still inadequate or uneconomic for current weed problems. In these cases weed containment and reduction in the weed seed population is the correct policy. Nevertheless I believe that the high degree of weed freedom that has been achieved in a limited number of crops during the last quarter century will be possible in many more crops during the next.

The introduction of new herbicides has slowed down but it will not cease. The development of superior control measures with existing herbicides is only prevented by the limitations of our present knowledge of weed biology and herbicide performance. There are far-reaching implications in a number of technical developments that appear to be quite possible within the short term such as effective equipment for spot spraying where the triggered nozzles are activated by weeds, methods of eradicating weed propagules in the soil by economic fumigants and chemicals that would induce weed germination or extend the dormancy of weed seeds in the soil (Hall 1979). Present reluctance to aim for weed freedom in crops, farms and regions is due partly to lack of confidence that it can be achieved and partly to lack of appreciation of the benefits that would accrue, in relation to the money spent. It is also due to a curious concern about the possible side-effects of a completely weed-free environment as if such a situation was in some ways erroneous and a challenge to nature. Yet when labour was cheap and plentiful before the Second World War the outstanding market gardens in north west Europe were maintained in a weed-free condition by repeated mechanical and hand hoeings. Paradoxically that situation is still regarded nostalgically by some as 'good husbandry' at its very best.

Obviously a change in husbandry practice to a virtually weed-free environment cannot be achieved without side-effects, some of which may be harmful. Run off and erosion, previously retarded by weed growth, may be severe on sloping sites. Weeds can also be important as sources of parasites and predators that reduce crop pests. Crops that depend on wild insects for pollination may suffer poor fruit set if the insect numbers are reduced by the absence of weeds; harmful insects that previously fed on weeds may turn their attention to crop plants with serious results if the crop is drilled to a stand. To some people the thought of the use of overall herbicides and complete weed suppression is anathema. They regard this as yet another example of the use of unnecessarily violent technology in an attempt to bash nature into subjection. They will be quick to use these and other examples of side-effects as indicative of the short-sighteness of the use of herbicides in a battle with nature which man can't possibly win. But technology often poses problems in the course of progress which require further technology to solve. The advantages of growing crops in a weed-free environment where this can be achieved are so great that other steps must be taken to overcome minor problems that may arise. Strips of organic mulches to prevent erosion will allow the overall herbicide concept to be applied to many fruit plantations on moderately sloping sites; better attention to insect control will prevent damage by pests in weed-free sugar beet.

As farm land is managed more and more intensively there will be an even greater need to manage parts of it more positively for nature conservation. Conservationists are justified in asking the farming community not to reclaim the last remnants of good wildlife habitat - the small woods, old hedges and ponds that still exist (Moore 1977). The Nature Conservancy Council deserves full support in its campaign for a rural land use strategy which will promote the protection of the best farm land for farming and at the same time integrate other national objectives such as nature conservation and the creation of good landscapes. This policy would also provide a greater measure of support for farmers to enable them to manage land for purposes other than food production.

The weed freedom that has been achieved in some fruit crops, bulbs and onions should serve as an encouragement to growers of other crops. What is needed is more aggression against weeds and less acquiescence and apathy. Too many vegetable and cereal fields from which crops have been harvested are allowed to become weedy before preparations begin for the following season's crop. Simple, timely post-harvest treatment with contact herbicides would do much to prevent the return of weed seeds to the soil. There are grounds for optimism therefore that before the end of this century a better understanding of the nature of the weed problem, a growing volume of information on the most effective means of controlling specific weeds and the development of more effective herbicides, will enable many crops, and also the ground in the inter-cropping period, to be kept in a virtual weed-free condition.

POST-INDUSTRIAL SOCIETY

Twenty five years from now we will be in the next century and probably moving gradually into a post-industrial economy, in which earning a living will constitute a smaller part of a person's activities. How soon this will come is impossible to say but already more and more people are doing things for their own sake. Increasing leisure will give people opportunities to develop new skills and arts and time to appreciate new delights. Many of today's leisure pursuits will become even more important to larger numbers of people - activities such as gardening, garden visiting, home vegetable production, hunting, hiking, camping and sports. We must anticipate increasing demands for a wider variety of outdoor recreational facilities.

