Proceedings 7th British Insecticide and Fungicide Conference (1973)

Opening Remarks

by

Sir Emrys Jones

I have pleasure in welcoming you to the 7th British Insecticide and Fungicide Conference which this year has received the highest support of any conference held here at Brighton. Nearly 1,500 delegates have registered to attend, of which approximately 600 are from oversea countries, and it gives me particular pleasure to welcome the participation of our oversea guests in this conference.

The programme of invited papers and research reports which have been arranged by the Programme Committee extends to 125 papers, and it is extremely gratifying to record the very high response there has been from potential authors to the conference this year. Support has been so great that the Programme Committee have been forced to be very selective, and we apologise to any disappointed authors, but only papers directly related to the subject matter of the session have been able to be accepted for presentation.

The conference this year is in a new format, and I would first like to refer to the Bawden Memorial Lecture, which has been inaugerated by the British Crop Protection Council as a permanent feature of these conferences. The first lecture of this series is to be presented by Sir Henry Plumb as a tribute to the memory of Sir Frederick Bawden the first President of the British Crop Protection Council. In addition the programme itself has been reorganised to provide for only four plenary sessions and to increase the number of concurrent sessions to 14, and this has been associated with an expansion of scientific subject matter to include for the first time a session on the use of insecticides for the control of ectoparasites in animals.

The Council are also pleased that a number of our European colleagues have agreed to act as Chairmen of sessions, and we particularly welcome Professor Kips and Professor van der Kerk to the conference.

The scientific content of sessions reflects the trend of pesticide development in the U.K. and three sessions dealing with cereal pathology both from the viewpoint of foliar and seed borne diseases indicate the continuing importance of this problem to the maintenance of our cereal yields. In session 5, papers will be dealing with the principles of collaborative work between industrial and government agencies for the clearance of secondary uses of pesticides, which is an increasingly important problem if the specialised sectors of the horticultural industry are to be kept supplied with new pesticides to meet their growing needs. Fundamental subjects are also dealt with in two sessions dealing with the biochemistry of pesticides in soil and also the problem of uptake and translocation of pesticides by plants. In addition problems of soil borne pests and diseases are dealt with in sessions involving studies on nematicides, soil borne diseases and insect attack.

I now have great pleasure in introducing Sir Henry Plumb who will present the first Bawden Memorial Lecture on "The future of Agriculture in the E.E.C." We must indeed consider ourselves fortunate in having a speaker of the calibre of Sir Henry to give this first Memorial Lecture to the memory of the First President of Council, Sir Frederick Bawden who passed away in February 1972. I now have great pleasure in formally declaring the conference open and inviting Sir Henry Plumb to present his lecture.

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1st BAWDEN MEMORIAL LECTURE

The first of a series of annual lectures
arranged under the auspices of the
British Crop Protection Council in memory
of the First President of the Council,
Sir Frederick Bawden.

THE FUTURE OF AGRICULTURE IN THE E.E.C.

by

Sir Henry Plumb

President, National Farmers' Union of England and Wales

Mr. President, Ladies and Gentlemen -

May I first of all say that I accepted the invitation to deliver this, the first Bawden Memorial Lecture, as an honour and a privilege. I do so, however, not only in my own person and as a farmer but still more so as the President of the National Farmers' Union of England and Wales, whose members owe to Sir Frederick Bawden and to Rothamsted a debt that we gladly acknowledge. This conference has established an enviable reputation in the agricultural life of this country, and it is entirely fitting that the first of these memorial lectures should come from the industry to whose welfare Sir Frederick devoted his great talents. But to speak only for the agriculture of this country would be to diminish the true stature of the man and the scientist, for ever present in his mind and in his work was the knowledge of what science might do for those vast areas of the world where in these last decades of the 20th century millions remain ill-fed and hungry.

Bawden was a big man in every way, physically, morally and professionally. His family life was a source of strength for his scientific work at home and abroad, and in Lady Bawden, a botanist in her own right, he was fortunate in having a partner whose devotion to the welfare of Rothamsted was no less than his own.

He was a man of great charm; frequently exuberant and humorous, in a manner - in the words of Norman Pirie, his friend and colleague for nearly forty years - "which partly hid a great intensity of feeling on matters connected with research and the welfare of Rothamsted". In his person, as in his work, he was a man of complete integrity, quick to detect ambiguity or insincerity in social or scientific discourse, immensely loyal to his colleagues and fiercely jealous of the independence of scientific research, and of that measure of independence that Rothamsted's constitution allowed.

Throughout his life, Bawden retained a great love for his native Devonshire and its people, and, although he himself was not born into farming, many of his ancestors were closely connected with agriculture, and one of them indeed designed and marketed a novel kind of plough. Like all the directors of Rothamsted, however, he became intensely interested in the problems and practice of farming. But unlike many academic scientists and too many politicians - in the years of farming depression between the wars - he really believed that the farmer's business was to produce food, and to produce it at a profit. Never did he forget the business aspect of farming. Like the farmer, he measured the fertility of a soil in terms of yield and the role of the scientist in terms of helping the farmer to reap the full rewards of his labour. To this end, he was tireless in propagating the view, in his own work and in that of his colleagues and staff, that the English language should be used with simplicity and clarity to communicate between agricultural science and agricultural practice.

Bawden was a tremendous worker, even when at Cambridge his fellow undergraduates could seldom reconcile his energetic social life with his enviable scholastic career. Part of the answer was his prodigious memory; he made no card index and very few notes throughout his professional life.

It was in his early days at Cambridge that he decided to become a plant pathologist, and, after taking a first class in Part One of the Natural Sciences Tripos, he joined the course in plant pathology taught by F.T. Brooks in the School of Agriculture, and there he obtained the Diploma of Agricultural Science in 1930. He was then appointed research assistant at the Potato Virus Research Station at Cambridge by R.N. Salaman.

Writing late of this period in his life, with that touch of humour so typical of him, Bawden recalled: "It is an understatement to say that working conditions were primitive. The laboratory was a wooden hut, and the most sophisticated apparatus was a recalcitrant Primus stove". Primitive as the conditions were for making virus preparations, at least, as he remembered later, he no longer had to cycle several miles conveying material from his glasshouse to his laboratory.

Typical of the respect and loyalty he always displayed toward worthy colleagues throughout his life, he later wrote of Salaman - the distinguished authority on potatoes - that his debt to him was 'enormous'. "I caught his passion for the crop", he said, "and have never lost it".

"Early influences have lasting effects", he went on, "and the best advice I can give anyone contemplating entering into research is to choose carefully with whom you first work". Sound advice too, for any young farmer!

That single word "passion" reveals the inner man, the determined seeker after scientific truth, that his cheerful outgoing personality so often concealed.

He was now becoming more widely known, and it was a logical step in his career when, in 1936, Sir John Russell invited him to Rothamsted as virus physiologist. It was in that year that he and Norman Pirie were the first to establish that tobacco mosaic is a nucleoprotein and that the same was true of several other viruses; and it was this work which helped to lay the foundations of what has since become known as molecular biology.

In 1940, at the age of 32, he became head of the plant pathology department; then deputy director of Rothamsted ten years later; and finally director in 1958, in succession to Sir William Ogg.

In the years that followed his arrival at Rothamsted, Bawden was to become a world authority on plant viruses and virus diseases. His books on 'Plant Viruses and Virus Diseases', first published in 1939, and 'Plant Diseases', published in 1950, have become standard text books on their subjects.

The growth of work at Rothamsted under Bawden can be partly measured by the fact that during his fourteen years as director, until his sudden and untimely death in 1972, the staff increased from 471 to over 700, with 48 more at Brooms Barn, near Bury St. Edmunds, in which he took such a keen interest. Bawden's first report from Rothamsted, for example, contained 283 pages and recorded 248 published papers. The report for 1970 was in two parts, in 644 bigger pages, recording 330 published papers.

George Cooke, a colleague at Rothamsted, recalls that during Bawden's directorship, the annual reports became far more widely read and more highly esteemed.

"During his time", Cooke records, "the annual report became more valuable to scientists, agriculturists and general readers Bawden's advice and help to departments in describing their work was invaluable, but the style of the report owed much to his own 'General Report', described in a recent review as a 'connoisseur's piece'. These reports, and his discussion of their relationship with current agricultural problems, were eagerly read by scientists and laymen. His keen pen examined old problems and suggested how our work might help their solution; usually there was comment on farming conditions and vigorous intervention in debates on topical subjects, particularly if farming lore was being given more weight than scientific evidence".

Every one of the several hundred papers published each year by Rothamsted staff passed under the critical eyes of the Director before publication. Norman Pirie recalls that "no other director took so much trouble over both the form and content of our papers - he was adept at detecting ambiguity - and ruthlessly pruned prolixity".

Bawden agreed with Swift: "You write with the point of the pen; not the feather".

Bawden's practical approach to agricultural science; his impatience with academic distinctions between pure and applied research; his impatience with narrow specialisation; and, above, his concern with clear and simple exposition of results, strikes a responsive chord in my own heart. We are plagued today by many kinds of specialists who cannot communicate with the farmer because they so often use a style and language we do not understand.

Editing the report of a group of scientists in 1962 - which advocated the setting up of international science centres, one of his constant concerns - Bawden wrote: "People able to write accurately about science for the general public are regrettably few. Both in their own interest and to improve the standard of scientific writing, the centres should not only employ writers but should, perhaps, provide scholarships in scientific writing to be held at the centres".

Bawden also emphasised the importance of co-operation in the varying aspects of plant pathology, and on the equal importance of work in the field as well as in the laboratory.

"Pathology needs specialists of many kinds", he wrote in his book on Plant Diseases, "but will drive most benefit when these are working together with the common aim of understanding pathogenicity and improving plant health".

Looking back to his early days on virus studies in the thirties and to recent trends towards narrow specialisation, he continued: "Forty years on it is salutary to look back and contemplate the optimistic expectations that knowledge of viruses would help to control virus disease. That it has not, is vividly illustrated by the fact that the tobacco mosaic virus, whose structure and composition is most completely known, is still prevalent in tomato crops in the United Kingdom, whereas little more is known about potato leafroll virus than in 1930; yet it is now a rarity in our potato crops, instead of the major cause of loss it was then".

Plant pathology offers many diverse problems for study, Bawden pointed out, adding that their solution calls "not only for an equal diversity of talents and techniques, but also for workers with inquiring and original minds. And they will be needed not only operating equipment in laboratories, but at least equally to work with plants under glass and in the field, because it is there that the discoveries are most likely to be made that will improve the health of crops; something vital if farmers are to reap the full harvest of their labour and the rapidly increasing population of people is to be adequately fed".

There speaks the director of a world-famous research institution on the essential links between the scientist, the laboratory and the farmer. It was that breadth of vision which helped to make Bawden, the brilliant research worker, into the influential director of Rothamsted.

In a paper of this kind, there is not time, nor am I qualified to assess the work of Bawden, the scientist. But as a farmer who has earned his living from the land, I will mention only two of the great contributions - in concert with his colleagues - we shall always remember.

One was the research which finally freed the King Edward potato from the paracrinkle virus. He refers to this in the 1959 Rothamsted Reports with particular pleasure, because it illustated the great practical benefit that may come from research done to gain fundamental information. The result of that work was a 10 percent increase in the yield of King Edwards: something like another 100,000 tons.

The other was the great encouragement he gave to the spray warning scheme, when aphid infections seemed likely to spread and carry beet yellows virus. It started in 1957, and within two years, more than 95 per cent of the total sugar beet acreage was sprayed on time and the net increase in income in 1958 as a result was estimated at about £5 million. This is where the scientist, the farmer and the farmer's banker are in perfect accord!

In conjunction with other measures, timely spray warnings have effectively controlled the incidence of yellows. Indeed, they proved so obviously beneficial that Bawden feared that some spraying was done unnecessarily, and he emphasised the importance - to quote his own words - of keeping "an indispensable practice from becoming an established ritual". As a farmer, I must confess that similar warnings could equally apply in other fields today!

The spray warning was a logical development of Bawden's own approach, the primary aim of which was to ensure that healthy and productive crops could be grown, as he said, "when and where a farmer wished". Emphasising the importance of detailed investigation into the habits of vectors, he argued strongly that the control of virus infection was fundamental to a rational use of insecticides. Killing insects after the damage was done is mere revenge. The important thing, he said, was to kill them before they infect the crops - and, better still, to kill them on the plants from which they obtained the infection.

I referred at the beginning of this paper to Bawden's concern for the hungry populations of the world. He clearly recognised that the control of plant diseases was essential if the standard of living of the developing countries was to be improved. To this end, he made Rothamsted a centre of training in plant pathology for overseas scientists and students, and he became a valued friend and counsellor to agriculture in many parts of the world - in the West Indies, Africa, India and Ceylon In spite of heavy commitments in the West Indies and at Rothamsted, he presided over the Agricultural Research Council of the Central African Federation, and when the Federation broke up following the Rhodesian unilateral declaration of independence, he was able to achieve an orderly division of the work into national groupings.

Of this period of his work in Rhodesia, Malawi and Zambia, Norman Pirie recalls: "His approach to the problems was characteristic: he visited farms to meet the farmers and assess the standard of agriculture. At research stations, he plunged into animated conversations with individual scientists about their work, but showed ill-concealed impatience with formal laboratory visits and tours. It was their ideas, not their hardware, he wanted to discuss".

When his responsibilities at Rothamsted inevitably reduced the time he could give to practical work, he devoted numerous evenings and week-ends to experiments in the laboratory or greenhouse. This, he said, was his 'occupational therapy'. Pirie recalls that the tall figure of the director could be seen on many a quiet evening, carrying four pots of Glutinosa in each hand and negotiating one sliding door after another without damaging a single leaf.

Bawden was honoured in many parts of the world, from Moscow to New York; but one other aspect of this many-sided man - scientist, teacher, administrator - is illustrated in Sir David Martin's comment on his contribution to the Royal Society, of which he was vice-president and treasurer, an activity in which he took great delight. "He was a valuable ambassador to many overseas countries", Sir David wrote. "In a period of expansion in the Society's activities, Bawden, as treasurer, kept a wise and firm grip on financial policy, but always placed the promotion of the Society's scientific activities as the first priority in the formulation of that policy".

How does one try and sum up the contribution of such a man - to agricultural science and to the practice and science of farming? Someone once said: "Enthusiasm is the wine we bring to the banquet of life", and I personally believe that Sir Frederick's breadth of vision, his concern with science as a tool in good farming, and, above all, his enthusiasm for and devotion to Rothamsted have left their imprint on the great institution and the industry he served for so long.

Agricultural science has come a long way since the Secretary of the Board of Agriculture could say - during Sir John Russell's time as Director at Rothamsted - "I cannot conceive the circumstances in which the Board will be at all interested in scientific work"! Even as late as 1941, Bawden - in a series of articles advocating the heavier and more profitable use of fertilisers - remarked that malnutrition among our crops before the war was more common than Sir John Orr (later Lord Boyd Orr) found it to be among our people. We regard Rothamsted, of course, as the real birthplace of the fertiliser industry, and the consumption of inorganic fertilisers in the United Kingdom today is over two million product tons. The 1971 Rothamsted survey of fertiliser practice in England and Wales indeed revealed that arable crops are now receiving applications of fertiliser very near the optimum. On the whole, however, our permanent and temporary grass still receives much less than the known economic levels. This situation is now changing, as we grow increasingly aware that our farming future in the European Community will depend more than anything on the expansion of our livestock, and especially on the grazing animal. Grass is Britain's most important crop, and it is on our grassland that the greatest use of inorganic fertilisers remains to be made.

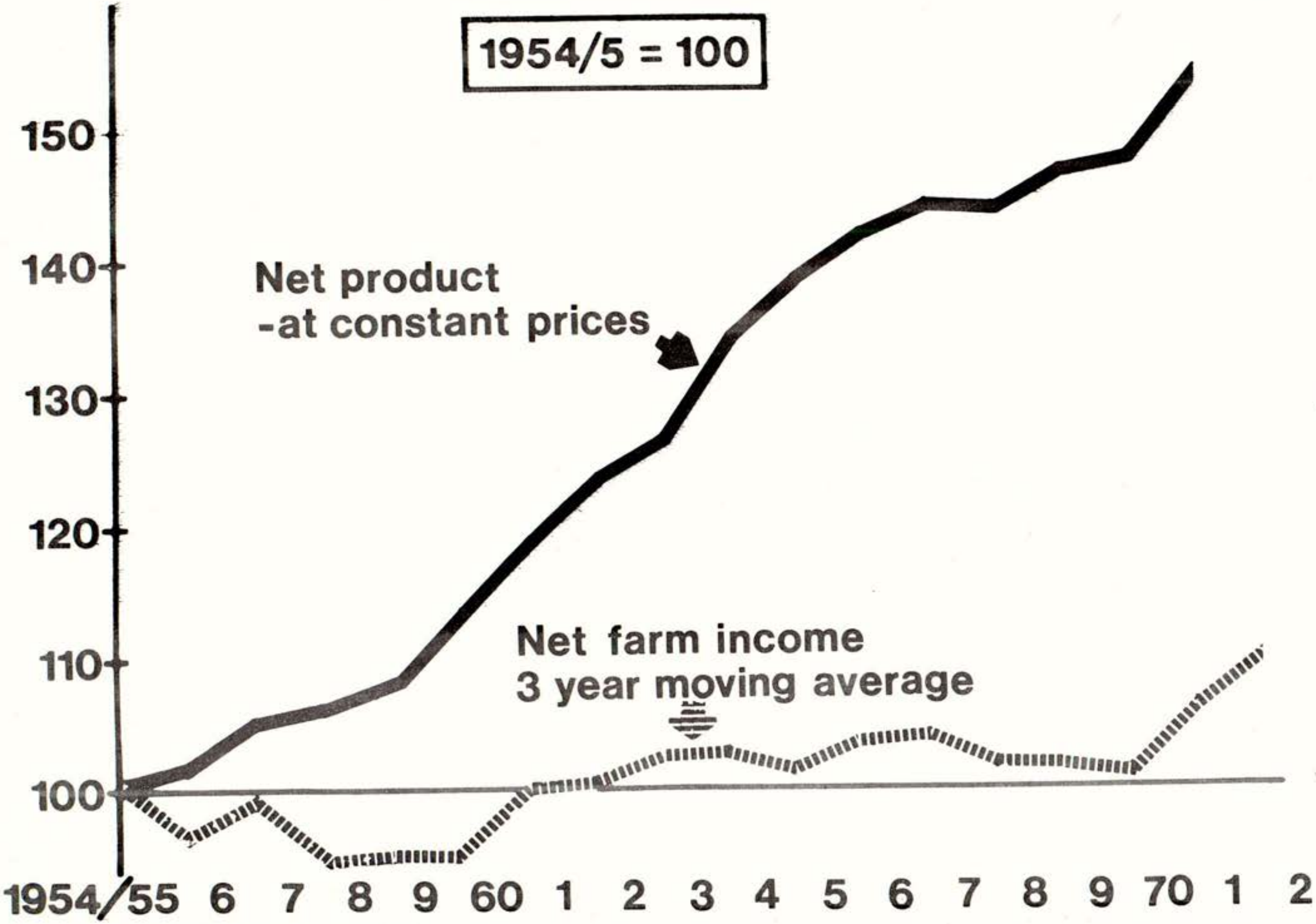
But it is impossible to quantify the contribution that science has made to modern farming. Agriculture calls upon practically every branch of science and technology, and the quantity and quality of the response in this country can be partly seen in a brief consideration of the industry's record.

Since the mid-1950's, when there were more than a million people on the land, production has increased by more than 50 percent, while the total number of workers has decreased by about as much. The usual method of comparison is through the index of net product calculated on a volume basis. Taking the average of the years 1964/65 - 1966/67 as 100, the index of net product today is forecast at 117. In the last five years, gross output - that is, the total value of all production, together with changes in the value of stocks and including all Government grants other than those of a capital nature - has increased from £2,241 million to a forecast of £3,152 million for 1972/73.

This tremendous increase in net output and in productivity was associated with the system of deficiency payments - now being phased out during our five years of transition to full membership of the EEC - which was introduced in the middle of the 1950's when the fixed prices introduced during the war were abandoned. Translated into terms of labour productivity, that 50 per cent expansion in output meant an average increase of nearly six per cent a year - twice the rate of increase in the economy as a whole.

I have already mentioned the drastic reduction in the labour force. This was accompanied by a tremendous increase in yields: a 50 per cent increase per acre for example in our cereals; 40 per cent per acre in potatoes; 50 per cent in the yield per bird of eggs; and 25 per cent more milk per cow. Few other industries in this country can match that record of productivity. But as we can see in this graph, based on a three-year moving average comparing net income with net output, the record was not uniformly progressive.

(DISPLAY GRAPH HERE)


1954/5 = 100
150
140
130
120
110
100
Net product
-at constant prices
Net farm income
3 year moving average
1954/55
6
7
8
9
60
1
2
3
4
5
6
7
8
9
70
1
2

Between the late 1950's and the mid-60's, net output increased in volume by about one-third; equivalent to a saving on imports at 1971-72 prices of some £400 million. Then for the next four or five years, there was comparative stagnation, reflecting the effects of disease and bad weather, and, most of all, the Scrooge-like policy of under-recoupment by successive governments, a period we still remember as the 'squeeze'. Since 1968-69, however, and following the more expansionist policies of the last two or three years, we have achieved an increase approaching 20 per cent, equivalent to a further saving of £300 million on imports at current prices.

This improvement has been achieved not only by the many aids science has given us, but through increased capital investment. No longer can British agriculture be described as a labour intensive industry. In fact we now employ £5,000 of tenant's capital - exclusive of land and buildings -for every man and woman in the labour force; far more than the capital employed per worker in our leading motor manufacturing companies and many others. While it is difficult to make comparisons with other sections of industry, some measure of the difference may be obtained from the fact that while net farm income in real terms has risen by only about six per cent since the early 1950's, gross trading profits of companies have risen by 46 per cent.