We will need to think more deeply about how we can use herbicides creatively for man's enjoyment and how they can contribute to the more satisfying use of his leisure time. I anticipate that many people will want to establish a "oneness with nature" but they will want to have nature under their control as far as possible. They will want the pleasure of seeing plants grow and thrive without the drudgery of keeping them weed free entirely by manual means. We could see the amateur market for herbicides increasing in importance with all the attendant problems of packaging, marketing and education associated with small-scale use.

Herbicides too are likely to become a more valuable tool in the preservation and enhancement of the environment. Just as we are now learning to manipulate agricultural grassland with selective herbicides and seed introduction, the scope for managing amenity grassland is equally great. Herbicides have been used to increase species diversity (Willis 1969) and, as we accumulate knowledge of the life history of wild flowers and their response to herbicides, we will be able to create and manage for recreational purposes large areas of grassland, bluebells, primroses, cow slips and other attractive native species.

During this century western Europe has lost many magnificent gardens due to the high cost of upkeep mainly for weed control. Herbicides can be very useful not merely to maintain amenity areas, sites of special scientific interest and nature reserves, but their use can result in better quality plants as woody ornamentals respond positively to herbicides in the same way as the closely related fruit crops. There has been too much unfounded criticism of herbicides destroying the environment and too little publicity on their role in enhancing it. In the future weed scientists will not be almost exclusively concerned with food crops as they are at present but will also be more interested in amenity aspects.

And so our problems in the future will arise from the challenges that face both agriculture and society. As each major problem is solved there will be a tendency for agricultural technology to set even higher targets and to modify increasingly traditional practice for a variety of reasons, e.g. to increase yields or reduce production costs. Thus as happened during the last quarter century, advances in weed control will result in further changes in production systems and greater efficiency but will inevitably expose new problems. The agricultural industry will be required to develop within an increasingly intricate regime of policies and procedures designed to satisfy two objectives - increased food production and protection of the environment.

With a stronger science-base today and greater opportunities for the transfer of technology between countries, it is inevitable that there will be many innovations during the next 25 years that we cannot foresee clearly today. Our basic challenge will be to co-operate effectively, nationally and internationally, to combine current knowledge with the even more sophisticated science and technology which will emerge during this period.

We have travelled a great distance in 25 years and the immediate way ahead seems set for continuing rapid progress. Better herbicides and formulations, a more intelligent use of existing herbicides, a greater understanding of weed biology, better application methods, improved data collection and retrieval, aided in the next generation by discoveries not yet apparent, suggest that we are starting today on the most creative period yet in the history of weed control.

At the British Weed Control Conference in 1964 I referred to the fact that the literature contains many warnings that chemicals should be looked on as an adjunct to cultivation and not as a substitute (Robinson 1965). Many speakers and writers still stress the continued need for good husbandry as the first essential of our farming as if there is some antagonism between chemical methods of weed control and good husbandry. I said in 1964, and I still believe, that the intelligent use of herbicides is good husbandry and that soil cultivation, which is so often done unnecessarily, it not good husbandry if it confers no benefits to soil or crop but only improves the short-term appearance of the soil to the human eye. For many crops cultivation and other methods of weed control are still needed at the present time but the major adjustment from crop and soil management by machinery to chemical management with herbicides which gathered momentum in the last generation will, I believe, continue rapidly in the next.

New technologies may create new problems and the effect of herbicides on the environment in particular needs to be watched with vigilance. If, in the future, herbicide technology causes problems such as pollution or resistant weeds, I have no doubt that technology can solve them. I have referred to some of the problems that will tend to retard progress during the next 25 years including the increasing cost of energy, more stringent regulatory requirements and a social reaction among some sectors of the public that will attempt to slow technological advance. But given the same dynamism and ingenuity in the weed control industry and by weed scientists generally, which has been so much in evidence during the past generation, these problems can surely be overcome.

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BAWDEN ESSAY COMPETITION

The Bawden Trust makes a number of awards each year to enable young people to attend the British Crop Protection Conference, held annually at Brighton. The awards are made on the basis of an essay competition, open to young people of any nationality, studying or employed in Great Britain. The winning essay for 1978 is presented on the following pages.

THE COMPLEMENTARY ROLES OF GOOD HUSBANDRY, PLANT BREEDING AND AGROCHEMICALS IN THE PRODUCTION OF HEALTHY CROPS

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The production of a healthy crop is dependent on disease and pest control and prevention of nutrient, water and light deficiencies in the crop plant.

The crop often determines the method of disease control to be employed. Crops grown in a protected environment such as glasshouses, or on a limited area such as orchard fruits, are traditionally protected from disease by fungicides. High acreage crops, such as cereals, were, until recent years, protected from disease by the use of seed dressings or by growing resistant varieties. However, their increased economic importance, combined with the discovery of effective systemic fungicides, has led to the increased use of fungicides in preventing diseases of high acreage crops. Application of fungicide on wheat at critical periods in the development of the crop, has been shown to be of considerable value in protecting the crop against a significant increase in disease. Resistant varieties eliminate the cost and labour involved in applying control methods. Frequently, the relative success of other control measures is determined by the preciseness of their use dictating mans involvement before or during crop production. Success of resistance is not so subject to such external variation. Plant resistance is used particularly for the control of air borne fungal diseases such as mildew and rust in cereals and blight in potatoes. Foliar sprays of chemicals are also used in the control of these diseases. Potatoes are sprayed against blight with a range of contact sprays based on metallic salts of manganese, zinc and tin and also thiocarbamates. Xylem translocated systemic fungicides such as benomyl are used against powdery mildew in barley.

Resistant varieties of a crop are obtained by hybridization or by selection of disease survivors after exposing the crop to a mutagen. In most resistant varieties one gene is changed and resistance is monogenic, that is specific against one pathogenic strain. A combination of genes may confer near immunity in several pathogenic races, but when a new virulent race appears, the variety is completely susceptible. The plant breeding programme must then be restarted to find a new gene for resistance. Established varieties however, may differ considerably in their reaction to disease in the field, often being destroyed less quickly in epidemics. This type of resistance is polygenic and called field resistance. Cereal breeders are now trying to combine major gene resistance with a satisfactory level of field resistance to make it more difficult for a disease to break down plant resistance. Field resistance combined with the principle of using fungicides to reduce the rate at which disease develops, may provide a new dimension to disease control.

One principle of disease control is seldom employed exclusively. The integrated use of resistant varieties with principles of exclusion, eradication, physical or chemical protection, avoidence, therapy and biological control is commonplace in modern agriculture, and illustrates the importance of disease control in the production of a healthy crop. Combinations of principles are used to combat the same and different diseases.

Elimination of weeds and alternate hosts from cultivated areas may enhance resistance to a particular disease. In the U.S.A. eradication of barberry bushes in areas grown with wheat and oats substantially reduced stem rust over a number of years, but did not check outbreaks of black stem rust in years such as 1935. High rainfall and late ripening in the south that year caused severe stem rust and resulted in large masses of urediospores reaching the barberry eradication areas, where similar weather conditions allowed the rust to become epiphytoxic. The success of the barberry eradication in previous years emphasises its failure in a year of massive widespread urediospore inoculum. Removal of an alternative host is a possible way of reducing disease inoculum and hence crop damage and is also useful in limiting the production of new races of the fungi. Eradicating all weeds using herbicides, for a distance of 23 metres around celery seedbeds in Florida, has decreased the incidence of Southern celery mosaic virus. Spinach yellow caused by cucumber mosaic virus and veinbanding mosaic virus in peppers are further examples of viruses brought under control by weed eradication schemes. In viral disease control, good husbandry is essential as no effective agrochemical control is available. Some work has been done on breeding varieties resistant or tolerant to viruses but control by vector eradication is still dominant.