Today, of course, we must look at our agriculture in the far wider context of the European Economic Community. We are now approaching the end of the first year, in the transition period of five years, that was negotiated with the aim of easing the way into the Community regime for our farmers and consumers and our foreign and Commonwealth suppliers. This easement began, in fact, after the 1970 election when the present administration introduced interim levies for certain key products, with the aim of making the industry more dependent on market returns. We should remember, however, that even when Exchequer support of the standard prices was at its greatest, the bulk of our returns came from the market. The system we are gradually leaving behind was based upon the twin concepts of stable prices for the farmer and encouragement to greater efficiency. It was never, may I emphasise, a cost-plus arrangement. The efficiency increased enormously, as I have already indicated. The rub for farmers, however, came when, as so often happened in the 'squeeze' of the sixties, successive governments retained most, and sometimes more, of the benefits resulting from the greater efficiency. Our prices invariably failed to catch up with our costs.

In the Community system, the nearest thing to a guaranteed price is the intervention price which applies to such commodities as wheat, barley, butter, skim milk powder, beef and sugar. However, the prices apply at the intervention centres, and not at the farm gate, and for some commodities the intervention arrangements are intended to provide no more than a safeguard against a complete market collapse, while for others, there is no form of internal support at all.

Farming in the U.K., therefore, will become more of a gamble in which the farmer will have to assess his likely returns from a market in which he will eventually compete with the farmers of eight other countries. With them, he will have the protection of variable levies and, where they exist, of intervention prices, export subsidies, and so on, but even so the gamble will remain. But we must be careful not to exaggerate the differences with the past. Even under our deficiency payments system, the individual farmer was certainly not guaranteed a fixed return If he marketed badly, his market price plus deficiency payment failed to reach the level guaranteed at the annual review of farm prices. Conversely, there were times when some individual farmers made more than the standard prices.

Where the country is concerned, while there will be a saving to the Treasury on deficiency payments and to some extent on production grants, the U.K. will have to bear her share of the Community budget, of which the largest proportion for some time to come will be devoted to agriculture. It is interesting to note, however, that in the Community's budget plans for 1974, the proportion allocated to agriculture has fallen from 90 per cent in 1971 to 66 per cent. Moreover, the latest estimates, which take into account the change in the world grain situation, suggest that there will be a decline, in absolute terms, in expenditure on agriculture in the coming year.

The fantastic increase in world prices of basic commodities that we have seen in recent months concentrates attention in this country on two factors: consumer prices of food; and the farmer's costs of production.

The end of the traditional cheep food policy was signalled with the introduction of interim levies by the present administration in 1970. It seemed as though the country gradually became aware of the true meaning of the deficiency payment system, and of its contribution to the prolongation of the cheap food policy, into an era in which this country no longer had the economic power to purchase cheap food, wherever and whenever it wished. The debate which preceded the Parliamentary vote in July of last year, which resulted in our membership of the Community, revealed the real depth of the anxiety over the ending of a system in which the taxpayer had eased the consumer's food bill for so long. The debate continues to this day, and it is a matter for some concern that the common agricultural policy - rather than world prices - is still so widely blamed for the sharp rise in the retail costs of food. In fact, as the Prime Minister made clear in the House of Commons last July, only one percent of the 15 per cent increase in retail food costs over the preceding twelve months was due to the C.A.P. Indeed, during the recent period of explosive prices, the C.A.P. - hitherto so often criticised for upsetting world markets with subsidised exports - became, in the original six member countries, a stabilising factor of more benefit to consumer than to farmers. World prices of basic commodities like grain and protein and red meat rose far above Community and U.K. levels.

For British farmers, however, the world market situation means that while our major costs are as high as - and in some cases higher than - those in the Community, our prices, which do not reach their levels until the end of 1977, are four or five years behind. In the face of unexpected world developments, the transitional arrangements are failing to provide the intended smooth adjustment to Community conditions.

In a situation in which feed costs have almost doubled in twelve months, our producers of milk - few of whom are also cereal growers on any scale - are in a serious situation. The risk of recession in this sector is especially grave. The Ministry of Agriculture and the National Farmers' Union are agreed that, mainly because of the steep rise in feed costs, our total cost increases could reach an annual rate of £400 million. This is not the time or place to enter into our domestic politics, but this situation - unless corrected very quickly - is of very real relevance to our immediate future in the Common Market; to the Government's expansion policy; and to our balance of payments.

As I see it, the lessons of the past twelve months are very clear. We had become too dependent on North American reserves of grain. In a world in which the standards of living of vast populations like those of China and Russia are rising; in which the claims of the Third World become more incessant and which we ignore at our peril, we need an international approach to the problem of marketing basic agricultural commodities. The National Farmers' Union, with the support of our fellow farm organisations in Brussels, has now put forward a plan based upon minimum reference prices accompanied by a commitment to stockpile when world prices reach or approach those minimum levels Only governments, however, can take the necessary action. An orderly development of international trade in agricultural commodities is an essential corollary to the effective maintenance of the system of Community preference.

Within the Community itself, it is imperative that any changes which may be made in the C.A.P. take full account of the present and likely future world supply of and demand for food and feedingstuffs. In my view, the Commission have faile to do this in the proposals which they are putting forward for the improvement of the C.A.P. The proposals seem to be based largely on an analysis of a situatio which no longer exists. There is a preoccupation with the need to avoid surpluse when, for most commodities, the major concern should be with maintaining a securit of supply.

I do not wish to decry all the Commission's proposals. Indeed, some element in their packages, perhaps particularly the recognition given to the need for an annual review through which prices will be determined in the light of objective criteria, are directly in line with my own thinking. To my mind, a Community annual review, broadly of the kind which we have known in the United Kingdom since the war, is essential if the agricultural industries of the nine countries are to develop in a sound and balanced manner.

I am, of course, particularly concerned with the development of agriculture in this country Against the background of a chronic balance of payments problem which the Middle East situation can only intensify - the rise in world commodity prices points more than ever to the need for us to develop the potential of our ow soil. We have to make up our minds what our priorities are in the use of our national resources Good housekeeping demands surely that we grow as much as we possibly can, and insulate our people as far as possible from the effects of wild fluctuations in world markets. We are now producing slightly more than half the food we need, or two-thirds of what can be produced in our climate.

British agriculture today is a dynamic industry. Over the whole field of production, I believe we have no rival in Europe, and I am more than confident of our ability to compete on level terms with our European colleagues. While our milk producers at this moment bear a heavy burden of unprecedented costs, I believe that in the longer term the future for our livestock producers is sound, although we must remember that in this country milk and beef are two halves of one whole. In the last year or two, there has been no more healthy trend than the revival of sheep farming, which has brought new confidence into the hills, and the opportunity of more grass breaks in many arable areas. Nor must we overlook the potential of our sheep industry in the export field - in breeding stock as well as finished lamb. Grass, livestock and stockmanship are the trump cards of our farming.

Even in the fruit sector - hitherto regarded as being most at risk, from surplus production in France and Italy - there are signs of a new confidence which is based on the quality and flavour of English fruit, and new developments in storage and marketing. Just as we successfully naturalised the Friesian breed of cattle, so we have successfully naturalised the Golden Delicious apple and used our much-maligned climate to give it new character and quality. Never would I suggest, however, that the Golden Delicious could replace the Cox's Orange Pippin, as the Friesian has replaced so many of our traditional dairy breeds!

Nevertheless, in spite of the hopeful signs of achievement and future potential, I must give a warning The much needed expansion of British agriculture will not be achieved automatically. Farmers and growers will be able and willing to invest in expansion only if they have confidence in the agricultural policy which provides the framework within which they must operate. Unfortunately, the framework is still far from secure.

British farmers accepted the entry of the U.K. into the Community on the basis of the existing C.A.P. While recognising that there would be difficulties, the general view was that on these terms, entry provided both a challenge and new opportunities. Now, it seems that the Commission wish to change the rules and that some of the changes could be particularly damaging to British producers. Inevitably, this will create a climate of uncertainty inimical to expansion.

Farmers and growers will make sure that the case for an agricultural policy which permits and encourages expansion does not go by default. They will also need to ensure that they get the best possible returns from the market. If there is one area of activity in which we lag behind many of our Continental counterparts, it is in our marketing. This is one of our major concerns today, especially where the integration of production with marketing is concerned on a commodity basis. The emphasis must now be on voluntary co-operation in these fields, and on collaboration with our first-hand buyers in the food industries, which are becoming increasingly sophisticated and rationalised.

In considering, however, the future of agriculture in this country, its contribution to our economy, and all the aids that science and technology can give us in meeting increasing pressures - not least a growing scarcity of labour - I believe there is one fundamental need; and that is for a change in social attitudes to the industry. It is a fact that while consumer spending right across the board has increased in step with increasing disposable income, expenditure on food declines as a proportion of the whole. I believe that a change in social attitudes, towards spending more of this disposable income on food, must come, and that this can be achieved by improvements in marketing.

This brings me to a brief consideration of the contribution that science, and especially the agro-chemical industries have made, and can make, to the immense task confronting us.

Of the immensity of that task, there can be no question, and in this country alone, we are likely to lose two million acres of good farmland to development by the end of the century if present trends continue, and there is not the slightest sign that they will not. With a population on present forecast of 66million, this means that each person's share of our improved farmland will shrink from two-thirds to one half of an acre.

On an international basis, the picture is no less dramatic. We have been told that it took the two hundred years to 1850 to double the world's population to 1000 million and only one hundred years to double it again to 2000 million, and, according to United Nations' estimates, it will more than treble again to 7000 million in the second half of this century.

Let there be no doubt we must find the solution to this problem of feeding the world's population, if civilisation, as we know it, is to continue. All that this nation of ours, and our fellow nations of Europe and the Americas, have strived to achieve in improved social and material conditions must finally depend upon the success of agriculture.

We have moved a long way since the first 'improvers' looked with fresh vision at the problems of farmers. Farming then was only dependent upon a few skills outside the farm gate; those of the blacksmith, the wheelwright, the saddler, and these craftsmen were local and familiar. We have now evolved into a highly complex industry dependent upon a whole host of ancillaries supplying some £1,400 million worth of requisites to our industry.

We rely on firms which are not only organised on a national basis but also internationally, with advanced manufacturing technology and complex skills - but all are dependent upon the prosperity of our basic industry.

under, and over-applications are remarkably wide, in many cases we are clearly not deriving the experimentally determined level of benefits. Weather, equipment, availability of information and other commercial pressures combine to weight the odds against realising their potential. We need the specialist skills and services, such as your industries can provide.

Of recent years, great progress has been made with pesticides, but we are probably only at the threshold of their potential use Your industry, for example, is beginning to reveal the possibilities in systemic insecticides and fungicides; chemical sex attractants, juvenile hormones, insect sterilants, and chemicals to break seed dormancy and stimulate or retard growth. We are entering an era when we hope we can look forward to more sophisticated techniques in the use of chemicals, so even smaller quantities of products are used at those critical stages when they can be most effective in preventing the build-up of pests while, at the same time, having a minimum effect on the environment as a whole.

In these times of inflation, the costs of development are reaching astronomical proportions, and it gives cause for concern to the farming industry that manufacturers may not find it worthwhile to develop the potential advantages of some new materials unless there is a large international market for them. Just as farmers are learning by experience that many of their development and marketing problems can be solved by co-operation, so I would suggest to you that, as we become more closely integrated with the E.E.C., there must be greater international co-operation in manufacturing expertise and in the development and formulation of chemicals for agricultural use, and particularly in the spheres of safety regulations and approval schemes.

The development of science and its applications to agriculture in research and commerce has provided channels through which talented men, who might otherwise have had little interest in farming, can devote their energies to its improvement to such good effect that capital can now be invested in the industry with a degree of confidence that was never there in the days when social and amenity values were the only assured return on investment.

Today, we are moving into an era of spun protein and other substitutes for meat based on soya and field beans, as well as industrially produced, single-cell protein based on methane or oil. But these new products are as yet either potentially valuable sources of animal feed or are forms of processed vegetable protein produced on the farms.

Whatever their future, they increase our dependence on fossil fuels for production and processing. At this time, when we are having our first taste of the effects of oil shortages, we must begin to think more seriously of how we use the whole range of our natural resources. Already, we hear that certain petroleum-based pesticides are likely to be in short supply next year; I sincerely hope that this is only temporary and that your industry will do all it can to reduce the shortfall, but it throws into prominence the continuing need for the development of agricultural techniques that can make the most efficient use of our resources.

Farmer and scientist are now joined in partnership as long as they both shall live. But there are vital conditions underlying what we do together; underlying all your research and the application of that research. Chemicals are tools for the farmer to use, and to use wisely: they are not substitutes for sound husbandry even when they enable us to use minimal cultivations. If we move on from here towards a greater control of those environmental conditions which militate against the full production potential, we need to be very much clearer about the effects of such control - for example, how much benefit do we get from unrecognised

My fellow farmers and I gratefully acknowledge the contribution made by all these industries, the engineers, the manufacturers of fertilisers, feedingstuffs, pharmaceuticals, crop protection chemicals, and many others. It is only as one large partnership that we can contemplate the present and the future. We have increasingly to learn how to apply new techniques, but it is essential that they are presented to us in such a way that they can be taken up safely and profitably.

We should look back over the way we have come, to try and discuss the way ahead. A farmer who looks back over the history of modern agriculture, would see three great advances with which scientific research and technology have provided him. The first, of course, was the introduction of fertilisers, with which the work of Gilbert and Lawes at Rothamsted will always be associated. The second was the Ferguson three-point linkage system. The third was the development of herbicides, including both the systemic insecticides and fungicides and the selective herbicides.

No one could question the immense contribution from Gilbert and Lawes, and I have already indicated the role that fertilisers have yet to play on the grassland of this country. We need to be able to manage it as intensively as our arable land without increasing problems of utilisation, animal health and pollution.

As farmers, we look to scientists and the science-based industries to give us a lead to the next stage. We are at a half-way stage; we now have many <u>aids</u> to husbandry but that husbandry remains an art the farmer practices.

Looking back over the last thirty years, we recognise the great changes that have swept through our industry - probably greater than in the previous three hundred years. It is impossible by crystal-gazing to see what technology can produce for us in the decades to come, but the challenge is all the greater since we still have so many unresolved problems.

A few years ago, in opening your conference as President of the British Crop Protection Council, Bawden himself wondered whether methods of soil fumigation would ever be cheap enough to use in agriculture, as they are used in horticulture. Experiments in which land under continuous cereals was partially sterilised, he pointed out, had yielded twice as heavily as untreated land, irrespective of the fertiliser used. We need to know far more about soil-borne disease, and indeed of the ecology of the soil as a whole.

Of late, we seem to have reached a plateau where our yields of grain are concerned, and as Dr. Pereira pointed out recently, that on the whole we are far from growing our cereals to optimum yield But disease, I believe, remains the major problem in the breeding and growing of cereals; pathogens play Jekyll and Hyde with the breeder as one new resistant variety breaks down after another. Last year, for instance, we had a further outbreak of yellow rust, comparable to that of 1966,

Weeds still remain a costly competitor with our crops and the wild oat alone costs us some £20 million a year, yet I cannot cease to wonder at the miraculous ability of herbicides selectively to kill the wild oat in a cereals crop. In association with good husbandry, and the laborious business of roguing, they have enabled me to eliminate on my own farm wild oats which came in with an unfortunate batch of seed corn. But you will note, I said <u>in association with good husbandry</u>. Many of my fellow farmers, however, had serious infestations before suitable chemicals were available, and now even with comprehensive programmes, including herbicides, do not find complete control an easy short term proposition.

In dealing with the current ranges of specialised chemicals, we are concerned with relatively small quantities of active ingredients and, while tolerances to natural control of pests and diseases in our cereal crops? If the microflora in our soils were destroyed, would our crops not be more vulnerable to new invading organisms not previously of significance as pests?

We must always remember our responsibility to the environment that we share with all living things. For this reason alone, I have a feeling that we must press on with research into biological control measures which so far have had little application in this country except to the glasshouse growers. Above all, we must concentrate, I am sure, on integrated methods of control, and never forget that chemicals are powerful tools with a potential for harming other organisms, as Bawden reminded this conference several years ago.

We farmers are no more than life-tenants of the land we farm and hold in trust for succeeding generations, as noted in the old advice that one should 'live as if one were going to die tomorrow, but farm as if we were going to live forever'. We have all learned the lesson about damage that can be caused by the excessive or ill-considered use, or misuse of pesticides, and accept the timely warnings given by Rachel Carson which, when published in 'Silent Spring', engendered so much bitter controversy. Today, it is being increasingly recognised that modern farming and wildlife can live together, and it is reassuring to find these interests in friendly discourse on the British Agrochemicals Association Wildlife Education and Communications Committee.

We must all work together, not only in Britain, but in the European Community as a whole, to ensure that by wise conservation we pass on to posterity the irreplaceable heritage of our countryside, together with the technology so that, working as one great partnership, food resources for the future may be assured and the quality of life improved for mankind as a whole.

CEREAL FOLIAR DISEASE SURVEYS

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on behalf of the Conference of Advisory Plant Pathologists, Agricultural Development and Advisory Service.

Summary The percentage leaf area affected by diseases recorded on commercial crops of spring barley and winter wheat in England and Wales showed that mildew was the major disease of barley in five years out of six, and Septoria was the major disease of wheat. The regional mean levels of diseases and tentative estimates of national grain losses are given.

Résumé: Le taux pour cent de la superficie foliaire atteinte par les maladies constatées pour les récoltes de commerce d'orge de printemps et de blé d'hiver en Angleterre et au Pays de Galles a révélé que le mildiou se trouvait être la principale maladie de l'orge, cinq années sur six, et que Septoria était la principale maladie du blé. On donne les niveaux régionaux moyens des maladies et on suggère des évaluations des pertes nationales de grains.

INTRODUCTION

The principal cereals grown in the U.K., spring barley and winter wheat, are susceptible to several foliar diseases which, in some seasons, can be sufficiently severe on some crops to cause substantial reduction in functional leaf area. The effect of this reduction has been the object of much research and trials work in which the yields from diseased plots have been contrasted with those from plots on which diseases have been partially controlled by the use of fungicidal sprays. Last (1955) found that grain yield of barley was reduced by 22 per cent by infection with mildew (*Erysiphe graminis*) and Large and Doling (1962) stated that in the years 1957, '58 and '60 mildew in trials caused a loss of 2 cwt per acre. In wheat during the years 1959, '60 and '62 the mean loss attributed to mildew in trials was about 1 cwt per acre (Large and Doling, 1963). Leaf blotch of barley (*Rhynchosporium secalis*) caused a mean loss of 7 per cent in trials in south-west England in 1965 (Jenkins and Jemmett, 1967) and in the following three years control of leaf blotch and other diseases, including brown rust (*Puccinia hordei*), by broad-spectrum fungicides, resulted in mean yield increases of about 40 per cent on mildew-resistant barley (Jenkins *et al*., 1972). Similar fungicides when applied to wheat have resulted in yield increases of about 35 per cent associated with control of Septoria disease (*Septoria tritici* and *S. nodorum*) (Jenkins and Wyndham Morgan, 1969). Other trials, where fungicides were not used but where susceptible wheat varieties have been contrasted with varieties resistant to yellow rust (*Puccinia striiformis*), have shown that this disease can cause losses up to 30 per cent (Doling and Doodson, 1968).

Many more examples of the damage caused by foliar diseases and the benefits to be derived from their control exist and it has been postulated that an increasing incidence of foliar pathogens, following the expansion and intensification of cereal growing which took place during the 10 years preceding 1967, was contributing to the difficulty which farmers, particularly those in the south-west of England, were experiencing in maintaining yields (Jenkins et al., 1972).

However, little was known of the relative importance of cereal foliar diseases in commercial crops and, for this reason, spring barley foliar disease surveys and winter wheat foliar disease surveys in England and Wales were initiated in 1967 and 1970 respectively by the Conference of Advisory Plant Pathologists of the N.A.A.S.. The surveys have been repeated each year with the exception of the barley survey in 1971.

A detailed report of the first four barley surveys has been published (King, 1972) and the first four wheat surveys will be published in detail elsewhere. This paper presents the annual national disease levels and the effect of geographical region on the levels recorded, and gives an indication of possible losses caused by the major diseases.

METHODS

A list of approximately 300 farms was selected at random from the returns of the M.A.F.F. census of 1965 and 1969 for barley and wheat respectively. Each list was stratified according to the regional acreages of wheat or barley so that unweighted means of farm data provide estimates of national disease levels.

Details of field selection and data processing for both wheat and barley were similar to those described for barley by James (1969). One field on each farm was selected at random and a sample of 50 tillers was taken along one diagonal of the field at growth stage 11.1 (Large,1954) when the grain was milky ripe. Barley fields were sampled by Agricultural Advisory Officers and wheat fields by Advisory Plant Pathologists. The top (flag) and second leaves of barley and whole tillers of wheat were sent to the Plant Pathology Laboratory where diseases were identified and their severities assessed in terms of percentage leaf area affected, using keys in the 'Guide for the assessment of cereal diseases' (Plant Pathology Laboratory, Harpenden, unpublished). In each survey since 1971, between thirty and fifty of the fields sampled at growth stage 11.1 were also sampled at growth stage 10.5, to provide information on the progress of diseases, principally mildew, for use in the estimation of losses.

RESULTS

Barley

The mean disease levels for England and Wales are given in Table 1. Mildew was the most severe disease in all years except 1970, occurring at the highest levels in 1967, '68 and '73. In 1970 an unusually early and severe epidemic of brown rust resulted in this disease becoming more severe than mildew. In other years except 1969, brown rust was the second most severe disease, being slightly more destructive than leaf blotch although the latter was relatively more important in 1969 and 1972. Yellow rust occurred at trace levels in most years and was most severe in 1973 when it was the third most severe disease on the flag leaf. In 1972, Septoria was recorded for the first time in the surveys. The level of infection on the second leaf was equal to those of brown rust and leaf blotch in that year but in 1973, the disease was slightly less severe. In both 1972 and '73 the Septoria symptoms included pycnidia and spores of *S. nodorum* and other species. Other diseases observed were halo spot (*Selenophoma donacis*) and net blotch (*Drechslera teres*) but their occurrence was only infrequent and their levels of infection slight.

Table 1

Percentage area of barley leaves affected by disease. Averages for England and Wales.

Disease	Leaf	1967	1968	1969	1970	1972	1973
Mildew	Flag	5	3	2	3	3	4
	2nd	17	19	8	11	10	15
Brown rust	Flag	4	1	1	12	2	3
	2nd	5	3	1	20	3	4
Leaf blotch	Flag	1	1	2	t	2	1
	2nd	2	2	3	t	3	2
Yellow rust	Flag	1	t	t	t	t	2
	2nd	1	t	t	0	t	1
Halo spot	Flag	t	t	t	0	t	t
	2nd	t	t	t	0	t	t
Net blotch	Flag	0	t	t	0	t	t
	2nd	0	t	t	0	t	t
Septoria	Flag	0	0	0	0	1	1
	2nd	0	0	0	0	3	1

t = <0.5

The regional mean levels of infection on the second leaf for the four major diseases in each of the eight M.A.F.F. administrative regions are given in Table 2.

The distribution of mildew levels between regions appears to be unpredictable, Levels were most severe in the East and in Southern regions in 1967, the East and the Midlands in 1968, the South West in 1969, the West Midlands and Yorks/Lancs in 1970, the Northern regions, West Midlands and Wales in 1972 and the Southern regions in 1973.

Other diseases have proved somewhat more predictable but even so, anomalies have occurred. For example, brown rust tended to be most severe in the East and the Southern regions but, in 1973, levels in the East Midlands and Yorks/Lancs were relatively high. Also, leaf blotch tended to occur at higher levels in Western areas but, in 1973, the disease was relatively severe in the Northern region. Yellow rust has occurred at levels too low to allow comparisons between regions but results suggest that highest levels may be expected from the North, Yorks/Lancs, the West Midlands and Wales. Halo spot and net blotch have not been severe in any region but tend to occur more frequently in the wetter South Western and Welsh regions.

Table 2

Regional barley disease levels. Average percentage area of leaf 2 diseased

Disease	Region	1967	1968	1969	1970	1972	1973
Mildew	North	7	17	7	12	14	13
	Yorks/Lancs	9	15	6	17	12	14
	E. Mids	12	20	9	9	9	14
	W. Mids	16	22	6	18	11	13
	East	20	24	10	11	7	13
	S. East	27	15	8	6	9	19
	S. West	18	18	10	9	9	21
	Wales	13	10	5	10	12	10
Brown rust	North	1	3	t	1	t	3
	Yorks/Lancs	2	2	1	9	2	6
	E. Mids	6	1	1	13	1	7
	W. Mids	1	1	1	13	1	1
	East	3	4	1	24	7	4
	S. East	10	3	3	30	4	5
	S. West	11	3	2	33	1	5
	Wales	4	1	t	6	1	t
Leaf blotch	North	1	1	1	0	1	3
	Yorks/Lancs	1	1	1	0	1	1
	E. Mids	2	1	1	0	1	1
	W. Mids	2	1	4	0	3	2
	East	3	t	t	t	1	1
	S. East	2	3	5	0	7	1
	S. West	1	4	9	t	7	4
	Wales	8	3	8	0	3	6
Yellow rust	North	t	1	t	0	t	5
	Yorks/Lancs	t	1	t	0	0	3
	E. Mids	t	t	t	0	t	1
	W. Mids	4	0	0	0	t	t
	East	t	0	0	0	0	1
	S. East	t	t	t	0	t	t
	S. West	t	0	0	0	0	t
	Wales	2	0	t	0	t	t

t = <0.5

In 1970, systemic fungicides for use against mildew became available commercially and have since been employed on an increasing scale (Table 3). Seed dressings against mildew were entirely ethirimol. Foliar sprays in 1970 consisted entirely of tridemorph but in the last two surveys ethirimol also was recorded and, in 1973, the sprayed crops included a single field sprayed with chloraniformethan* and one treated with chlorquinox**.

Mean mildew levels were lower on crops treated with fungicide than on those which were untreated and the results suggest that the seed dressing was more

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*Proposed BSI common name for N-[2,2,2-trichloro-1-(3,4-dichloroanilino)ethyl] formamide.

** Proposed BSI common name for 5,6,7,8-tetrachloroquinoxaline.

effective than a foliar spray in controlling mildew. However, the sprays were applied at various times ranging from the first week in May to the third week in June, and since it is known that in any year there is an optimum time to spray (Jenkins, 1973), it is probable that many of the sprays were applied at times when the resulting control of mildew would be sub-optimal, and the mean levels (Table 3) are probably an inaccurate measure of the true potential of the fungicides used. **Valid** comparisons of the effects of different spray materials are impossible due to the small size of the sample provided by the surveys.

Table 3

Incidence of crops treated with fungicide (per cent). Mildew level on leaf 2 in parenthesis

Fungicide	1970	1972	1973
Seed dressing	0 (-)	10 (6)	14 (5)
Foliar spray	3 (6)	7 (9)	11 (9)
Untreated	97 (11)	83 (10)	75 (18)

Wheat

Table 4 lists the mean disease levels for England and Wales on the flag and second leaves for each of the four years.

Table 4

Percentage area of wheat leaves affected by disease. Averages for England and Wales.

Disease	Leaf	1970	1971	1972	1973
S. nodorum	Flag	1	2	5	2
	2nd	5	18	26	17
S. tritici	Flag	t	t	2	t
	2nd	t	1	7	1
Mildew	Flag	1	1	t	1
	2nd	7	4	2	3
Yellow rust	Flag	t	1	3	t
	2nd	t	2	4	t
Brown rust	Flag	t	t	t	t
	2nd	t	1	t	t

t = <0.5

Septoria was the most severe disease in all years except 1970 when it was slightly less severe than mildew. Two species of the pathogen, S. nodorum and S. tritici, occurred frequently but occasional leaves infected with S. avenae f. sp. triticea also were recorded. Mildew was most severe in 1970 but in no year was it as serious as it usually is on the barley crop. Yellow rust occurred in more than trace amounts in 1971 and '72 when the epidemic was associated with variants of the pathogen capable of attacking the four most popular cultivars in commerce. Brown rust has affected less than one per cent of the leaf area in each survey.

The mean levels of diseases recorded in the eight regions indicate that the

Septoria diseases tended to occur more severely in the southern regions and Wales (Table 5).

Table 5

Regional wheat disease levels. Average percentage area of leaf 2 diseased

Disease	Region	1970	1971	1972	1973
S. nodorum	North	t	5	33	26
	Yorks/Lancs	1	10	25	15
	E. Mids	t	8	30	15
	W. Mids	12	17	34	17
	East	1	15	18	15
	S. East	6	44	22	15
	S. West	23	31	28	24
	Wales	8	22	35	14
S. tritici	North	0	t	3	t
	Yorks/Lancs	0	0	2	t
	E. Mids	0	t	1	t
	W. Mids	t	t	2	t
	East	t	t	2	t
	S. East	t	4	13	1
	S. West	1	3	26	9
	Wales	1	t	10	1
Mildew	North	4	3	t	2
	Yorks/Lancs	4	6	2	2
	E. Mids	6	4	2	4
	W. Mids	12	3	2	1
	East	5	3	2	5
	S. East	7	5	2	2
	S. West	13	3	t	3
	Wales	15	5	1	1
Yellow rust	North	0	1	4	t
	Yorks/Lancs	0	t	1	1
	E. Mids	0	3	5	t
	W. Mids	0	t	4	t
	East	0	2	4	1
	S. East	0	4	6	t
	S. West	t	3	8	t
	Wales	t	t	2	t

t = <0.5

This was most marked for S. tritici in all four years and particularly in 1972 when the ratio of S. tritici to S. nodorum was unusually high in these areas. In 1973, a relatively high level of Septoria was recorded in the North but it was noted that all the samples from this region were received after July 24, at least one incubation period after the start of the heavy rains which undoubtedly would have enhanced the spread of the disease earlier in that month. The level of Septoria in the West Midlands was markedly higher than average only in 1970 but there has been a consistent effect of county, Shropshire and Herefordshire having given higher figures than elsewhere in the region.

The distribution of mildew levels, as in the case of barley, has been different in each survey. Highest figures were recorded in Wales, the West Midlands and the South West in 1970; Yorks/Lancs, the South East and Wales in 1971, and the East and East Midlands in 1973. In 1972 levels were generally low, particularly in the North and the South West.

Yellow rust in 1971 and '72 was most severe in the southern regions and the East Midlands and least severe in the Yorks/Lancs region.

ESTIMATED LOSSES IN GRAIN YIELD

Although primarily intended to assess the relative importance of diseases in terms of severity on the foliage, the results of these surveys provide a means of ranking the diseases in order of economic importance. However, the effects of foliar diseases on yield of grain are a matter of controversy and for circumspection since, although many experiments have shown that most diseases can reduce yields, evidence to indicate a mathematical relationship between disease levels and yield loss exists for only one or two diseases.

Relationships between severity and per cent loss in yield have been determined for mildew of spring barley (Large and Doling, 1962) and winter wheat (Large and Doling, 1963), and for yellow rust of wheat (Doling and Doodson, 1968), in field trials extending over several seasons. Unfortunately, application of these relationships to the results of the A.D.A.S. surveys is difficult in the case of mildew and impossible in the case of yellow rust because the method and timing of assessments in the trials were different from those employed in the surveys. A relationship between barley leaf blotch severity and yield loss (James et al., 1968) is more easily applicable because similar methods were used both in the trials and the surveys. Other diseases, in spite of the severe defoliation which they can cause on some crops, have not occurred at high levels nationally with sufficient regularity to attract much attention from workers interested in crop loss appraisal. Consequently no co-ordinated field trials covering a sufficiently wide area and number of seasons, have been conducted. Brown rust of barley and Septoria of wheat particularly are diseases which occur severely on some crops each year and which can be extremely severe on a national scale but for which no direct mathematical models relating severity to yield loss exist. Consequently, when faced with the problem of estimating national yield losses caused by such diseases, one is forced to look to the results of individual experiments which, although providing significant relationships between severity and loss for a parti- cular site in a particular year, may or may not prove representative of the average crop in any season. Furthermore, the establishment of these relationships usually has involved either, contrasts between a range of differentially susceptible varieties or, the use of broad-spectrum fungicides to achieve variable levels of severity or a combination of both techniques and there is a possibility that yields of sprayed plots were increased as a result of physiological effects of the fungi- cides and control of minor parasites and saprophytes. James et al. (1968) believed that such effects in the trials on barley leaf blotch were unimportant but it is possible that in more recent trials on other diseases, involving the use of modern systemic materials, control of other recorded or unrecorded diseases which are difficult to exclude completely from most sites, may have occurred. For example, it is known that benomyl, a compound used in current A.D.A.S trials on wheat, is effective against eyespot (Cercosporella herpotrichoides) (Fehrmann and Schrödter, 1972) and partially controls infection of wheat nodes by S. nodorum and Fusarium spp. (Anon, 1973), aspects of disease which are not usually assessed in foliar disease trials. Alternatively, fungicides may be phytotoxic causing a yield- reduction, thus off-setting part of the increase obtained by disease control, resulting in an underestimate of the effect of the disease on yield (Wolfe. 1969).

Another factor which is usually ignored, is the possibility of interaction between two or more unrelated pathogens as described by Van der Wal et al. (1970), who showed that the yield loss caused by a combined infection of wheat by *Puccinia recondita* and *S. nodorum* was greater than the sum of the losses caused by each pathogen alone. A further complication is that, in most trials from which data are available, a particular host variety or combination of varieties has been used which is not representative of the range of varieties encountered in the surveys, so that any estimate of loss must be made on the assumption that all varieties respond to a given level of disease by exhibiting a similar loss in yield.

In spite of these difficulties, it is pertinent to those involved in control of diseases to estimate the effects of diseases on the national grain yield, with the reservation that the estimates must be subject to revision.

Mildew of barley and wheat.

Large and Doling in 1962 and 1963 published relationships between mildew severity and yield loss for barley and wheat respectively. For barley, per cent loss = $2.5 \times \sqrt{\text{mildew}}$ and for wheat, per cent loss = $2.0 \times \sqrt{\text{mildew}}$; the mildew figure being the per cent disease scored on the top four leaves in whole plot assessments at the 10.5 growth stage. In order to estimate losses caused by the levels of mildew recorded in the surveys at growth stage 11.1, an extrapolation to a theoretical level at growth stage 10.5 is necessary. Since 1971, this has been done by examining data recorded in the preliminary survey samples taken at growth stage 10.5. In earlier surveys, information on mildew progress was derived from field observations and from assessments made on untreated plots in field trials. The linear regression of mildew assessments for leaf 3 at 10.5 on the assessments for leaf 2 at 11.1 was calculated and the resulting formula used to estimate a national mean level of mildew occurring at the earlier growth stage. It is assumed that the level of mildew on leaf 3 is approximately equal to the whole plot assessment as indicated in the assessment key used by Large and Doling (1962). Estimated mildew levels at growth stage 10.5 and associated losses are given in Table 6.

Table 6

Estimated mildew levels at growth stage 10.5 and estimated annual losses caused by mildew.

Crop	Year	Mildew at G.S. 10.5	Per cent loss in yield	Loss in tons x 10^3
Barley	1967	28.0 ± 4.6	13	1165
	1968	29.8 ± 4.1	14	1123
	1969	5.3 ± 0.9	6	466
	1970	12.8 ± 0.9	9	603
	1972	11.6 ± 1.6	8	661
	1973	26.4 ± 4.4	13	924*
Wheat	1970	1.3 ± 0.3	2	82
	1971	3.8 ± 0.3	4	192
	1972	1.5 ± 0.7	3	142
	1973	4.9 ± 1.1	5	258

*assuming a 75% recovery of loss on the 25% of crops treated with fungicide.

Leaf blotch of barley.

James *et al.* (1968) showed that the percentage loss in yield caused by barley leaf blotch was equal approximately to one half the percentage area affected on the second leaf; two thirds that on the flag leaf. Taking the average of these two figures, national losses caused by leaf blotch were estimated to have been about 0.6 per cent (45000 tons) in 1967, '68 and '73, 1 per cent (76000 tons) in 1969 and '72, and almost zero in 1970.

Septoria of wheat

Although there is no direct information on the relationship between Septoria and yield loss, the disease is too important to be ignored and a method of calculating annual losses has, of necessity, been devised. Data collected in four unco-ordinated field trials between 1967 and 1970 has led to the development of a provisional working formula whereby the per cent loss caused by Septoria (*S. nodorum* plus *S. tritici*) is equal to 1.3+ (0.9 x the per cent area infected on the flag leaf at growth stage 11.1), a relationship which is closely similar to that derived independently from a variety trial in 1972 at the Cambridge Plant Breeding Institute (Scott, personal communication). Using this formula, losses caused by Septoria are estimated to have been about 2 per cent (81000 tons) in 1970, 3 per cent (147000 tons) in 1971 and 1973, and 8 per cent (400000 tons) in 1972.

Yellow rust of wheat

In a single field trial performed on Joss Cambier wheat in 1972, the per cent loss in yield was equal to $4.87 \times \sqrt{\text{yellow rust}}$; yellow rust being the per cent area infected on the flag leaf at growth stage 11.1 (Mundy, 1973). This leads to estimates of loss caused by the disease equal to approximately 4 per cent (192000 tons) in 1971, 8 per cent (400000 tons) in 1972 and 3 per cent (152000 tons) in 1973. In 1970, losses would have been negligible.

Other diseases

Published information relating disease severity, as assessed here, to yield loss in the U.K. is totally lacking for foliar diseases other than cereal mildew and barley leaf blotch but the very low levels recorded for diseases other than those mentioned above indicate that losses caused by them have probably been small, with the possible exception of brown rust of barley in 1970 when the high national mean level of the disease indicated that losses caused by it were greater than those caused by mildew. The severe levels of brown rust reported in 1971, when no survey was made, suggest that losses caused by the disease were substantial in that year also.

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AN EVALUATION OF THE CONTROL OF CEREAL LEAF DISEASES BY FUNGICIDES IN ENGLAND AND WALES

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Summary It is estimated that annual losses from barley mildew in the period 1967-73 varied from £12 million to a possible £37 million in 1973 and that threequarters of these losses could have been avoided by the use of fungicides. Over the same period it is estimated that fungicide use would have been worthwhile in 40% of the crops. Seed dressings are used as an insurance against mildew attack; for the maximum yield increases from sprays correct timing is important. Brown rust is severe only in some years; new fungicides are promising but criteria for timing sprays to get maximum benefit are lacking. Losses due to wheat leaf diseases over a four year period are estimated to have ranged from £5 million - £30 million. In experiments frequent applications of fungicides have given a good control of Septoria and mildew and large yield increases but an economic control of these diseases in the field has not yet been achieved. For yellow rust some fungicides can give an effective control but satisfactory criteria for timing sprays are not available.

The ADAS surveys described by King (1972, 1973) have shown that over the period 1967-73 barley mildew was the most severe and probably the most damaging of the cereal leaf diseases. By good fortune, or perhaps by design, it is also the disease for which the most effective fungicides are available to the farmer.

BARLEY MILDEW

An estimate of the cost to the farmer of the loss in yield due to barley mildew can be made by applying the estimated yield losses (King, 1973) to the annual value of the barley crop (using Ministry of Agriculture, Fisheries and Food data for production and farmers' total return). This shows (Table 1) that the loss varied from £12 million in 1969 to a possible £37 million with the much higher barley prices in 1973. In making these estimates an allowance was made for the control of mildew by fungicides in 1972 and 1973 so that the cost of the disease should also include the cost of fungicides in these two years. This would increase the estimated costs to £19 million and £39 million for 1972 and 1973 respectively.

Table 1

Estimated value of losses caused by barley mildew (£ million)

1967	29	1970	17
1968	28	1972	17
1969	12	(1973*	37)

* based on provisional data and a price of £40/ton.

The next most obvious question is how much of these losses could have been avoided if fungicides had been used? One can obtain some estimate of this from the results of experiments carried out over the past three years by ADAS plant pathologists which showed that a single well-timed spray resulted, on average, in about three-quarters the yield increase obtained from a programme of sprays which gave a nearly complete control of mildew. In the case of the ethirimol seed dressing there does not appear to be any data comparing the seed dressing alone with a programme giving complete control but there is evidence that the seed dressing and a well-timed spray would give similar yield increases. From this it would appear reasonable to assess the potential benefits of fungicides to be about three-quarters of the estimated losses.

These estimates, although based on carefully conducted surveys and experiments, cannot take into account the many complicating factors which occur in commercial crops such as the effects of a second disease on leaves kept free from mildew, the interaction of two or more diseases, or the efficiency of the fungicides, besides the effects on the economics of the crop of yields increased through disease control. However, the estimates do indicate the size of the barley mildew problem, which is large, and the kinds of benefits, which are also large, that can be obtained from the use of fungicides.

Although the potential benefits of fungicide usage are large, one cannot justify the use of fungicides on all crops because the severity of mildew varies with season, district and variety. To make some assessment of the proportion of crops in which fungicide treatment would have been worthwhile it has been assumed that crops in the ADAS surveys (King, 1973) with 10% mildew or more would have given an economic response to fungicides (ie at least 2-2½ cwt in the average crop of 30 cwt/ac). Applying this standard, which some would consider to be conservative, fungicide treatment would have been worthwhile in about 40% of the crops over the six years of the survey (Table 2). This includes annual variation from just over 50% in the years 1967, 1968 and 1973 to 35% in 1970 and 1972 and only 25% in 1969. There is also a good deal of variation from region to region within any one season though this variation is not large if the averages for the six year period are compared when most regions are near to the 40% national average (Table 3). This data does not indicate the severity of mildew in the regions but it does show that the disease is important in all parts of the country and not only in the southern half as has been sometimes suggested.

Table 2

% Fields of spring barley with >10% mildew; England and Wales

1967	1968	1969	1970	1971	1972	1973	Mean
54	57	25	34	(-)	34	51	42

Table 3

% Fields of spring barley with >10% mildew; regional distribution, averages for the period 1967-70 and 1972-3

	North	Yorks/Lancs	E Mids	W Mids	East	S East	S West	Wales
	40	43	37	49	43	41	46	36
range	(19-50)	(19-63)	(26-54)	(21-72)	(24-67)	(14-51)	(23-63)	(14-46)

Farmers first used fungicides for barley mildew control in 1970 and the acreage treated has increased steadily each year since then. Whilst it has not been possible to obtain accurate information on the amount of fungicide used, estimates from the surveys and the chemical companies suggest that about 30% of the barley acreage was treated in 1973 and about 20% in 1972. This compares with the 51% and 34% respectively estimated from the survey data as being likely to give economic response to fungicides, ie approximately two-thirds of the area which was worth treatment was treated, assuming that all treatments applied went onto crops which would have had more than 10% mildew.

The other means of mildew control is by the use of resistant cultivars. Cultivars with race-specific resistance have not survived more than a few years before becoming susceptible and breeders are now paying more attention to forms of "field resistance" which may be effective for a longer period of time. Fungicides would not be used on cultivars with effective race-specific resistance but it is worth enquiring into the possible effects of the use of fungicides on field resistant varieties.