The simplest form of eradication scheme is the removal of the diseased plants or rogueing. Rogueing is important in the maintenance of healthy stocks of seed potatoes; its success relies on early recognition of symptoms. Large scale eradication schemes can totally eliminate a disease as happened in the case of citrus canker in the U.S.A.

Disease resistance is often more effective when crop rotation or sanitation is utilised, since both these practices frequently tend to reduce the amount of initial inoculum. This is particularly important when the crop residue constitutes the chief source of inoculum as in the case of leaf spot of tobacco. Burning of potato haulms and removal of all residues destroy a large source of potato blight inoculum. Stubble cleaning using cultural and chemical methods of weed control, eliminates volunteer cereal plants. These plants from seed shed at harvest, may be infected with powdery mildew and rust and so act as a source of infection for later sown crops.

Elimination of plant pathogens and pests by cultural methods is practised, particularly with root diseases. The choice of a cropping sequence which allows appropriate intervals between suceptible crops, for example 5 years between main crop potatoes in the same field, eradicates pathogens by depriving them of the host plant. Crop rotations vary according to the disease; 1 to 2 years between wheat gives adequate control of take all, but 8 to 10 years may be needed between brassica crops grown in the same field to control club root. Pathogens with a wide host range or those that form resting structures, such as sclerotia, are difficult to deal with in this way, though deep ploughing or catch crops to stimulate germination of sclerotia and resting spores are possible alternatives. That, and chemical treatment of the soil may also be used to eradicate soil borne plant pathogens and nematodes. Steaming is the most popular heat treatment but a considerable number of less expensive chemicals are available for soil treatment. Though some chemicals have more specific toxicity, many of these chemicals such as methyl bromide are generally toxic to most animals and plants and should be used well before planting. For maximum effectiveness, the soil zone in which the pathogen and host are likely to meet, the effects of the chemical on the soil (and vice versa) and the penetration of the soil by the chemical, must be known.

Brassica production is a good example of integrated control against a root disease, Plasmodiophora brassicae. Crop rotation, treatment of the roots with calomel, regulation of the soil moisture and acidity by drainage and lining are combined to produce a healthy crop free from club root. Some resistant varieties are also available but are not in wide commercial use.

Many soil borne pathogens are sensitive to soil reaction; for example an alkaline soil favours common scab on potatoes and take-all on cereals. Under cold, wet conditions, damping-off fungi may cause severe loss of germinating seedlings. Early sown peas are often severely attacked by soil borne fungi unless adequately protected by fungicidal seed treatments. Adequate drainage to remove excess soil moisture and timely cultivations to avoid damage to soil structure help to maintain crop vigour and health and offset the risk from soil borne diseases. Drainage may also reduce the incidence of slugs.

The timing of sowing and spraying of crops is important in minimising disease. Early autumn sowing of cereals may increase the risk of rust and mildew infections, but late sowing often entails drop in yield so a compromise sowing date is needed. Varieties of potatoes with a short early growing season reduce nematode numbers by allowing attack but preventing the completion of the nematode life cycle. Main crop potatoes derived from early planted and well chitted seed, may mature before a severe attack of blight develops and so escape damage. Late sowing of carrots may avoid damage by first generation carrot fly. Spacing of the plants can also effect their health, parsnip canker being more prevalent in widely spaced fields.

Correct timing of spraying is essential for adequate disease control. Leaves formed after spraying receive little or no control. Spraying is often expensive and the number of applications is therefore kept to a minimum. The number of treatments needed is dependent on the persistence of the fungicide and the particular host and pathogen concerned. Pesticidal sprays are often toxic to man and animals and hence spraying immediately before harvest should be avoided to prevent toxic residues reaching the consumer.