Work at the National Institute of Agricultural Botany has shown that the yield response of varieties to fungicides is related to their susceptibility to mildew, so that the mildew resistance rating in the NIAB list of recommended varieties can be used as a guide to the relative increase in yield which can be expected through the use of fungicides (Little and Doodson, 1972) (the exception was Proctor which gave a lower response than its mildew rating indicated). In the NIAB trials the cultivars Vada and Julia, which have consistently shown some field resistance, gave an increase of about 7% in all trials and 11% in the trials in which only mildew occurred (compared with 9% and 20% for very susceptible cultivars). These findings have been confirmed in other experiments and by observations in the field and suggest that with the present level of field resistance fungicides are still necessary to give an effective control of mildew.

Some further evidence about the effects of cultivars on the severity of mildew can be obtained by relating mildew to the acreages of cultivars. In 1967 and 1968, when mildew was severe, 60-70% of the barley acreage in England and Wales was composed of very susceptible varieties such as Proctor and Zephyr with an NIAB rating of 3 or less. In 1973 only 25% of the acreage was occupied by these or similarly susceptible cultivars but even so, mildew was nearly as severe as it had been in 1967/68 (King, 1973). Furthermore, in 1973 the average levels of mildew recorded on the four most popular cultivars, Proctor, Julia, Vada and Lofa Abed, were very similar although the last three are rated as having field resistance. The reason for the relatively severe attacks of mildew on these field resistant varieties is uncertain. It may be associated with the season or it may be that the pathogen is now better adapted to these varieties, in which case their present mildew ratings may not reflect their field performance so that the comparisons between 1967-68 and 1973 are not valid. It remains to be seen whether the reaction of these present varieties would be different in a season less favourable to mildew, or whether new varieties with a higher level of field resistance can remain sufficiently resistant under commercial conditions. However, the present indications are that resistance to the disease may not provide a permanent, reliable form of control and that fungicides will continue to play an important role in the control of mildew.

Just as the mildew fungus varies in virulence in relation to varieties so it can be expected to vary in relation to fungicides and tolerance to ethirimol has now been reported from the field (Wolfe and Dinoor, 1973). The significance of tolerance in terms of disease control and yield loss has not yet been assessed and it will be necessary to monitor the situation carefully during the next few years.

There are two kinds of fungicide available for the control of barley mildew, the seed dressing (ethirimol) and the spray (tridemorph, ethirimol, chloraniformethan and chlorquinox). The farmer's choice is largely influenced by conditions on the farm - the average severity of mildew in the past, the choice of variety, the availability of labour, etc. The seed dressing is slightly more expensive at a cost of about £2 per acre (the price of 1 cwt of grain in 1973) but with present barley prices the cost of fungicides is not an important factor in determining their usage. Seed dressing is used as an insurance against mildew attack and farmers find it more convenient because it avoids the extra operation involved in spraying. Spraying on the other hand is more flexible and fungicides need only be applied if mildew seems likely to spread in the crop.

Where sprays are used then it is important to time their application correctly in order to obtain the maximum benefit in increased yields. Where spring barley is near to winter barley, the most important source of mildew in early spring, the highest yield responses have resulted from sprays applied very early, usually not later than the time of herbicide application. In situations where winter barley is not near, then the highest yield responses have been obtained from sprays applied later, usually after the herbicide has been applied (Table 4). Recent work (Polley and Smith, 1973) has shown that certain weather criteria can be used to assist in the correct timing of spray application. Other work by ADAS plant pathologists suggests that the crop can be used as an indicator, sprays being applied as soon as there is about 5% mildew on the lower leaves and a trace of mildew on the second youngest expanded leaf. Under most conditions, the yield difference resulting from the best and the next best timed spray is small, but spraying without regard to mildew development in the crop or favourable weather conditions can result in relatively poor yield responses.

Table 4

The effect of single sprays on the yield of spring barley, (A) adjacent to winter barley and (B) not near winter barley. Yields expressed as a percentage of the untreated crop

(A)*	121	118		108			99		102		109	
(B)†			102		101	113		108		101		105
			May						June			

* untreated yield 27.4 cwt/ac

† " " 31.1 cwt/ac

Most sprays are applied by tractor-drawn sprayers and this can result in damage to the crop. At High Mowthorpe EHF on the Yorkshire Wolds, work over the past four years has shown that average losses (calculated for a 32 ft boom) were nil when crops were sprayed at growth stage 5, (Large, 1954), nearly 2% at growth stage 8, and 3½% at growth stage 10.5. The losses varied according to the condition of the crop: in one year when the crop was thin and affected by drought, losses at growth stage 8 were nil, whereas at the same growth stage in another year the damage to a lush crop was about 3%. Spraying from aircraft is an alternative to ground spraying; it is known to be successful with most of the fungicides though there is no data on the relative efficiency of aerial spraying compared with ground spraying. Damage to the crop is avoided, but the cost of application is higher and the correct timing of sprays may be difficult since this will depend upon the availability of the aircraft.

Brown Rust

The next most important barley disease after mildew is brown rust. In contrast to mildew, brown rust was severe only in 1970 and 1971 and these epidemics were probably partly due to the growing of highly susceptible varieties (mainly Sultan and some Midas) as a high proportion of the barley acreage. A relationship between the severity of brown rust attack and yield loss has not been established but if one assumes an arbitrary 10% or more rust on the leaf below the flag leaf as indicating a significant attack, one can again use data from the surveys (King, 1973) to study the frequency and distribution of such attacks (Table 5). Only in 1970 (though probably also in 1971 when there was no survey) was a high proportion of the crops attacked in this way (ie, 44% in 1970 and ranging from 3-16% in the five other years). In contrast to mildew, there was a marked regional distribution of "significant" attacks with the south having the highest proportion of fields affected. This somewhat erratic distribution of severe attacks over a period of time raises problems for the farmer and the fungicide manufacturer which are very different from those associated with mildew. The manufacturer has to decide if it is worth investing in a chemical which may be in demand in one year and not in another. For the farmer, it is not economic to use fungicides as a routine precaution and he will require information to help him to decide if control of the disease is likely to be worthwhile, and if so, how best to time the spray. At present, we are not in a position to answer these questions.

Table 5

% Fields of spring barley with > 10% brown rust

1967	1968	1969	1970	(1971)	1972	1973	Mean
16	7	3	44	(-)	7	13	15

A few experiments have indicated that large yield increases can be obtained when brown rust is controlled with fungicides. In the south west (Melville, pers. comm.) programmes of zineb sprays increased yields by up to 30%, but single sprays have not so far been successful though this may be due to incorrect timing. Recently, BASF reported that single sprays of a new fungicide, benadonil (BAS 3170F) increased yields by 10-50% depending on the severity of the brown rust attack. New fungicides such as this are likely to be more expensive than the mildew fungicides and, because brown rust epidemics tend to occur relatively late in the development of the crop, the cost of application, by aircraft or by tractor spraying with consequent damage to the crop, is also likely to be higher. It is therefore particularly important that criteria should be developed for deciding if and when to spray a crop affected by brown rust.

Leaf Blotch

The third important leaf disease of spring barley is leaf blotch (*Rhynchosporium secalis*). Using estimates of yield loss (King, 1973) one can put values on the losses due to this disease in England and Wales. These range from almost nil in 1970 to about £1 million in 1967 and 1968, about £2 million in 1969 and 1973 and just over £2 million in 1972. The disease is rarely severe in the main barley areas in eastern England but it can be serious in coastal districts of south and south west England. From surveys carried out in the south-west in 1967-69 (Melville and Lanham, 1972) it can be estimated that in 3, 15 and 19% of the crops, fungicide treatments would have been worthwhile, assuming that the treatments would have cost less than the equivalent of 2-2½ cwt of grain per acre. In fact, we are not able at present to control leaf blotch economically. Programmes of sprays, mainly of zineb, have resulted in very high yield increases in crops where leaf blotch was severe (Jenkins *et al*, 1972) but reduced programmes or single sprays did not prove satisfactory. Recently ICI (Bent, pers. comm.) obtained a striking control of leaf blotch by applying a single spray of captafol at a very early growth stage before the disease became established on young plants. This is a rather different approach to the control of leaf diseases with sprays from the one so far adopted for the mildews and the rusts. In this case, the spray is presumably aimed at preventing the build-up of inoculum in the crop. This approach may be more successful with a splash spread disease such as leaf blotch where the sources of inoculum are mainly within the crop, than with mildews and rusts which are spread by air-borne spores from sources outside the crop to be treated. Should this method prove successful, then the farmer's decision on whether fungicide use is economic will depend, as in the case of seed dressings for mildew, on the probability of the disease occurring at severe levels, and this in turn must be based on experience of the disease in the district and on the susceptibility of the variety being grown.

Most of the recent cereal fungicides have been developed to control one specific disease. Although some have been found to control other diseases, eg the barley mildew fungicide tridemorph also gives some control of yellow rust of wheat and barley, a broad spectrum fungicide which will control several cereal leaf diseases has not yet been developed, though such a fungicide would have obvious advantages to both the farmer and the manufacturer. So far, broad spectrum fungicides such as zineb have been used only experimentally as programmes (Jenkins *et al*, 1972) or as single sprays (Yarham, pers. comm.). In some of these experiments a feature of the results has been the relatively large increase in yield when low levels of disease have been recorded. It is not clear whether these increases were due to the control of low levels of disease, the control of unrecorded diseases (eg eyespot) or some other factor, nor is it known whether this phenomenon occurs frequently.

WHEAT

With the possible exception of one of the rust fungicides none of the presently available fungicides has been developed specifically for the control of wheat leaf diseases. So far, the use of fungicides in farm crops of wheat has been restricted to attempts to control yellow rust but a number of fungicides have been used against a range of diseases in experimental plots.

The most important leaf diseases of wheat are mildew, yellow rust and the Septoria leaf diseases. There is little information on the relationships between these diseases and yield but using some tentative estimates of yield loss (King, 1973) and applying them to the value of the crop, the estimated total cost of these diseases to the farmer ranged from about £5 million in 1970 to £30 million in 1972.

Mildew and Septoria

Wheat mildew, although rarely serious over large areas, can cause severe losses in particular crops of the more susceptible varieties. The development of the mildew epidemic in wheat is very different from that in barley. In contrast to barley most of the crop is winter sown and the ears may become severely affected and virtually nothing is known about how to time spray applications to give the best yield responses. Furthermore the fungicides which are effective for the control of barley mildew are much less so for wheat mildew. A combination of these circumstances means that it is difficult to advise farmers on how to control the disease effectively and economically.

In some experiments carried out in the past two years (author, unpublished) repeated applications of benomyl gave a good control of moderate attacks of mildew and increased yields by about 30% in very susceptible varieties but the application of one or two sprays at or just after ear emergence gave little control and increased yields by only 10% or less.

A somewhat similar situation exists in the case of Septoria leaf diseases. Again little is known about the timing of spray applications to give the most effective control and/or the best yield response, and none of the fungicides has so far proved to be very effective when applied only once or twice. In one experiment where _S. tritici_ was more important than _S. nodorum_ a yield increase of 35% was obtained by frequent applications of zineb but two applications just after ear emergence resulted in a poorer control of the disease and a yield increase of 10% (Jenkins and Morgan, 1969). In another experiment, where only _S. nodorum_ was present, frequent sprays of benomyl resulted in a good control of the disease and a yield increase of 43%. Poorer control and smaller yield increases were obtained with similar applications of dichlofluanid (29%) and zineb (19%) (Melville and Jemmett, 1971).

In an attempt to explore further the effects of benomyl on diseases and yield ADAS plant pathologists carried out a series of experiments in 1971 in which frequent sprays of benomyl were applied to three cultivars of differing susceptibility to mildew and Septoria (King, pers. comm.). The highest yield increases were obtained where Septoria was most severe, eg up to 90% in the susceptible cultivar Maris Ranger. In other cultivars, where Septoria was less severe or where mildew was at a significant level, the increases in yield were lower. However, taking the twelve experiments in the series as a whole, the yield increases from "high disease" situations were much greater than those from "low disease" situations (Table 6).

Table 6

The effect of repeated applications of benomyl on the yield of winter wheat in high and low disease situations

	% Yield Increase		
	Cappelle Desprez	Maris Ranger	Cama
High disease	24.0	50.4	33.4
Low disease	13.7	14.5	15.5

These experiments have shown quite clearly, as did similar experiments in the south west of England in spring barley (Jenkins _et al_, 1972), that frequent sprays of a broad spectrum fungicide in a high disease situation can result in large yield increases. Such results indicate the kind of benefits that may be obtained from the use of chemicals though at present we seem unable to achieve these benefits with an economic spray programme. These and other experiments have also indicated that significant yield increases can be obtained by frequent spray applications or sometimes by one or two applications where diseases are not severe. As in the case of barley it is not clear if these increases are due to the control of low levels of disease, diseases which are not recorded (such as eyespot, Fusarium stem rot, nodal infection by Septoria nodorum), or some other factor not associated with disease control. There does seem to be a case for more extensive work to discover how common are the responses to one or two sprays of about 10% yield increase. At present prices of wheat and fungicides this level of response would be worthwhile.

The economic control of severe attacks of Septoria and mildew must await the development of new fungicides and/or a different approach to the use of fungicides, eg more attention might be paid to the delay or prevention of severe attacks by controlling the level of inoculum within the crop by applying sprays much earlier, as suggested above for leaf blotch in barley.

Yellow Rust

The third important disease of wheat is yellow rust. Chemical control of this disease has become of greater importance because farmers are now choosing to plant some high yielding cultivars of winter wheat which are known to be susceptible to existing races of the fungus. Farmers take the view that growing a small proportion of their acreage in these susceptible cultivars is a justifiable risk in view of their potential high yields and that if yellow rust does occur then a fungicide can be used. Whether this view is correct in seasons favourable to yellow rust remains to be seen.

Some control of yellow rust has been obtained with tridemorph or chloraniformethan or, more frequently, one of these in combination with a dithiocarbamate; a more persistent control has been obtained with the new fungicide benadonil (BAS 3170F).

In the 1971 yellow rust epidemic farmers showed their willingness to use fungicides on wheat even if it meant taking a sprayer through the crop at a late growth stage. An ADAS survey in 1971 (Taylor and Roberts, pers. comm.) estimated that the main susceptible variety, Joss Cambier, occupied about 30% of the wheat acreage and about half of this was rated by the farmers as being severely affected by rust. At this time the fungicides being used in an attempt to control yellow rust were recommended tentatively after only very limited trials, but even so about 25% of the Joss Cambier acreage was sprayed. The yield increases following spraying were very variable. In some experiments yield increases of up to 60% were recorded (BASF, pers. comm.) and the survey data suggested average yield increases of 2.7 cwt/acre in severe disease situations. However there were also many cases where spraying did not increase yield because either the sprays were applied too late in the epidemic or the disease was limited for other reasons. Again, as with most of the other leaf diseases, there are no good criteria to help a farmer decide if or when he should apply a spray to get the best yield response except that it is known that sprays must be applied before the phase of rapid spread of the disease.

CONCLUSIONS

In the case of barley mildew, fungicides are effective and a good deal is known about how to use them. However, the situation is not static. New varieties are being introduced, some of them more resistant to mildew than the varieties they are replacing, and the barley mildew fungus is a variable organism capable of producing strains which are more virulent in respect of the varieties and tolerant to fungicides. To make sense of this changing situation it will be necessary to continue surveys and other means of monitoring the disease, the pathogen and fungicide use. We may then be in a better position to recognise new trends, should they occur, at an early stage and perhaps be able to recommend appropriate action.

Although the present barley mildew fungicides are excellent, the existence of tolerance emphasises the need to continue the search for new and different fungicides for this disease and new fungicides are needed for most of the other cereal leaf diseases. In the case of the rusts, we have one, perhaps two or three, fungicides which are effective but for wheat mildew and Septoria none of the present fungicides is very effective.

Except for barley mildew, the frequency of severe attacks of most of the cereal leaf diseases tends to be erratic, so that the application of chemicals for prophylactic purposes cannot be justified. More needs to be known about the epidemiology of these diseases and their effects on yield so that attempts can be made to devise criteria to help farmers to decide if or when sprays should be applied to get the maximum benefit in terms of yield increases.

In the testing of fungicides more information should be obtained on the performance of fungicides on a field scale as well as in plots and also on the effects of fungicides on different varieties. It would be useful too, to have some data on the effects of these fungicides in the absence of a severe attack of disease. In this way one could measure any beneficial effects, such as those shown by some broad spectrum fungicides, as well as detecting any phytotoxicity. Fungicide trials should be monitored for fungicide tolerance, so that the interpretation of disease control and yield increases will be more meaningful.

The last few years have seen very significant developments in the use of fungicides in cereals. In the next few years one hopes to see some new fungicides and a better knowledge of diseases and the ways in which fungicides should be used. Perhaps then, we can approach the situation when the two main means of disease control, by varietal resistance and the use of fungicides, can be integrated to give the most economic means of control for the farmer and at the same time extend the period of varietal resistance and delay the build-up of fungicide tolerance.

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CHEMICAL ASPECTS OF THE LOSS OF INSECTICIDES FROM SOIL

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Summary When insecticides are applied to soil they are lost mainly by evaporation and degradation. Losses by leaching or by transfer to plants or soil animals are very small for the organochlorine, organophosphorus and carbamate compounds that are established soil insecticides. The extent of the losses by evaporation in the field are ill defined. Quantification of the process may provide a sufficient spur to the finding of ways of reducing the loss and so lead to more efficient use of the compound.

The range of reactions involved in the degradation of the common soil insecticides is not large. Organochlorine soil insecticides degrade slowly and mainly by oxidation reactions although dehydrohalogenation and isomerisation reactions are also evident. For organophosphorus compounds and carbamates hydrolytic reactions predominate. Many of the degradation processes in soil are catalysed by enzymes but some compounds can degrade even in sterilised soil by hydrolysis or by metal or surface catalysed processes.

The subject is a somewhat broad one. During this short review I will therefore be concerned mainly with broad principles. I want to examine the rates at which pesticides disappear from the soil, the routes by which they disappear and the factors affecting their disappearance. I will discuss only those aspects which influence the biological performance of the compound. I will confine myself to insecticides that are applied to the soil and I will be concerned with the compounds that are shown in Figure 1. This restriction results in the omission of a large number of important compounds but the list is still a formidable one.

A very large number of soil insecticides are available but the organochlorine compounds, aldrin, BHC, chlordane, DDT, dieldrin and heptachlor account for the bulk of the usage. In 1970, outside the U.S.A. and U.S.S.R., the organochlorine compounds that are listed accounted for three quarters of the soil insecticide market. Organophosphorus compounds and carbamates accounted for almost all of the other quarter. Since 1970 there has been increasing use of organophosphates and carbamates but the overall changes have not been dramatic.

The chemical structures of the organochlorine compounds are shown in Figure 2. Whilst aldrin, chlordane, dieldrin and heptachlor have structural similarities, BHC and DDT are not related to them. In all of these compounds the presence of the carbon-chlorine bonds confers considerable chemical stability. However, the compounds are not immutable and they can be decomposed by a large number of biological systems.

The organophosphorus compounds that are effective in soils usually contain two ethyl groups (Figure 3). Fonofos contains an ethyl group linked directly to phosphorus but in all of the other compounds both ethyl groups are linked to phosphorus by an oxygen atom. Compounds containing methyl groups instead of ethyl would be less stable and would be insufficiently persistent to be effective in soils. Compounds with larger alkyl groups than ethyl are not usually more effective biologically and are frequently less effective. Most of the important compounds except chlorfenvinphos are P-S compounds.

The carbamates shown in Figure 4 are also effective nematicides. They are all derivatives of N-methylcarbamic acid. Aldicarb and methomyl are closely related compounds although their discoveries were quite independent.

These then are the important soil insecticides. When these compounds are applied to soils they will disappear gradually and the overall rates of depletion are shown in Figure 5. The chemical persistence is shown in the bar chart. The values are average ones and have not been established for all of the compounds under the same conditions. The data for aldrin and heptachlor include their epoxides that are formed in the soil since the epoxides are also active insecticides. The depletion rates fall into two groups. The organochlorine compounds where the time for 50% loss is measured in months and the organophosphorus compounds and carbamates where it is in terms of weeks. There is very little published information on the persistence of the carbamates and the values that are shown may not be representative.

Harris (1969a) and Harris and Hitchon (1970) have compared the persistence of many of these compounds under standard conditions by bioassay. Their ratings of biological persistence (Figure 5) compare well with the chemical data except for the carbamates, again suggesting that the chemical data for these compounds may not be representative.

Whilst the depletion rates cover a wide range most of the compounds have some degree of persistence and this is likely to be an important feature of any compound that is an effective soil insecticide.

Having looked briefly at the depletion rates let us now look at the routes by which the pesticides are lost from the soil (Figure 6).

Only a very small fraction of the applied material is likely to be transferred to plants or to soil animals. The amount is unlikely to exceed 1% and is generally less. This small amount can sometimes be important environmentally but it does not contribute appreciably to depletion.

Although the pesticide may remain in the soil it may be strongly adsorbed and this may result in a considerable decrease in the amount of pesticide immediately available for biological action. However, the adsorption is usually reversible and the pesticide will be released slowly into soil moisture to replace depleted material.

In spite of the importance of adsorption I need not discuss it extensively since it is discussed in the papers being presented to this Conference by Dr. Briggs and by Dr. Hayes and his colleagues.

In the absence of strong adsorption a pesticide can be removed from the site of its action by leaching. A comparison of the mobility of various pesticides in soil is shown in Figure 7. This shows the relative mobilities of pesticides in soil columns measured (Harris, 1969b) in the laboratory under standard conditions. The organochlorine and organophosphorus soil insecticides are among the least mobile pesticides in soil and their loss by leaching is not appreciable.

Run-off can occur when the surface soil containing the pesticide is washed away from the treated field. Incidents are unusual involving the losses of appreciable quantities of pesticide in this way and I will not discuss it further.