Countries differ in their approach to the problem of toxic residues in food and the environment resulting from the use of pesticides. For a pesticide to be effective it must be fairly persistent, but its persistence in the environment, in natural food chains, its toxicity to wildlife and the health hazards that the use of pesticides produce, are now matters of social concern. The increasing use of agrochemicals by the farmer is now a topic of which we are increasingly aware and tighter legislation on the use of pesticides in agriculture, especially in developing countries, places increasing emphasis on the need for good husbandry and the development of more varieties of disease resistant crops. The use of resistant varieties is of major importance in developing countries where the lower level of education increases the hazards from the use of pesticides, but the need for healthy crops is greatest in order to feed an ever expanding population.

In addition to foliar sprays, seed treatments play an important role in disease control. Seed disinfectants and insecticidal and fungicidal treatments are widely used but again these are highly toxic. Seed should be weed free, true to variety and free from major seed borne diseases, good seed management being vital to a healthy crop.

The use of chemical compounds in the control of insects is of prime importance in crop production. The use of insecticides does of course pose a threat to man, wildlife and the balance of predators to pests. The need for precise application of insecticides cannot be over stressed. As an alternative, biological control, that is, control of pests by natural predators is being encouraged. But there are few cases of the successful commercial application, an example being the control of red spider mites on cucumbers. Breeding crops with insect resistance has been successful in a number of instances, as for example, resistance to Hessian fly in wheat, but the degree of resistance varies.

The use of clean seed and timely cultivations do much to prevent crop losses from soil pests such as potato and sugar beet eelworm. Chemical treatments and steam sterilization of the soil can also be used against nematodes. Varieties of potato resistant to potato root eelworm, selective nematicides, soil fumigants and crop rotation are all means available to produce a more healthy crop. However, the action taken by the farmer is usually governed by costs.

Pests such as aphids and nematodes are often more important as virus vectors than for the direct damage they do to crops. Insecticides, combined with the use of resistant varieties, are often used against aphids in order to prevent the spread of viruses such as barley yellow dwarf and cucumber mosaic virus. Chemical soil treatments can be used to limit the spread of nematode transmitted viruses such as arabis mosaic, but care in the movement of propagating material and weed control are also important factors.

As well as the disease controlling pesticides, fertilizers are needed in the production of healthy crops. If the soil is to supply adequate nutrients to the crop, the farmer must maintain its fertility. Without the essential elements for growth, a crop will show deficiency symptoms and normal growth will be prevented. Soil fertility is usually maintained by the application of chemical fertilizers containing known amounts of nitrogen, phosphorus and potassium. Organic manures and green cover crops may also be incorporated into the soil to increase its nutrient content. Ploughing-under of green cover crops or green manuring reduces the incidence of potato scab presumably by creating a soil environment more conducive to antagonistic microbes.

Growing leguminous crops such as clover and lucerne also increases the nitrogen content of the soil as these plants can fix atmospheric nitrogen due to their symbiotic bacteria. Adequate supplies of nutrients are essential for vigorous and high yielding crops. However, excess application of nitrogen to cereals may increase their susceptibility to foliar diseases such as powdery mildew, rust and septoria and also increases lodging.

Liming supplies calcium and magnesium and also affects the soil pH so dictating the availibility of other essential elements. Soil pH may also affect the susceptibility of the crop to diseases such as club root in brassicas. Fertilizers may also affect soil pH; superphosphate, for example, gives an acid reaction.

In addition to nutrients, an adequate supply of water and light is needed for a healthy crop. Water stress may have many effects on crop growth and development which can be avoided by timely irrigation. New crop varieties resistant to drought promise more healthy crops in areas of low water supply. Uniformity of variety of a crop combined with adequate spacing enables it to make maximum use of light. Less shading results in more uniform growth. The use of herbicides or inter-row cultivation, minimises weed competition.

The breeding of varieties resistant to diseases and pests enables man to increase the health of his crops while caring for them less. Most crops are subject to attack by one or more pathogens from planting to harvest and it is unlikely that a single variety of any crop species will be developed with resistance to all races of all its pathogens. Resistance to some diseases may make fungicidal control of the remaining ones an easier and economically feasible task. Pesticides, whilst a powerful influence in maintaining crop health, are not a substitute for good husbandry and are also a powerful weapon against the environment. Combinations of control measures are needed if man is to continue to produce healthy crops.