The main routes for the loss of a pesticide from a soil are by evaporation and by degradation. It has been demonstrated that many of the pesticides being considered here can evaporate under laboratory conditions. It has also been shown that some of them can evaporate under field conditions, even when they are mixed into the soil. However, little valid information is available on the extent of evaporation under field conditions. Indeed, it is difficult to design experiments to provide such information. Collection of the evaporating pesticide can be attempted but is unlikely to be quantitative. The loss from the soil by evaporation can be calculated if the soil is analysed for the pesticide and all possible degradation products but this is obviously very difficult to do.

For DDT losses of up to 50% have been attributed to evaporation in the field (Lloyd-Jones, 1971). For aldrin it can be estimated from indirect evidence that up to 65% of an application might be lost by evaporation under field conditions in the first year even when the compound is mixed into the soil (Decker et al 1965, Elgar unpublished data). Field studies have shown that after one year 25% of the initial application typically remains either as aldrin or dieldrin. Radiochemical studies under outdoor conditions (Klein et al 1973) indicate that conversion of aldrin in soil into other metabolites is unlikely to exceed 10% and thus one can estimate that in the field some 65% of the applied aldrin might have evaporated. However, these values are not known with any certainty and information on the other compounds is even less reliable.

One can compare the vapour pressures of these compounds (Figure 8). It is evident that all of them have volatilities that are greater than that of DDT. Many of the compounds are more volatile than aldrin. These other compounds are no more strongly adsorbed by the soil than DDT or aldrin and it is possible that evaporative losses could be appreciable for several of them. For some of the compounds, however, degradation rates may be too high for evaporation to contribute significantly to the loss.

It is worth pointing out that although the evaporation may reduce the quantity of pesticide in the soil there is ample analytical evidence that the residues that do evaporate are removed efficiently from the air. These removal processes include photochemical degradation and reprecipitation of the pesticide on to soil followed by degradation.

Some of the reactions, such as the first three, epoxide formation, PS oxidation and S-oxidation, convert the parent compound into products that are active insecticides. Indeed in many cases, for example aldrin and heptachlor, it is the product that is the more active compound. Oxidation of P(S) compounds to P(O) often produces more active products but these products usually hydrolyse more readily. The reactions other than the first three lead to loss of effective biological activity. The conversion of organophosphorus compounds into P-OH derivatives can proceed by hydrolysis, that is attack of the P atom by hydroxyl ions, or by oxidation of the alkyl group. Indeed other reaction mechanisms are possible and these will be discussed in the paper being presented to this Conference by Adamson and Inch.

I have not listed the additional reactions that can convert the inactive degradation products into carbon dioxide and water in the soil although oxidative processes are abundant.

The list of reactions that is shown is not a long one. Reactions of pesticides involving hydroxylation of aromatic rings and conjugation reactions with sugars and amino-acids are common in animals and plants as they strive to convert foreign compounds into water-soluble materials. Such reactions are most unusual in soils. However, it is possible that a larger number of reactions can occur in the rhizosphere around the plant roots and this, of course, is usually the region where the pest attacks. Perhaps for soil insecticides as much attention should be paid to degradation in this region as is usually paid to the degradation in the bulk soil.

The isomerisation reaction that is shown in Figure 9 is catalysed by light although there is some suggestion that micro-organisms can also effect the conversion. The other reactions are usually catalysed by soil enzymes and can be shown to be slower when the soil is sterilised. However, this is not always so and there is good evidence that the hydrolysis of several pesticides can be catalysed chemically. Catalysis by copper compounds in soil has been demonstrated with diazinon and chlorpyrifos (Mortland and Raman, 1967), and catalysis by other inorganic components of the soil matrix can occur.

In soils it is probable that organophosphorus compounds and carbamates are decomposed mainly by hydrolysis whereas oxidation reactions are more important for the organochlorine compounds.

The complete degradation pathway for one organophosphorus compound is shown in Figure 10 (Beynon and Wright, 1967). The only reaction observed with the original compound is hydrolysis although the reaction mechanism has not been established with certainty. This degradation reaction can occur in two ways but both eventually lead to the same product which then undergoes a series of reactions, including reduction, oxidation and isomerisation. Many of these reactions would be difficult to achieve in the chemical laboratory.

The conversion in the soil of the organochlorine compounds aldrin and dieldrin is shown in Figure 11 (Klein et al, 1973). The decomposition of dieldrin and photodieldrin is slow, but finite, although the products have not yet been characterised fully.

Thus we see that pesticides can be lost from soils by evaporation or by degradation and we know the total rate of loss. We also know the many factors that affect the overall loss and these are summarised in Figure 12. I do not intend to discuss these in any detail. They have been discussed extensively in the past and there is not a great deal that can be added even today to the excellent review of them produced some 8 years ago (Edwards, 1966).

A great deal is known about the relationship between the chemical structure of a compound, the degradation rate and the biological activity. For related series of compounds structure-activity relationships are frequently established which can lead to an early definition of the optimum chemical structure. These relationships have a great predictive potential but need further development if they are indeed to be used to predict and not just to confirm existing knowledge.

The other effects that are listed are well established for some of the commercial products I have discussed but I do not think that information is available for all of them. Information on the effects of all these parameters needs to be obtained systematically for each compound and this work should be, and now usually is, an essential part of the development programme of a new compound.

In conclusion we can say that pesticides are lost from the soil by evaporation and degradation. We know the overall rates of loss but do not know the relative contribution of evaporation and degradation under field conditions. Effective soil insecticides are already available and possibly their effectiveness could be improved even further if the main process that effects their loss could be defined.

At the present time there is a pressure to replace the persistent soil insecticides by compounds that are of limited persistence and of a narrow spectrum of activity. This pressure is proving very difficult to meet and let us ensure that any change is based on sound scientific criteria and not on subjective arguments.

Acknowledgements

I am grateful to Mr. J. Brammer of Shell Research Ltd. for preparing the list of the values for vapour pressures of pesticides which includes his own unpublished data (aldrin, dieldrin, chlorfenvinphos and methomyl) as well as published data from other sources. These sources include Martin (1972), Spencer and Cliath (1970), Richardson and Miller (1960), Dickinson (1956) and Gückel <u>et al</u> (1973).

I am also grateful to the many workers whose data were used in the preparation of Figure 5. Sources of information include Edwards (1965), Decker et al, (1965), unpublished data from K. E. Elgar, Suett (1971), Malone (1967), Onsager and Rusk (1969), Schultz and Lichtenstein (1971), Lichtenstein and Schultz (1964), Parker and Dewey (1965), Menzer et al (1970), Kearby et al (1970) and Harvey and Pease (1973) as well as our own work (Beynon et al 1966).

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Chlorinated hydrocarbons

- Aldrin
- BHC
- Chlordane
- DDT
- Dieldrin
- Heptachlor

Organophosphorus compounds

Chlorfenvinphos	(Birlane^{R})
Chlorpyrifos	(Dursban^{R})
Diazinon	(Basudin^{R})
Disulfoton	(Disyston^{R})
Fensulfothion	(Dasanit^{R})
Fonofos	(Dyfonate^{R})
Parathion	
Phorate	(Thimet^{R})

Carbamates

Aldicarb	(Temik^{R})
Carbofuran	(Furadan^{R})
Methomyl	(Lannate^{R}, Nudrin^{R})

Fig 1 Insecticides for the control of pests in soil

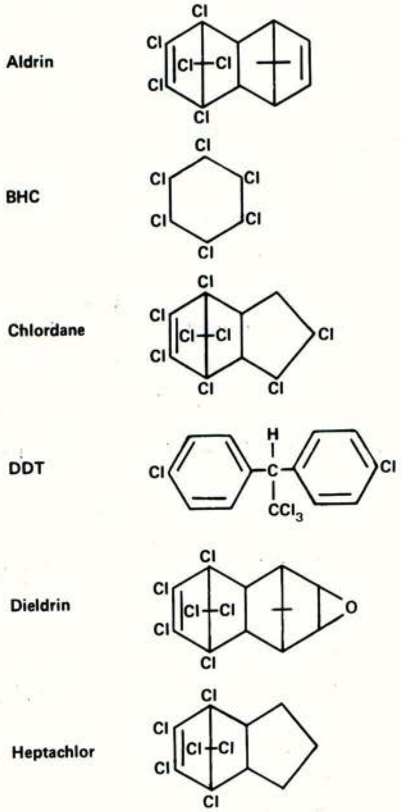
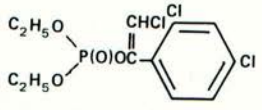
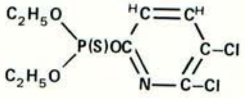


Fig 2 Structures of chlorinated hydrocarbons

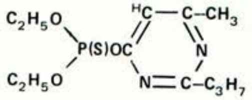
Chlorfenvinphos (Birlane^R)



Chlorpyrifos (Dursban^R)



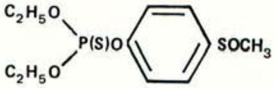
Diazinon (Basudin^R)



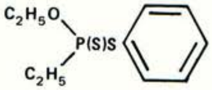
Disulfoton (Disyston^R)

$(C_2H_5O)_2P(S)SCH_2CH_2SC_2H_5$

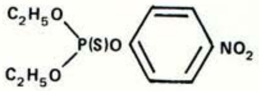
Fensulfothion (Dasanit^R)



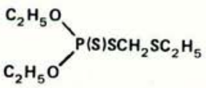
Fonofos (Dyfonate^R)



Parathion



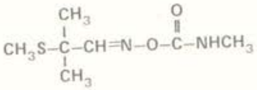
Phorate (Thimet^R)



$(C_2H_5O)_2P(S)SCH_2SC_2H_5$

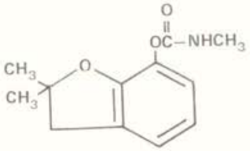
Fig 3 Structures of organophosphorus compounds

Aldicarb (Temik^R)

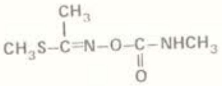


$$CH_3S{-}\underset{CH_3}{\overset{CH_3}{C}}{-}CH{=}N{-}O{-}\overset{O}{\overset{\|}{C}}{-}NHCH_3$$

Carbofuran (Furadan^R)



Methomyl (Lannate^R, Nudrin^R)



$$CH_3S{-}\overset{CH_3}{C}{=}N{-}O{-}\underset{O}{\underset{\|}{C}}{-}NHCH_3$$

Fig 4 Structures of carbamates

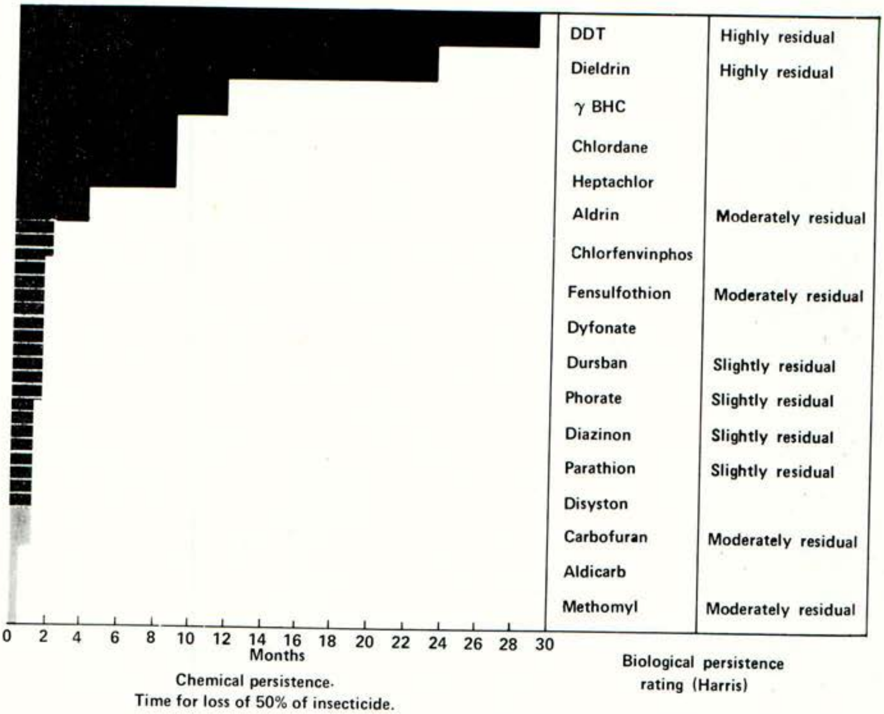


Fig 5 Depletion rates of pesticides from soil

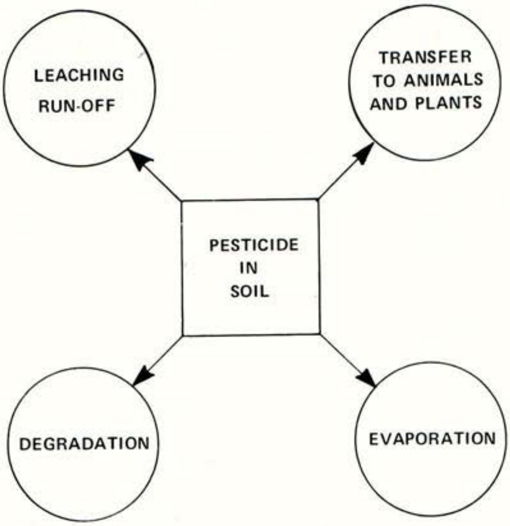


Fig 6 Routes for the loss of pesticides from soils

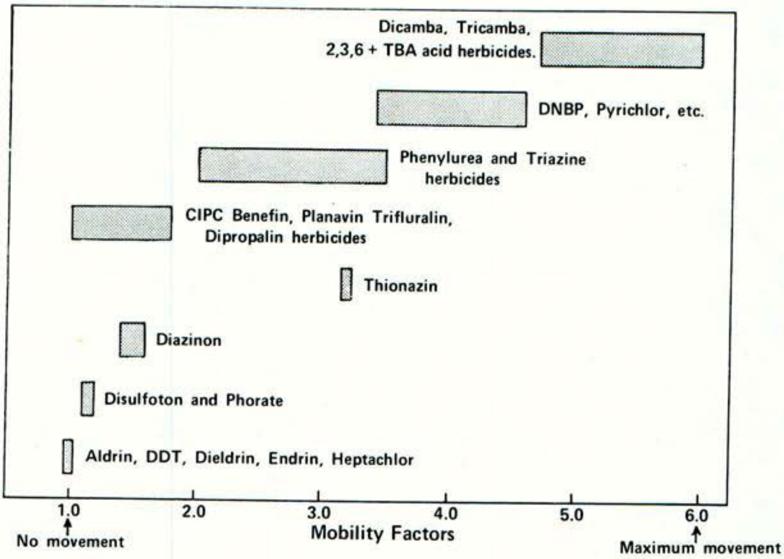


Fig 7 Relative mobilities of pesticides in soil

	Vapour pressure [mm Hg at ( )°C] $\times 10^{6}$	
Organochlorine Compounds		
Aldrin	75	(20)
γ–BHC	33	(20)
Chlordane (pure)	10	(25)
PP$^{\prime}$–DDT	0.18	(20)
Dieldrin	.3	(20)
Heptachlor	300	(25)
Organophosphorus Compounds		
Chlorfenvinphos	4	(20)
Chlorpyrifos (Dursban)	19	(25)
Diazinon (Basudin)	140	(20)
Disulfuton (Disyston)	180	(20)
Fensulfothion (Dasanit)		
Fonofos (Dyfonate)	210	(25)
Parathion	38	(20)
Phorate (Thimet)	840	(20)
Carbamates		
Carbofuran (Furadan)	20	(33)
Methomyl (Lannate, Nudrin)	2.4	(20)

Fig 8 Vapour pressures of soil insecticides

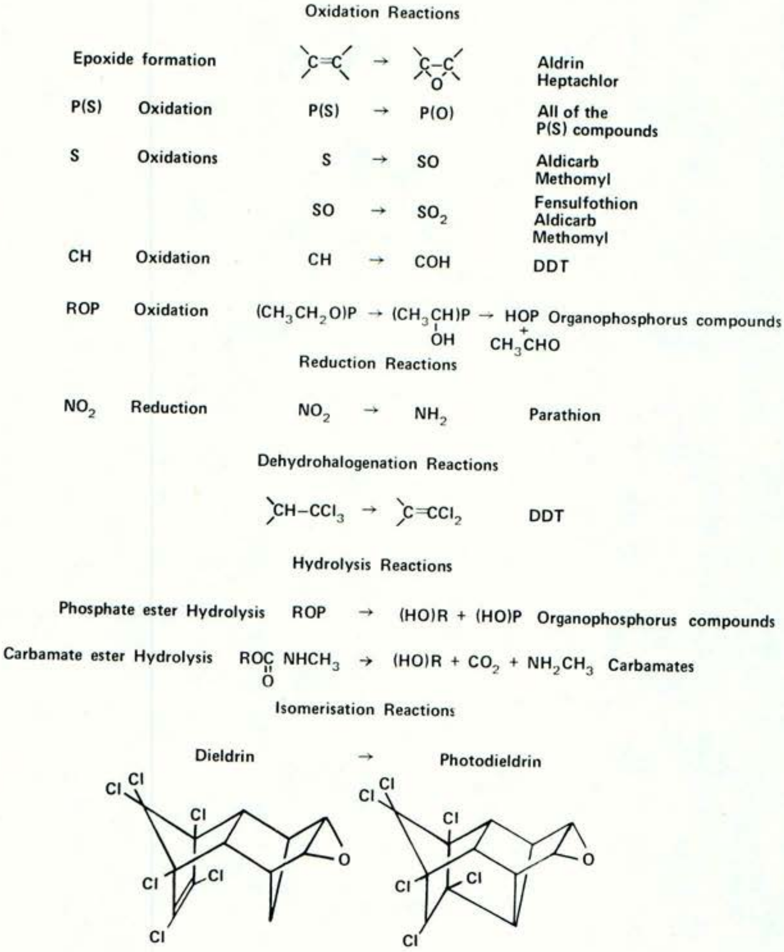


Fig 9 Conversions of insecticides in soils

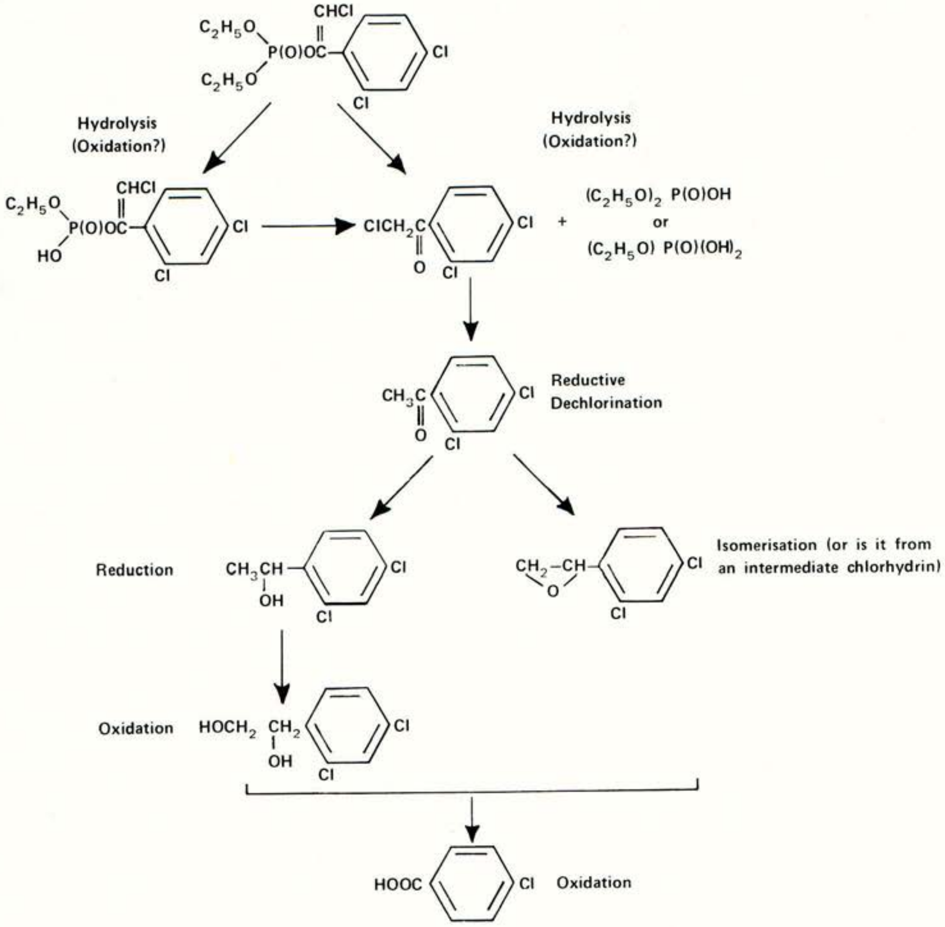


Fig 10 Degradation pathway of chlorfenvinphos (Birlane) in soil

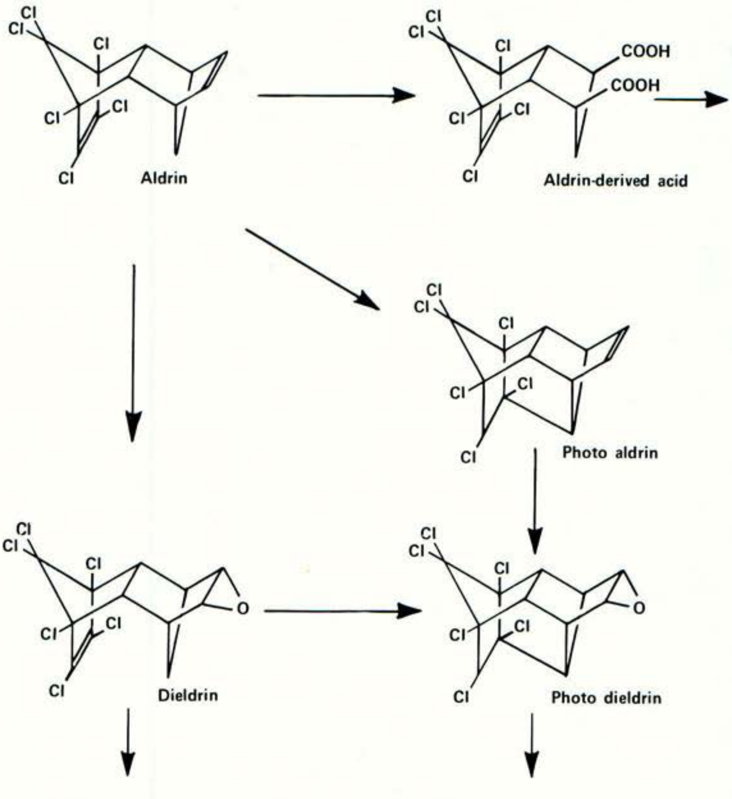


Fig 11 Initial degradation pathway of aldrin and dieldrin in soil

Chemical structure

Applied concentration

Formulation
Application procedure
Soil properties

Climatic factors

Extent of plant cover
Extent of cultivation

Fig 12 Factors affecting the degradation rate and evaporation of soil insecticides

NOTES

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BIOLOGICAL ASPECTS OF THE DEGRADATION AND BEHAVIOUR OF PESTICIDES IN SOIL

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Summary Microorganisms are important in degrading pesticides in soil. The relative contributions of microorganisms, plants and animals to the overall breakdown and removal of pesticides from soil are discussed. Microbial breakdown is the most important of the biological agencies of degradation. Removal of pesticides with the crop could be only 10% at most, and no more than 1% can be locked up in animal tissues.

Résumé Les micro-organismes jouent un rôle important dans la dégradation des pesticides dans le sol. On discute la participation relative des micro-organismes, des plantes, et des animaux à la destruction globale des pesticides et leur élimination du sol. Parmi les agents biologiques de la dégradation, la décomposition par les microbes a une importance prépondérante. Tout au plus 10% des pesticides ne pourrait être éliminé par absorption par les récoltes, et pas plus de 1% ne peut être immobilisé dans les tissus des animaux.

Dr. Beynon has dealt with some of the chemical aspects of the degradation of pesticides in soil. He has discussed the rate at which they disappear, and suggested that significant amounts of even non-volatile compounds are lost from soil by evaporation, and has outlined details of the chemical breakdown of some pesticides in soil.

My task is to add to this story by discussing some of the biological aspects of the degradation and behaviour of pesticides in soil. Soil is a complex of diverse mineral materials, intimately combined with organic matter and humic compounds. It contains a vast range of living organisms all interdependent on one another for food and living space. Our knowledge of the interactions of these organisms and their role in breakdown of pesticides is still scanty, so all that I can do is to discuss those organisms that have been shown to influence the degradation and behaviour of soil pesticides. I intend to confine most of my talk to the degradation of insecticides, but, because we have much information on the role of soil organisms in the breakdown of herbicides (Alexander, 1969), and many of the principles involved are the same, I shall use examples of herbicides, where necessary, to demonstrate the possible significance of soil organisms in degradation of some pesticides.

1. The role of microorganisms in degradation of pesticides in soil

It is difficult to differentiate precisely between the chemical or biological origin of pesticide degradation reactions. Soil contains water, oxygen, organic matter and mineral ions, which facilitate both simple and complex reactions in the breakdown of pesticides and can be catalysed by heavy metals or by other substances. Nevertheless, there is good evidence that much of the breakdown of pesticides in soil is enzymatic. Enzymes are of biological origin although they may exist outside living organisms. They may be released from dying organisms, by micro-organisms, from the roots of plants, or excreted by soil animals, and remain active in soil for considerable periods. This raises the problem of distinguishing between truly biological degradation of pesticides and those occurring in soil itself. Fortunately, this can be quite easily established, because if the degradation slows down or stops after soil sterilisation, this is clear evidence that the breakdown is at least partially mediated by microorganisms. However, there are different methods of soil sterilisation and not all retard breakdown equally; heat sterilisation is the most effective (Lichtenstein and Schulz, 1960, 1964) whereas gamma radiation (Getzin and Rosefield, 1968) and chemical inhibitors such as sesamex, piperonyl cyclonene, piperonyl butoxide (Lichtenstein *et al*., 1963) are much less effective but more specific. Supplementary evidence that degradation is microbial can be obtained by careful study of the kinetics of breakdown (Alexander, 1969), because if extracellular chemical breakdown occurs, it begins shortly after application of the pesticide to soil and the rate of breakdown either remains constant or declines with time. By contrast, microbial breakdown does not begin until microbial populations build up, and then the rate of chemical loss increases with time, eventually becoming logarithmic, particularly if only a single species of microorganism is involved. There seems to be good evidence that when some pesticides, especially herbicides, are repeatedly applied to soil, after each successive treatment populations of those microorganisms involved in their breakdown increase rapidly in numbers and the chemical breaks down more rapidly (Gunner and Zuckerman, 1968). If such a pattern is observed this is also good circumstantial evidence of microbial breakdown.

Some workers have demonstrated that particular species of microbes can degrade certain pesticides, but it is much more common for breakdown of a pesticide to be non-specific, with a wide variety of microorganisms possessing the ability to degrade any particular pesticide (Table 1). Many species of microorganisms seem able to degrade pesticides, including most of the commoner genera of soil-inhabiting bacteria, the three main actinomycete genera (*Nocardia*, *Streptomyces* and *Micromonospora*) and many fungi. There are some indications that microbial breakdown may be synergistic; neither *Arthrobacter* nor *Streptomyces* can degrade diazinon alone, but together can break down large quantities of this pesticide (Gunner and Zuckerman, 1968).

Microbial degradation of pesticides in soil can sometimes be accelerated by providing an additional source of energy to the soil; for example, when a ground alfalfa foliage was added to soil containing DDT, the breakdown of the pesticide was greatly accelerated (Guenzi and Beard, 1968; Ko and Lockwood, 1968) and when glucose was incorporated in soil the breakdown of parathion was speed up (Lichtenstein and Schulz, 1964).

Other workers have demonstrated that microbial breakdown of pesticides often progresses faster under anaerobic conditions. For instance, this has been demonstrated by keeping soil flooded for extended periods, which greatly accelerated the degradation of DDT (Guenzi and Beard, 1968; Kearney *et al*. 1969) and of BHC (Yoshida and Castro, 1970; Tsukano and Kobayashi, 1972).

Certain soil environmental factors can influence the rate of microbial breakdown of pesticides; those conditions that favour microbial activity, such as adequate soil moisture and high temperatures, accelerate breakdown. Organic soils tend to have larger populations of microorganisms capable of degrading pesticides than mineral soils, and pH also influences microbial activity; bacteria and actinomycetes being more active in neutral soils, whereas fungi thrive better in acid soils. It has been suggested that the dose of a pesticide, its particle size and its placement can all considerably influence its susceptibility to microbial degradation (Martin and Evvin, 1970). Breakdown by microorganisms is a complex process, and there is some evidence that the activities of some microorganisms might actually retard loss of pesticides from soil. For instance, aldrin is rapidly converted into dieldrin by microorganisms and it has been shown that because dieldrin is much less volatile than aldrin, overall losses may be slowed down by the conversion (Lichtenstein *et al*., 1968).

Some pesticides become more toxic to pests after microbial attack; these include aldrin, (becomes dieldrin) and heptachlor (becomes heptachlor epoxide) (Lichtenstein and Schulz, 1960). Others become less effective as pesticides e.g. BHC, DDT and isobenzan, because their metabolites are less toxic to pests. There is no recorded instance of microbes completely breaking down a persistent insecticide, although some workers have reported the production of ^{14}C-labelled CO_2 during the breakdown of ^{14}C-labelled pesticides such as dieldrin (Jagnow and Haider, 1972) (Table 1). There are not many reports of microorganisms being able to cleave the benzene ring of organochlorine pesticides, although a few workers have claimed that this occurred (Focht and Alexander, 1970). Populations of some species of microorganisms increase after applications of pesticides to soil, but it is not yet clear whether such increases occur because the pesticide provides an additional food source or because it eliminates competing species. Some pesticides are toxic to microorganisms, but not usually unless large doses are used; such decreases in microbial populations may decelerate the breakdown of other pesticides.

Many microorganisms can take pesticides into their tissues and store them, either in their original or degraded forms. Moreover, it has been shown that they can concentrate organochlorine insecticides such as DDT and dieldrin, so that they accumulate amounts greater than those in the surrounding soil (Chacko and Lockwood, 1967; Ko and Lockwood, 1968). These workers claim to have shown that fungal mycelia can bind these insecticides much more readily than other soil organic matter, and reported that the addition of only 0.1% of dry mycelium of *R. solani* could bind as much dieldrin as 3.8% of other soil organic matter. However, in the soil studied, the proportion of the dieldrin bound in this way was only about 10% of the total present; it seems unlikely that soil microorganisms are able to bind up large amounts of insecticides although they may be important in their degradation.

It seems important to attempt to evaluate the overall importance of soil microorganisms in pesticide degradation. However, this is difficult, because we still have insufficient information, but some idea can be obtained from comparison of the rate of disappearance of pesticides in sterile and non-sterile soils (Table 2). The slow-down in the rate of breakdown ranged from 2 to 40 per cent but all these results were from short-term laboratory experiments. However, in none of the experiments did degradation stop completely after sterilisation, indicating that breakdown by microorganisms accounts for only a relatively small part of the overall losses of pesticides.

2. The role of plants in degradation and removal of pesticides from soil

Many pesticides are systemic, and when these are taken up by plants, either they may remain within the plant tissues in the form in which they are absorbed, or, more usually, become at least partially degraded within the plant tissues. In extreme instances, the pesticide may harm the growth of the plants or even kill them. Thus, plants may be important in breaking down pesticides in soil; this is particularly true for herbicides and the systemic organophosphate insecticides. Even non-systemic pesticides such as organochlorines, and some organophosphates including parathion, may be taken up into plant roots and foliage. Table 3 lists the amounts of some organochlorine insecticides that have been reported in the tissues of plants growing in treated soil; the data have been selected to show the maximum potential for uptake; probably, the amounts that are usually taken up are less than these.

Another aspect of uptake into plants influences the loss of pesticides from soil; when crops are harvested, the insecticide residues they contain are removed with them. Simple calculations, using the data in Table 3, enable the potential loss of insecticides in this way to be assessed. An average figure for the foliar weight of a wheat crop is 3,500 kg/ha and if this were all removed and contained 1 ppm, the amount of insecticide taken with it would amount to only 0.0035 kg/ha, a very small proportion of a normal treatment. This figure might be higher for crops with a greater foliar weight but nevertheless would still be very small. More could be removed in this way by a root crop, with an average yield of about 33,000 kg/ha, and which would probably contain more insecticide residues, because these seem to be concentrated in storage tissues. Even if, exceptionally, the root crop contained as much as 5 ppm of insecticide residues a total of only about 0.16 kg/ha of insecticide would be removed with the crop. It follows that plants are not greatly important in the overall losses of insecticides from soil.

3. The role of animals in degradation and removal of pesticides from soil

Some pesticides penetrate the tissues of soil invertebrates or are taken into their bodies with their food. This happens most frequently with the lipophilic organochlorine insecticides. Although there is not much data available, it is clear that pesticides can break down in the tissues of invertebrates. For instance, DDT is converted to DDE in the bodies of mites (Aucamp and Butcher, 1971), earthworms (Wheatley and Hardman, 1969; Edwards and Jeffs, 1973), springtails (Butcher et al., 1969; Klee, 1971) and many insects. It seems probable, therefore, that many pesticides are at least partially degraded in the bodies of invertebrates.

Some soil invertebrates can also concentrate insecticides from soil into their tissues so that some of the insecticide residues in a treated soil could become locked up in the tissues of the invertebrates that live in it. Furthermore, many soil invertebrates spend only part of their lives in soil, and when they migrate to other habitats they take the insecticide residues with them. However, the amounts locked up or lost in this way can be calculated and must be small. It has been estimated that an average soil contains 25 tonnes/ha of living organisms (Stockli, 1950). If 5 ppm of a pesticide occurred in these organisms only 0.025 kg/ha of insecticide would be locked up; a very small proportion of a normal treatment.

4. Interrelation between pesticides, soil organisms and soil organic matter

Dr. Beynon mentioned the adsorption of pesticides in his talk; one of the most important soil fractions responsible for adsorption is the organic matter. Adsorption is important because it influences not only the effectiveness of the pesticide, but also its persistence in the soil. Pesticides can become adsorbed gradually on to organic matter after application to soil, or may reach the soil in dead plant material that falls on to the soil. In either instance, the soil biota is important because it helps to break down the organic matter and move it through soil. In the absence of soil animals, most of the organic matter remains in a tight mat of relatively undecomposed plant material at the soil surface; any pesticides falling on to such a surface are largely adsorbed and inactivated. Since pesticides may also be responsible for considerably diminishing populations of soil animals, these two effects may act together to decrease the effectiveness of a pesticide.

Soil animals may be a factor in increasing the persistence of unwanted pesticide residues in soil. Most pesticides disappear up to ten times faster when left exposed on the soil surface than when thoroughly mixed into the soil. Earthworms, in particular, move considerable amounts of soil and organic matter into the lower soil layers; when these contain pesticides the persistence of the pesticides is increased. Alternatively, such activities may influence the effectiveness of a pesticide. For instance, in New Zealand, it has been shown that control of chafer grubs can be increased from practically nil to almost 100% by the activity of earthworms in taking the pesticide into the lower soil layers. It has been shown that up to 20% of soil may be turned over annually by earthworms so eventually most of the residues of a very persistent pesticide may be transported to lower soil layers (Edwards and Lofty, 1972).

The way in which pesticides are adsorbed by organic matter are largely unknown, but it has been suggested that humic materials are important in this process, and if this is so, because soil organisms are important in humus formulation, they may indirectly influence the degree of adsorption of pesticides.

To summarise, although it has been established that soil organisms are important in mediating the degradation of pesticides there are still many unknowns and many alternative non-biological pathways of breakdown exist. We still do not know the ultimate fate of the more persistent pesticides and the relative importance of biological and chemical pathways of degradation. It seems probable that whereas movement of pesticides through the environment is mainly due to chemico-physical factors, their ultimate breakdown is probably brought about biologically.

Table 1. Microorganisms that can degrade insecticides in soil

Pesticide	Microorganism	Breakdown product	Reference
Aldrin	*Pseudomonas*	dieldrin	Matsumura *et al*, 1968
"	*Fusarium*, *Trichoderma*, *Nocardia*, *Streptomyces* *Micromonospora*	dieldrin	Tu *et al*, 1968
"	*Aspergillus flavus* *A. niger*, *Penicillium notatum*	-	Korte *et al*, 1962
Chlordane	*Aspergillus flavus* *A. niger*, *Penicillium notatum*	-	Korte *et al*, 1962
DDT	*Proteus vulgaris*	DDD	Barker *et al*, 1965
"	Yeast	DDE	Kallmann and Andrews, 1963
"	*Aerobacter aerogenes*	DDE	Plimmer *et al*, 1967
"	*Hydrogenomonas*	benzene ring broken	Focht and Alexander, 1970
"	*Actinomycetes*	-	Chacko *et al*, 1966
Diazinon	*Arthrobacter*, *Streptomyces*	CO_2	Gunner and Zuckerman, 1968
Dieldrin	*Trichoderma viride* *Pseudomonas* *Bacillus* sp.	-	Matsumura and Boush, 1967
"	*Nocardia* *Corynebacterium* *Micrococcus*	CO_2	Jagnow and Haider, 1972
"	*Aerobacter aerogenes*	aldrin diol.	Wedemeyer, 1968
Heptachlor	*Aspergillus flavus* *A. niger*, *Penicillium notatum*	-	Korte *et al*, 1962
"	*Trichoderma*, *Penicillium*, *Rusarium*, *Aspergillus*, *Rhizopus*, *Mucor*, *Nocardia*, *Bacillus* *Arthrobacter*, etc.	H. epoxide 1-hydroxychlordene Chlordane	Miles *et al*, 1969
Isobenzan	*Aspergillus flavus* *A. niger*, *Penicillium notatum*	-	Korte *et al*, 1962
"	*Aspergillus* *Penicillium*	Hydrophilic metabolites	Korte and Stiasni, 1964
Lindane	*Bacillus cereus* *Bacillus* sp.	dehydrochlorination	Yule *et al*, 1967
"	*Clostridium*	pentachlorocyclohexane	Sethunathan *et al*, 1969
Parathion	yeast	aminoparathion	Lichtenstein, 1965

Table 2. Persistence of insecticides in normal and sterile soils

Insecticide	Period	Percentage of applied dose remaining in:		Reference
		normal soil	sterile soil	
Aldrin	112 days	61	46	Lichtenstein and Schulz, 1960
Diazinon	15 days	29	31	Lichtenstein *et al*, 1968
"	4 weeks	58	70	Getzin, 1967
Heptachlor	112 days	39	65	Lichtenstein and Schulz, 1960
Lindane	15 days	76	91	Lichtenstein *et al*, 1968
Parathion	6 days	54	86	Lichtenstein and Schulz, 1964
"	15 days	25	66	Lichtenstein *et al*, 1968
Thionazin	4 weeks	52	79	Getzin, 1968

Table 3. Amounts of organochlorine insecticides taken into plant tissues from soil

Insecticide	Crop	Amount in soil (ppm)	Amount in plant (ppm)	Reference
Aldrin	Pea foliage	2.3	0.19	Lichtenstein et al, 1967
"	Pea roots	2.3	15.5	
"	Carrots	1.34	0.53	Lichtenstein et al, 1965
"	Potatoes	0.94	0.07	Lichtenstein et al, 1968
BHC	Pea foliage	0.62	22.9	Lichtenstein et al, 1967
"	Pea roots	0.62	82.6	
"	Carrots	1.7	6.0	Lichtenstein, 1959
"	"	0.095	0.025	Oloffs et al, 1971
"	Potatoes	3.0	0.62	Lichtenstein, 1959
Chlordane	Alfalfa foliage	0.25	75.6	Dorough et al, 1972
"	Sugar beet	1.23	0.22	Onsager et al, 1970
DDT	Alfalfa foliage	1.39	0.11	Ware et al, 1968
"	Carrots	4.99	0.04	Oloffs et al, 1971
"	Sugar beet	1.54	0.10	Onsager et al, 1970
dieldrin	Alfalfa foliage	0.054	0.026	Saha et al, 1968
"	Carrots	0.48	0.11	Hurtig and Harris, 1966
"	Corn shoots	0.84	0.24	Beestman et al, 1969
	Corn roots	0.84	9.35	
	"	4.12	55.43	
"	Wheat	1.13	0.17	Wingo, 1966
endrin	Wheat	1.92	0.41	Saha and McDonald, 1967
heptachlor	Alfalfa foliage	0.23	0.67	King et al, 1966
"	Wheat	1.94	0.11	Wingo, 1966
"	Alfalfa roots	0.23	0.41	King et al,
"	Carrots	1.33	0.98	Lichtenstein et al, 1965
"	Sugar beet	2.5	0.14	Lichtenstein and Schulz, 1965

Table 4. Amounts of organochlorine insecticides in invertebrates and the soil in which they live

Pesticide	Animal	Amount in soil (ppm)	Amount in animal (ppm)	Reference
aldrin	earthworm	0.03	0.10	Gish, 1970
BHC	earthworm	0.08	0.30	Davis and Harrison, 1966
DDT	earthworm	1.96	5.36	Cramp and Olney, 1967
"	earthworm	0.82	9.75	Davis, 1968
"	earthworm	9.75	26.65	Davis and Harrison, 1966
dieldrin	earthworm	0.07	0.34	Davis, 1968
"	earthworm	0.28	1.30	Edwards and Thompson, 1972
"	earthworm	0.10	0.99	Gish, 1970
aldrin	slug	0.006	0.10	Gish, 1970
DDT	slug	1.96	6.49	Cramp and Olney, 1967
"	slug	7.10	11.69	Davis and French, 1969
dieldrin	slug	0.009	5.14	Gish, 1970
"	slug	0.04	0.30	Davis, 1968
endrin	slug	3.47	134.06	Gish, 1970

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NOTES

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USE OF BUSAN 30 AS A SEED TREATMENT IN CANADA

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Summary Busan 30 is the designation assigned to a liquid formulation containing 30 percent 2-(thiocyanomethylthio)benzothiazole. This seed treatment is used as an efficient replacement for mercurial-type seed treatments. Busan 30 does not precipitate or turn viscous at the low temperatures prevailing in Canada during the seed-treating season. The product can be applied directly using ready-mix seed treaters which were used to treat cereal seed with mercurial-type seed treatments until December 1970 when the mercurials were banned.

Busan 30 is used at the dosage of 0.75 fl. oz/bushel of wheat, barley, and oats seed. It is recommended for the control of stinking smut or bunt of wheat; false loose and covered smut of barley; loose and covered smut of oats; and seed- and soil-borne seedling blights (seed-borne root rots) of wheat, barley and oats.

Résumé Busan 30 est le nom donné à une formulation liquide contenant 30% de 2(thiocyanomenthyltio)benzothiazol. Ce produit est appliqué dans le traitment de graine et est un remplacement efficace des produits à base de mercure. Busan 30 ne se précipite pas et ne devient pas visqueux aux basses températures qui peuvent sévir au Canada durant la saison de traitement de graine. Ce produit peut être appliqué directement en employant des appareils utilisant les mélanges tout prêts qui furent employés pour traiter des graines de céréales avec des produits à base de mercure avant que ceux-ci ne devinrent interdit en décembre 1970.

Busan 30 est employé à une concentration de 0.75 (3/4) once fluide par boisseau de blé, d'orge ou d'avoine. Ce produit est recommendé pour enrayer le charbon ou la carie du blé, le faux charbon couvert de l'orge et de l'avoine et plusieurs autres maladies des graines et des semis, telles que la nielle des céréales et le mildiou des racines du blé, de l'orge et de l'avoine.

INTRODUCTION

In Canada, the mercurial pesticide registrations for cereal seed treatments were cancelled on December 1, 1970. The liquid formulations based on mercury pesticides were applied with the different types of ready-mix seed treaters. Those formulations were stable at low temperatures (-40°F). A suitable replacement for mercurial seed treatments would be a liquid pesticide that showed a useful spectrum of biological activity and that did not have the toxicological or residue problems of mercurial seed treatments.

Busan 30 is the designation assigned to a liquid formulation that contains 30 percent of 2-(thiocyanomethylthio)benzothiazole (TCMTB).

This paper reports some of the tests performed with Busan 30 on barley, oats, and wheat seed to show that it is an efficient replacement for mercurial seed treatments.

METHOD AND MATERIALS

Brookfield viscosity measurements were determined on Busan 30 using a model LVT viscometer. The LV-1 spindle was used at -49°F, -40°F, -20°F, and 0°F. Readings were made only at 12 and 30 revolutions/min and the average reported.

The biological activity of Busan 30 against a broad spectrum of saprophytic and pathogenic seed-borne fungi was determined by treating the seed and plating it on sterile potato dextrose agar. Observations made on the amount of mycelial growth indicate the effectiveness of the seed treatment. Fungi that could not be evaluated by this procedure were tested in the field by planting four replications of each treatment. Each plot consisted of a single row planted with 200 seeds per 12 feet. Disease rating was determined by counting the total number of plants and expressing the number of diseased plants as a percentage of the total.

Barley, oats, or wheat seeds were treated with Busan 30 at the recommended dosage of 0.75 fl. oz/bushel of seed. The reliability of a seed treatment test depends on the seed being evenly coated with the product. This is difficult to achieve under laboratory conditions due to the small quantities of seed and product used. The appropriate quantity of Busan 30 was placed in a 1.4 British (Br.) quart stainless steel jar which was rotated to spread the seed treating liquid as much as possible. A quantity of seed, 1.76 avoirdupois (av.) oz was added and the jar covered and placed on a 0.25 hp Red Devil paint shaker for 2.5 min. After treatment, the seeds were stored for 24 h in sealed plastic envelopes before planting.

The biological activity of Busan 30 against soil-borne pathogens was determined by treating the seeds and planting them in artificially infested soil. Natural soils contain both pathogenic fungi and their autogenic microorganisms. However, in order to study the range and effectiveness of Busan 30 as a cereal seed treatment, tests were performed against individual species of selected genera. This paper reports the tests performed with Busan 30 on barley seed in soil infested with _Helminthosporium_ spp., on oat seed in _Pythium ultimum_ infested soil, and on wheat seed in _Rhizoctonia solani_ infested soil.

The soil infestation procedure consisted of growing the fungus for three days in approximately 2 (av) oz of wheat/lima-bean medium and preparing a suspension from one inoculated flask in 8.45 Br. fl. oz of water. The suspension was mixed with 1 Br. pint of sterile sand, which was incorporated into 4 Br. quarts of steamed soil. This mixture was placed in 10.75 x 7.75 in plastic boxes (crispers). To each crisper also was added about 0.7 (av) oz of oats infested with the specific fungus under study. The infested oats were prepared by boiling 0.88 Br. quarts of whole oat seed in enough water to flood the seed for 45 min. The seeds were autoclaved in flasks at 30 lb/in^2 (140°F) for 30 min on two successive days. The flasks of sterile oat seeds were inoculated with pure petri dish cultures of the fungus under study, and incubated for 3 to 5 days at 75°F before adding to the soil.

After addition of the infested oat seed, the crispers were closed and stored at 60°F for 24 h before planting. Busan 30 treated cereal seed was planted at the rate of 50 seeds per crisper, covered with fungus-infested soil, and incubated at 60°F for 3 days. The lids were removed and the crispers placed in the greenhouse for 12 days. Four replications were prepared for each treatment. Results were expressed as the percentage of the number of planted seeds which germinated and grew in a normal manner.

The fumigating action of Busan 30 was determined by placing forty infested seeds on ten petri dishes of sterile potato dextrose agar at a rate of four seeds per dish. Each petri dish was enclosed in a polyethylene bag containing 1 fl. oz of either Busan 30 or of water. Five of the bags contained Busan 30 while the other five contained water. The bags were sealed and maintained in the culture room at 75°F for 7 days. Profuse fungal and bacterial growth developed in the petri dishes enclosed in the polyethylene bags containing water.

RESULTS AND DISCUSSION

Viscosity

At -49°F, -40°F, -20°F, and 0°F, Busan 30 has a viscosity suitable for ready-mix type seed treaters. The average viscosities determined at these temperatures were 60.3, 48.3, 32.5, and 18.0 centipoises. No other changes in the physicochemical properties of Busan 30 were noticed at these temperatures. These properties of Busan 30 coincide with those required for liquid seed treatment to be used under cold climatic conditions in Canada and the United States of America.

Control of saprophytic fungi

Busan 30 treated and untreated seeds were plated on sterile potato dextrose agar. After 7 days, no mycelial growth was noticed on the petri dishes where the Busan 30 treated seeds were plated, whereas the petri dishes containing untreated seeds showed mycelial growth of several species of fungi. These observations confirmed that Busan 30 controlled the saprophytic fungi which impair the grain seed germination when their mycelial growth is enhanced by appropriate environmental conditions. The main saprophytic genera identified on the untreated cereal seed used were *Penicillium*, *Rhizopus*, *Nigrospora*, *Chaetomium*, *Aspergillus* and *Curvularia*.

Control of seed-borne diseases

Busan 30 is an effective seed treatment for the control of false loose (*Ustilago hordei*) and covered smut (*U. nigra*) of barley; loose (*U. avenae*) and covered smut (*U. kolleri*) of oats; and stinking smut or bunt (*Tilletia caries* and *T. foetida*) of wheat. Tables 1, 2, and 3 show examples of results from tests prepared with Busan 30 as a cereal seed treatment by Canadian Agricultural scientists. These data confirm the effectiveness of Busan 30 and the mercurial seed treatments for control of the smut diseases mentioned above.

Table 1

Barley seed treatment for control of false loose and covered smut

Treatment	Dosage Fl. oz/bushel of seed	Barley smut % diseased ears
Control	0.00	4.3
Control	0.00	3.6
Mercurial treatment	0.75	0.0
Busan 30	0.75	0.0
Busan 30	1.00	0.1

Table 2

Oat seed treatment for control of loose and covered smut

Treatment	Dosage Fl. oz/bushel of seed	Oat smut % diseased ears
Control	0.00	12.1
Control	0.00	9.9
Mercurial treatment	0.75	0.1
Busan 30	0.75	0.4
Busan 30	1.00	0.0

Table 3

Wheat seed treatment for control of wheat bunt

Treatment	Dosage Fl. oz/bushel of seed	Wheat Bunt % diseased ears
Control	0.00	16.9
Control	0.00	10.5
Mercurial treatment	0.75	0.1
Busan 30	0.75	0.8
Busan 30	1.00	0.3

Busan 30 also controlled pathogenic seed-borne fungi such as those in the genera Helminthosporium, Piricularia, and Gibberella. Members of the last two genera were pathogenic fungi found on rice seed.

Control of soil-borne diseases

Busan 30 can be used as a seed treatment on barley, oats, and wheat to protect the seed and seedlings against soil-borne fungi which impair germination and seedling development. In the tests on soil-borne pathogens, the fungi were grown under optimum conditions for their development. Their control by Busan 30 confirmed the effectiveness of this seed treatment. The main genera of soil-borne pathogenic fungi are Phythium, Helminthosporium, Rhizoctonia, and Fusarium. Tables 4, 5, and 6 show the effectiveness of Busan 30 for control of some of these genera which are believed to be the most important in Canada.

Table 4

Barley seed treatment for control of *Helminthosporium* spp.

Busan 30 dosage fl. oz/bushel of seed	% Seedlings growing in *Helminthosporium* spp. infested soil
0.00	69.5
0.75	91.5

Table 5

Oat seed treatment for control of *Pythium ultimum*

Busan 30 dosage fl. oz/bushel of seed	% Seedlings growing in *P. ultimum* infested soil
0.00	59.5
0.75	71.0

Table 6

Wheat seed treatment for control of *Rhizoctonia solani*

Busan 30 dosage fl. oz/bushel of seed	% Seedlings growing in *R. solani* infested soil
0.00	57.0
0.75	92.0

Other properties

Barley, oats, or wheat seed plated on sterile potato dextrose agar in the presence of Busan 30 vapours do not show any mycelial growth from saprophytic or pathogenic seed-borne fungi. Seed treaters do not coat each individual grain seed uniformly. For this reason, the fumigating action of a seed treatment is an important property for a successful commercial operation. Busan 30 and the mercurial seed treatments have this property.

Toxicological tests and experience gained while manufacturing Busan 30 and treating grain seeds have shown that it has a moderate toxicity when compared to many of the pesticides used in agricultural production. No objection has been raised to the use of Busan 30 as a seed treatment by either the Plant Product Division in Canada or the Pesticide Regulation Division in the U.S.A. Nevertheless, any product which is sufficiently toxic to be a good seed treatment should be handled with respect. The precautions recommended for handling pesticides are recommended for Busan 30.

Busan 30 has already been used under farm conditions at the dosage of 0.75 fl. oz/bushel of barley, oats, and wheat seed in Canada for two years.

NOTES

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PATTERNS AND PROCESSES OF MOVEMENT OF CHEMICALS IN HIGHER PLANTS

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Summary Solutes are translocated in higher plants either in the apoplast from the roots to the zones in the shoot from which water is lost, or in the symplast from areas where carbohydrates are synthesised to areas where they are used. Movement from the apoplast to the symplast may depend on specific carriers in the membranes bounding the protoplasm; it normally requires the expenditure of metabolic energy. The apoplast of the roots and the shoots do not seem to form a continuous system; at the endodermis of the root the bulk of the apoplastic flow seems to be diverted through the protoplasm. The significance of this and other features of the transport system are discussed.

Résumé La migration des solutés dans les plantes supérieures se fait soit dans l'apoplaste, des racines aux zones de la pousse d'où l'eau se perd, ou dans le symplaste, à partir des zones ou les hydrocarbones sont synthétisés, aux zones où elles sont utilisées. Le mouvement de l'apoplaste au symplaste peut dépendre d'agents transporteurs spécifiques présents dans les membranes voisines du protoplasme; normalement une perte d'énergie métabolique résulte de cette action. Les apoplastes des racines et celles des pousses ne semblent pas former un système continu; à l'endoderme de la racine, la plus grande partie du courant apoplastique semble être détournée au travers du protoplasme. La signification de ceci, et d'autres aspects du système de transport, sont examinés.

INTRODUCTION

This paper aims to outline general patterns of translocation in higher plants, as they might affect the use of systemic pesticides, and to collect scattered pieces of information related to one or two key areas of ignorance and use these to indicate possible lines of development. Translocation in plants has been surveyed recently (Crowdy 1972) and much of the information has been drawn from this survey.

APOPLASTIC MOVEMENT

Translocation in higher plants is conveniently considered as taking place in two main systems, the "apoplast" and the "symplast"; in each of these it shows its own characteristic features. The apoplast is outside the living protoplasm and comprises the free space in the cell walls and the lumen of the xylem; most of it is capable of exchanging material with the environment by diffusion. The free space was originally defined in terms of the movement of solutes in aqueous solution and refers to the extra-cellular water in the tissues; it does not include spaces filled with air. Movement in the apoplast is not directly related to metabolic activity and occurs passively along gradients of chemical potential. There are exceptions to this general statement, which will be reviewed by Dr. Shephard (1973), but these seem to relate more to special impediments to movement than to the mechanics of movement itself. The main gradients concerned in movement seem to be diffusion gradients within the tissues and between the plant and the environment, and differences in water potential which result in water loss from the leaves and its replacement by a mass flow via the transpiration stream from the roots. The major part of the apoplastic movement of solutes in the plant occurs in the transpiration stream. This flow of water carries with it mineral salts taken up from the soil, amino-acids synthesised in the roots and certain growth regulating chemicals; in addition, a number of foreign chemicals presented to the roots will also be transported. The main channel of this movement is the xylem, which is a network of dead tubes extending from the roots to the leaves. Analyses of xylem sap usually yield 0.1 to 0.4% solids. The xylem is not directly in contact with the outside, and, if it is exposed by damage, it is usually sealed rapidly. The xylem communicates with the free space, which also lies outside the living parts of the cell, in the cell walls; these are usually highly hydrated. There is free diffusion between the free space and the air and water outside the plant, though the rate of exchange can be regulated by the plant to a large extent. There is a good deal of evidence that the free space is not continuous throughout the plant. The free space of the root cortex seems to be separated from that of the rest of the plant by the endodermis. This is a single layer of cells which encloses the vascular tissue of the roots in regions which are surrounded by living cortex; it is well adapted as a barrier to movement in the cell walls at this point since the radial cell walls contain deposits, the Casparian strip, which render them impervious to water. Thus the influx of water from the root surface to the root xylem is largely diverted through the living protoplasm of the cell at this point.

The water solubility of the chemical must set a limit to the concentration which can be carried in this system. However, within this limit the structure of the free space and xylem condition the actual materials that they carry. We know very little about this in detail. There is evidence that cations are retained, especially in the xylem, and that there is ion-exchange capacity in the cell walls. There is also evidence that the lipoid-water partition of a chemical will influence its apoplastic movement.

Excessively lipoid-soluble or water-soluble chemicals may not move freely. There are some clues as to where the movement of some chemicals is impeded; retention of cations in the xylem can be demonstrated by perfusing appropriate solutions through detached segments of xylem. However, in other cases the position is not so clear. For example, both water-soluble compounds such as sodium phosphate or the chelate of lead and ethylene-diaminetetra-acetic acid and some more lipoid-soluble derivatives of griseofulvin tend not to be freely mobile from the roots. The last seem to accumulate in the roots and possibly partition from the transpiration stream into lipoid phases in or bounding the free space, while the water-soluble compounds may not be so readily accumulated and may actually diffuse out of the roots after they have been rejected at the endodermis. The distinctions between these two effects can be of practical importance since accumulated material may act as a reservoir.

The pattern of movement in the apoplast system is determined by the forces which maintain the transpiration stream. Movement is normally from the roots to the leaves, and in the leaves from the base to the tips or the margins. Ultimately solute may be leached by rain from the leaves and returned to the soil. In experiments the flow can be reversed by manipulating the water potentials; if one leaf of a transpiring plant is immersed in an aqueous solution, it will act as a source of water and solute in much the same way as a root, but much less efficiently. Many fruits do not lose water readily and hence do not tend to accumulate solute distributed in the apoplast. While it is not appropriate here to consider the soil, it should be noted that this is where the transpiration stream starts and the behaviour of an applied chemical in the soil may be as important as its behaviour in the plant. The soil may act as a reservoir for insoluble chemicals such as the herbicides simazine or diuron and Graham-Bryce and Coutts (1971) have suggested that the fungicides ethirimol and dimethirimol may be adsorbed in the soil and released slowly to the plant.

SYMPLASTIC MOVEMENT

The protoplasts of living cells are connected through the cell walls via the plasmadesmata to form a continuous network, and this is generally referred to as the symplast. A chemical passing from the apoplast to the symplast must cross the plasmalemma, the membrane which bounds the outside of the protoplast network. Movement from the protoplast into the cell vacuole involves crossing a second membrane, the tonoplast. These membranes are complex and our knowledge of their structure has recently been reviewed by Branton (1969). They appear to have a hydrophilic surface, probably of protein and a hydrophobic centre of appropriately oriented phospholipids. At intervals they appear to be penetrated by protein structures. These membranes are readily traversed by water, possibly via hydrophilic 'pores', but solutes only cross them slowly if passive diffusion processes are involved. Some solutes are actively transferred across these membranes and, with the expenditure of metabolic energy, hypertonic solutions of these solutes can be maintained within the cell. This transfer is commonly attributed to carrier systems and the proteins which extend through the membrane are thought to be involved. The capacity of a membrane to transfer a solute is limited since the carriers become saturated at high concentrations of the material transported. Sodium and potassium are probably transferred by different carriers, but rubidium will share the potassium carrier; similarily, chloride and sulphate require different carriers, but the chloride carrier will also carry other halides. Similar carrier systems seem to operate when organic chemicals enter the cell. This has been shown, for example, with uracil and the related maleic hydrazide, which appear to compete for the same carrier system. (Coupland and Peel, 1972.) A plant is unlikely to develop a specific carrier mechanism for a foreign chemical completely unrelated to its natural products. This suggests that effective symplastic transport may be restricted to foreign chemicals which resemble closely materials naturally entering and transferred in the symplast.

Long distance transport in the symplast takes place in trains of cells in the phloem, the sieve tubes. Phloem transport is mainly concerned with the removal of carbohydrate from the areas of synthesis, usually the leaves, and its distribution through the plant to the zones where it is required for growth, metabolism or storage. The phloem sap is a relatively concentrated solution, containing 10% to 25% dry matter, most of which is sucrose, other sugars and sugar alcohols may occur and there are small quantities of mineral salts, amino acids and hormones. The phloem is a distribution system as well as a pathway for long distance transport so one can expect loss and addition of material to the solution flowing through it. Our understanding of the mechanisms of movement in the phloem is confused, despite years of study. However, studies with radio-active tracers have provided a fairly complete picture of the patterns of movement, and indicate a flow, particularly of carbohydrates, from sources of supply to sinks where the material is used. The concept of sources and sinks is simple, but it is seldom easy to define the actual sources and sinks and the patterns of movement may be complex. Foreign chemicals, such as the hormone herbicides, seem to follow the general pattern of carbohydrate movement; they may remain immobile if no carbohydrate is moving. The range of chemicals which move in the phloem is restricted, probably to those which can be actively transferred from the apoplast to the symplast. Relatively large amounts of material are translocated in the phloem and this requires special structures, transfer cells, in which the surface of the protoplast is extended by ingrowths of the cell wall, at the points of loading and unloading. The main loading area in the leaf is associated with the phloem of the minor veins.

THE ENDODERMIS

The endodermis seems to be the one zone in which movement in the apoplast is interrupted; at this tissue movement through the symplast may be compulsory. Since entry into the symplast is more selective than entry into the apoplast, the endodermis probably provides the main selective filter controlling the solutes which enter the plant. For this reason alone it deserves some detailed consideration. Unfortunately, the endodermis is a single layer of cells buried deep in the root tissue and is not available for direct study. However, most of its special properties seem related to the fact that it is a living tissue and its behaviour can be inferred from the behaviour of other living plant cells. Certain algal species, notably *Valonia*, have giant cells which may measure 40 to 60 mm in length and 0.4 to 0.6 mm in thickness; they are large enough to handle singly and have sufficient vacuolar sap to permit chemical analysis or bioassay. These have proved valuable in the study of movement across plant cell membranes.

There is evidence that the endodermis acts as a semipermeable membrane and probably mediates the accumulation of certain solutes in the vascular cylinder actively against a concentration gradient. Semipermeability and a capacity for active uptake are both properties of living membranes and might be expected in a tissue in which the water-permeable pathways are occluded with living membranes. Transport across the endodermis probably presents no problems for chemicals which are normally translocated in the symplast, since there will be the appropriate systems for active uptake; these chemicals could even be accumulated against a concentration gradient, as are certain salts. This is illustrated by data derived from Bange and Vliet (1961), Table I, which compare the uptake and distribution of potassium, which is freely taken up and distributed in the symplast, with that of sodium, which, normally, is not. There were only minor differences in the absorption of sodium associated with the presence or absence of potassium.

Table 1

Uptake and distribution of sodium and potassium, applied as phosphates at pH6, in maize

Treatment (m.eq/l.)		Location in plant	Concn in plant (m.eq/g d.m.) after			
			12 h in treating solution		12 h in treating solution then 12 h in water	
K	Na		K	Na	K	Na
0.1	2.0	Total	0.4	0.24	0.4	0.24
		root	0.15	0.23	0.11	0.23
		shoot	0.25	0.01	0.29	0.01
2.0		Total	0.6		0.6	
		root	0.29		0.2	
		shoot	0.31		0.4	

During the initial 12 hour treatment the entry of potassium into the plant is roughly double that of sodium, when they are applied at the same concentration; even when the potassium concentration is smaller by a factor of 20 times, more potassium is taken in. Further, while the sodium is practically confined to the roots, about half the potassium is transferred to the shoots and this transfer continues when the supply has been removed. These data show also that the active transport systems operate more efficiently in low concentrations and tend to saturate as the concentration increases.

Chemicals which are not actively transferred, the bulk of chemicals available, probably rely on particular physical properties for traversing living membranes. Here data from cells of Valonia species are of interest. Pramer (1955, 1956) used this system to compare the uptake of streptomycin and chloramphenicol. Streptomycin was accumulated actively against a concentration gradient and reached a concentration seven times that of the external solution in 18 hours, while chloramphenicol seemed to diffuse in slowly and only reached a concentration of 50% of the external solution in 34 hours. Collander (1954) and his associates studied the diffusion of 70 assorted chemicals into Valonia cells. These ranged from deuterium hydroxide and ethyl acetate to glycerol and pentaerythritol. All were relatively hydrophilic. Within quite narrow limits the rate of diffusion into the cell was directly proportional to the logarithm of the partition coefficient of the chemical between either diethylether or olive oil, and water.

RETENTION IN THE ROOTS

Selective penetration at the endodermis may partly explain the accumulation of chemicals in roots, but there is some evidence that lipoid-soluble chemicals partition out of the water phase in the roots. Crowdy et al. (1956), working with griseofulvin, showed that the concentration in the roots stabilised in about 35 minutes at levels above that in the treating solution. This accumulation occurred as readily if the shoots were present or not, and so was independent of the transpirational water flow. This retention in the roots also seems to be related to lipoid-water partition.

Fig. 1 is derived from Crowdy et al. (1959) and refers to a series of griseofulvin derivatives. The graph relates the proportion of the total chemical recovered in the plant which was found in the shoot to the logarithm of the partition coefficient between hexane and water. These points also fall on a straight line, but the amount translocated is inversely proportional to the partition coefficient. One compound, 7-chloro-4', 6'-dihydroxy-4, 6-dimethoxy-2'-methylgrisan-3-one, shown as a star in the figure, is markedly aberrant and shows both a low content in the shoots and a low partition coefficient. The low concentration in the shoots could reflect breakdown in the plant, or it may illustrate the relative difficulty with which water-soluble compounds are translocated. This poor transfer has already been noted for sodium and was also shown by the lead-EDTA chelate, which appeared to be retained at the endodermis (Tanton and Crowdy, 1972), and may be related to Collander's results with Valonia cells. If one is prepared to accept this point as a basis for speculation, it implies an optimum partition coefficient and selection against excessively water-soluble or lipoid-soluble chemicals. It would be interesting to discover the optimum value of this coefficient and decide whether it differed for different types of chemical, or different plants.

Whatever the reason, different plant species differ in their ability to translocate the same chemical. Pramer (1954) noted that streptomycin was translocated to a limited extent to the shoots of tomato, which had been treated via their roots for 14 hours, but was absent from the shoots of broad bean similarly treated. If the roots were cut off, movement was improved in tomato and occurred to a limited

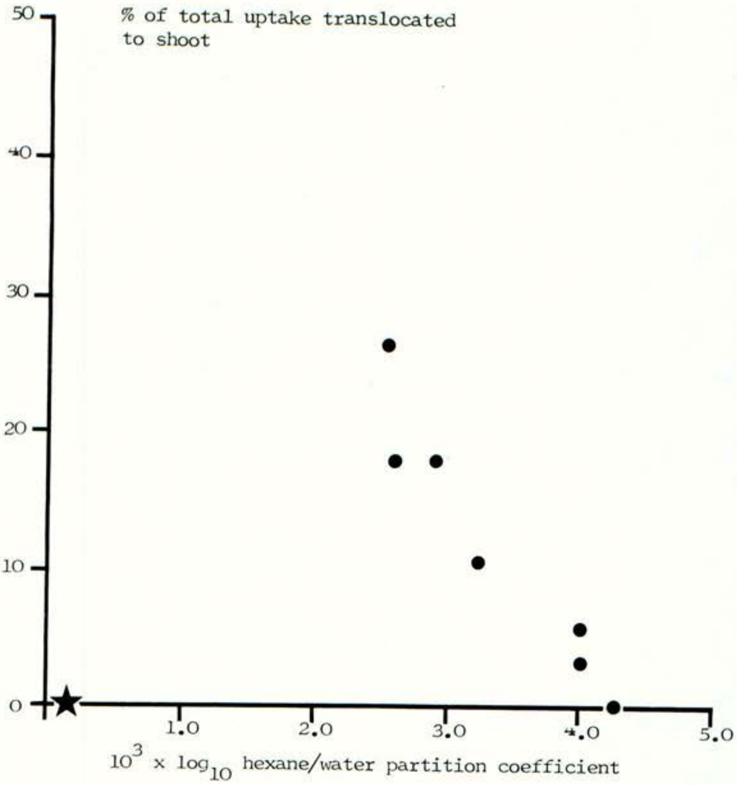

Fig. 1 Translocation of griseofulvin derivatives to the shoots of broad beans. (after Crowdy et al. 1959)

extent in broad bean. Even after prolonged treatment via the roots (10 to 14 days) no streptomycin could be assessed in the expressed leaf sap of broad bean, while it was recorded in the leaf sap of tomato, lettuce, cabbage and wheat (Crowdy and Pramer, 1955). Similar differences have been recorded for the movement of the xylem-mobile herbicides atrazine and linuron (Walker and Featherstone, 1973). Some of these results are summarised in Table 2.

It is worth noting, however, that retention in the roots is not necessarily a disadvantage. Material accumulated in this way can serve as a reservoir when the source of supply is removed. All the griseofulvin accumulated in roots of bean plants was transferred to the shoot when the griseofulvin round the roots was replaced by water (Crowdy et al. 1956). In similar circumstances lead-EDTA chelate is released from dead root tissue and transferred to the shoot; this is illustrated in Table 3, which is derived from Crowdy and Tanton (1970).

These admittedly are limited observations but do seem to indicate an effect which should be more thoroughly investigated as part of the optimum pattern of uptake and distribution of systemic pesticides.

Table 2

Translocation of atrazine and linuron in different plant species

Plant species	Average concn in translocation stream as percentage of concn in treating solution	
	atrazine	linuron
Parsnip	36	12
Carrot	36	20
Lettuce	74	50
Turnip	74	74

Table 3

Accumulation of lead-EDTA chelate in the roots of wheat seedlings and its later transfer to the shoots

Treatment (0.025M lead-EDTA chelate in culture solution)	Concn of lead-EDTA chelate (µg/g fresh wt)	
	roots	shoots
lead-EDTA, 24 h	235	262
lead-EDTA, 24 h followed by water, 24 h	117.5	430

DISCUSSION

Pesticides are known which move either in the phloem, or in the xylem, or in both systems. The growth-regulating herbicides are typically transported in the phloem; movement seems to follow the assimilate stream from source to sink, and is inhibited by anoxia and by metabolic inhibitors. This pattern of movement is also shown by some of the substituted benzoic acids, dalapon and amitrol and a number of systemic insecticides. The speed and freedom of movement in the phloem vary with the chemical; 2, 4-D is only transported at about half the speed of indolylacetic acid. Some chemicals are translocated particularly readily to the roots. Methoxyphenylacetic acid and some of the substituted benzoic acids may even be released from the roots into the surrounding medium in sufficient quantities to allow transfer to adjacent plants. This pattern of movement is clearly of interest from many points of view and admits the possibility of treating root diseases with sprays. However, phloem movement in general carries its risks since the valuable parts of the plant are frequently the storage organs and these constitute major sinks for materials transported in the phloem. Phloem-transported chemicals should, therefore, be degraded quite readily in the plant and this may reduce their efficiency.

Chemicals entering into the symplast probably have to exploit specific carrier systems developed for normal metabolites; logical progress would seem to depend on a much deeper knowledge of the properties which favour the loading and movement of these normal plant constituents. A more empirical approach through modifying chemicals which are known to be transported in the phloem only occasionally seems to yield results.

Chemicals mobile in the apoplast are probably easier to find and may be less likely to accumulate in fruit or storage organs when these do not lose water readily; Peterson and Edgington (1971) have demonstrated that benomyl is not transported to tomato fruit. This comparative safety is bought at the expense of a capacity for redistribution within the plant. Apoplastic movement takes place normally only from the roots to the leaves on the transpiration stream; within the leaves, movement is only to the edges or the tips. This means that a pesticide will not reach tissues which have grown after the plant is sprayed or after supplies to the root have been exhausted and, further, that the pesticide may be washed from areas which were protected while treatment was continuing. There seem to be at least two ways of tackling these difficulties associated with chemicals translocated in the apoplast: the simpler is probably to explore the possibility of selecting chemicals which are retained reversibly in the roots or in the soil surrounding the roots and which would be released when the concentration in the transpiration stream falls, thus providing a reservoir. The second might be to search for chemicals which are specifically retained in the organs at risk.

This discussion must have made it clear that we lack almost all the basic knowledge which we need to design or use efficient systemic pesticides. We are probably only scratching the surface of the potential value of these chemicals in the present state of our knowledge.

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NOTES

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BARRIERS TO THE UPTAKE AND TRANSLOCATION OF CHEMICALS IN HERBACEOUS AND WOODY PLANTS

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Summary Evidence is presented for the existence of barriers which limit the uptake and translocation of chemicals in the roots, stems and leaves of plants. The concentration of several pyrimidines decreased as the solution supplied to the roots entered and moved through the plant. Different species behaved in different ways. Apple and vine accumulated the compounds in their roots whereas wheat and cucumber, did not. In these plants accumulation of the pyrimidines in the roots was correlated with poor translocation. The passage of compounds through the xylem of woody stems resulted in a decrease in concentration, which varied with the chemical and the host species. Entry into the foliage through the cuticle and movement in a leaf were subject to similar selective processes.

Résumé Évidence est présentée pour l'existence de barrières qui limitent l'absorption et la migration des pesticides par les racines, les pousses et les feuilles de plantes. La concentration de plusieurs pyrimidines diminue quand la solution offrie aux racines pénétrait et était transportée dans la plante. Les espèces differentes se comportaient aux manières differentes. Les pommiers et les vignes, accumulaient les substances dans leur racines, tandis que le blè et le concombre ne les accumulaient pas. Il y était une correlation manifeste entre l'accumulation des pyrimidines dans les racines et le mouvement pauvre les pousses. Le transport des substances dans le xyleme des tiges boisées resultait assi à une diminution de concentration qui variait avec la substance et l'espèce de plante. La pénétration du feuillage à travers le cuticle et la migration dans la feuille étaient exposées aux semblables precédés sélectifs.

INTRODUCTION

The pathways for translocation in plants have been described by Crowdy (1973). In general, materials are transported from areas of surplus to areas of transpiration growth or storage. 'Unnatural' compounds introduced into these pathways, if not impeded, might be expected to follow the stream and be carried to the same destination as the natural materials. In practice, however, it is rare to find two compounds which are translocated in exactly the same way. Most 'unnatural' compounds encounter barriers within the plant which restrict translocation and influence the pattern of accumulation.

The nature and position of these barriers is not well understood although Crafts and Yamaguchi (1960), Shephard (1971), Erwin (1971), Cavell _et al_ (1971), and Crowdy (1973) have all found evidence for their existence.

This paper examines evidence for the existence of barriers in different parts of the plant. The evidence is taken mainly from recent work with fungicides, and in particular a group of pyrimidines studied by the author. It also includes observations on the patterns of phytotoxicity of a large group of miscellaneous compounds applied to three crop species.

In all experiments the chemicals were applied directly to the appropriate part of the plant under standard conditions. Movement through root, stem and leaf are considered separately.

MOVEMENT THROUGH ROOTS

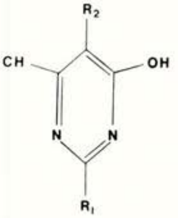
The uptake and translocation of about 2000 miscellaneous compounds was studied by observing the patterns of phytotoxicity observed when the chemicals were applied, at rates of up to 500 ppm., to the roots 2-3 week old cucumber, apple and vine seedlings growing in nutrient solution. It was considered that a region of damage indicated a region of accumulation.

Some compounds accumulated at the margins of the transpiring leaves where they caused marginal necrosis. A few accumulated in and damaged the youngest leaves. Others caused interveinal spotting of the leaves, damage near the veins, collapse of petiole or stem, or death of the roots, according to the region in which the compound accumulated to a toxic level. Considerable differences were noted between species. In general, marginal damage to the leaves occurred more frequently in cucumber than apple, with vines intermediate. It was rare to find a compound which damaged the leaves of one of the woody species but only damaged the roots of cucumber. Compounds with a variety of molecular structures and physical properties appeared to be able to move through the roots and cause damage to the shoots.

When the systemic fungicides dimethirimol and ethirimol were included in this test they were found to accumulate at the margins of the leaves of cucumber and, when the rate was high enough, necrosis occurred. The same compounds on apple seedlings rarely produced any foliar damage but severely damaged the roots. Autoradiographs subsequently confirmed that the compounds accumulated in the regions where damage had occurred (Cavell _et al_ 1971).

A study using a group of ^{14}C labelled pyrimidines (see Fig. 1) showed that these were all more freely translocated in cucumber than in

FIG. 1.



Comp.	Substituent	
	R_1	R_2
A	$NHCH_3$	nC_4H_9
B	NHC_2H_5	..
C	$N(CH_3)_2$	..
D	..	nC_5H_{11}

B = ethirimol
C = dimethirimol

apple, and that all were restricted to the roots and the veins of the lower leaves of the apple. Quantitative measurements of uptake over 48 hr., using 3-4 week old cucumber and apple seedlings growing in a controlled environment, in nutrient solutions containing 4 ppm of the compound, indicated that movement may be seriously impeded in this relatively simple system (Table 1). When uptake was expressed as a proportion of that which would have been taken up, assuming unimpeded entry with the water transpired, it was found that there was considerable exclusion by the roots. The proportion entering (ambient to root in Table 1) differed with host species and compound, but was generally below 50%. The proportion of each compound which having entered the root was transferred to the shoot within the 48 hr. treatment period was also less than unity. For each compound transference was appreciably larger for cucumber than for apple and there were again appreciable differences between compounds (root to stem Table 1). The two factors were cumulative so that the concentrations entering the base of the stem were only a small fraction of those in the ambient solutions (ambient to stem Table 1). Similar reductions in the concentration of ethirimol as it passed through the roots of barley were found by Shone (1973).

From the data available it appears that at least two different and highly selective barriers were impeding movement through a few centimetres of root to the base of the stem.

Treatment of isolated root systems with a solution of labelled ethirimol plus nutrients resulted in high levels of accumulation in apple and vine but not in cucumber and wheat (Fig. 2). When the roots were transferred from the ethirimol solution to successive aliquots of deionised water, most of the ethirimol was eluted from both species. The rate of elution from

Table 1

Movement of pyrimidines from the ambient solution to the roots and stems of cucumber and apple seedlings

Movement from	Host	Proportion moved in 48 hr.•			
		Compound (see Fig.1)			
		A	B	C	D
Ambient solution to root	apple	17	19	34	51
	cucumber	33	-	43	36
Root to stem	apple	31	35	46	48
	cucumber	46	-	82	75
Ambient solution to stem	apple	5	7	16	25
	cucumber	15	-	35	27

•Observed ^{14}C, expressed as a percentage of that theoretically available assuming unimpeded flow with the water transpired.

FIG. 2. UPTAKE OF ETHIRIMOL BY EXCISED ROOTS

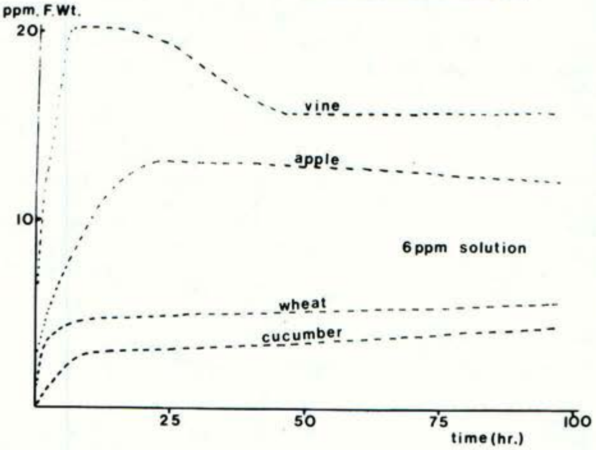
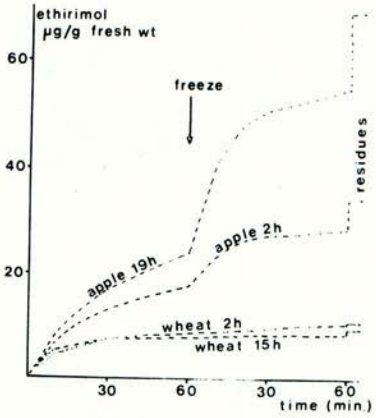


FIG. 3. ELUTION OF ETHIRIMOL FROM EXCISED ROOTS



2h, 15h, 19h = 2, 15, or 19 hours uptake

Table 2

Accumulation in excised apple roots

Compound+	Conc. in roots•	
	1 hr	5 hr
A	8·0	19·8
B	11·4	17·5
C	14·5	32·8
D	22·4	26·3

•ppm. fresh weight
(4 ppm ambient solution was used)
+ See Fig.1.

apple roots was increased by freezing and thawing (Fig 3), indicating that some of the accumulated material was probably on or within membranes. All four pyrimidines accumulated in apple roots to an overall concentration well above that of the ambient solution (Table 2), the rate of uptake being lowest for compound A.

MOVEMENT THROUGH STEMS

The restriction of the pyrimidines to the stem and veins of the lower leaves of the apple compared with a free permeation of the whole shoot of the cucumber has already been mentioned (Cavell *et al* 1971). This suggested that further barriers were impeding the movement of compounds which had reached the base of the stem.

To assess the extent of possible losses during translocation through the stem, labelled compounds were drawn through 11 or 22 cm. lengths of one year old dormant vine, apple or elm wood, with a peristaltic pump. Chemicals of four different types were put through this system. The effluent from the stems was sampled at intervals and its concentration expressed as a percentage of that supplied at the other end.

The maximum concentration of the effluent was always less than that supplied. With a 22 cm. piece of vine wood and two compounds E. and F.•, both of which had appeared by bioassay to be freely translocated through this species, the concentration was reduced to approximately 70% of that supplied (Fig 4). The concentration of compound E. in the effluent from apple and elm was reduced to an even lower level (Fig 5), but this increased gradually throughout the period of sampling.

•coded experimental materials, structure not available.

FIG. 4. TRANSLOCATION THROUGH WOODY STEMS

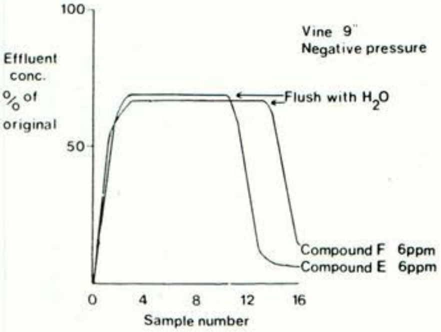
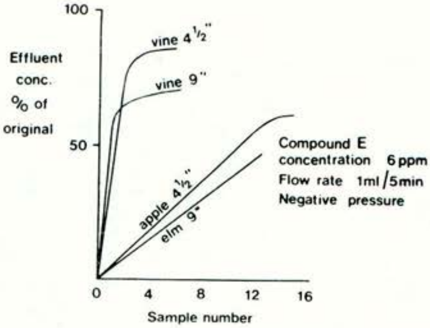


FIG. 5. TRANSLOCATION THROUGH WOODY STEMS



Note: 4½" and 9" indicate 11 cm and 22 cm lengths of stem

The concentration of effluent was also dependent on the length of stem through which it had passed. When some of the pyrimidines used in the earlier studies were fed into apple stems,barely detectable quantities of label emerged from the other end.

There are thus very effective barriers to translocation in some woody stems which again vary with the species and the compounds to be moved. Comparable studies have not yet been done with herbaceous stems, but it is assumed that as some of the pyrimidines control mildew on leaves which may be more than two metres from the point of application on a cucumber plant, they must be translocated through the stem of this species fairly freely.

MOVEMENT IN LEAVES

The structures which confront a spray droplet arriving on a leaf surface have been reviewed by Crowdy (1972). Little is known of the penetration of the outer wax layers because these cannot be isolated without destroying their configuration. Suffice to say that they are largely impervious to water and the main avenues for penetration probably lie in the gaps between the wax platelets. A recent study by Solel and Edgington (1973) has shown that the residual cuticular membrane, prepared by treatment of apple leaf discs with zinc chloride and hydrochloric acid, behaved as a highly selective barrier to the penetration of a number of fungicides, including benomyl (methyl(1-butylcarbamoyl)-benzimidazol-2-yl-carbamate) and MBC (Table 3).

A recent study of the uptake and translocation of foliar applied benomyl and MBC, on cucumber and beans, by Upham and Delp (1973) also indicated differences in the penetration of these two compounds, a decrease in uptake as the leaves aged and an increase in uptake with the addition

Table 3

Penetration of cuticular membranes by fungicides•

Compound	Dose applied (n M.)	% penetration	
		Adaxial cuticle	Abaxial cuticle
thiophanate-methyl	3·3	56	87
benomyl	3·3	28	65
methyl-2-benzimidazole-carbamate (MBC)	3·3	8	17
dodine	17·4	0	traces

• data from Solel & Edgington 1973

of a surfactant. Observation of the translocation after penetration indicated that both materials moved with the transpiration stream towards the leaf margin, but MBC moved less readily than benomyl.

The author's observations of disease control on leaves where part of the surface had been treated and part left untreated indicated that chemicals did not behave in the same way in different species. Both dimethirimol and benomyl, when applied to the proximal half of a cucumber leaf readily controlled powdery mildew on the distal area. When applied to apple leaves in a similar test the same compounds controlled mildew only on the treated area. Upham and Delp (1973) also noted that uptake and translocation of benomyl and MBC occurred more freely in cucumber than in the bean.

All compounds applied to leaves did not move across them to the margin. Some produced local phytotoxicity at the point of application e.g. certain oils. More rarely, a compound did not damage the leaf to which it was applied, except at high concentration, but was translocated to and damaged the younger leaves e.g. amitrole. The latter compound is known to move via the phloem to both roots and young leaves (Crafts 1961).

The retention of the pyrimidines in the region of the veins of apples following root treatment has already been noted. The experimental compound F., in contrast, moved through the apple leaves to accumulate at the leaf margin. Similarly, 2,6,-dichlorobenzamide was found by Leach et al (1971) to accumulate at the margin of apple leaves following root treatment.

The fate of a chemical entering a leaf via the petiole or through the cuticle therefore again depends on both the type of chemical and the species to which it has been applied.

DISCUSSION

It is clear from the fore-going that barriers to uptake and translocation occur in most parts of the plant.

The evidence presented has been taken from experiments in which the availability of the chemical to the plant was known to be good. However, it should be noted that, in a crop protection situation, initial contact may be difficult to achieve and the environmental conditions around the roots or leaves may not favour uptake over a prolonged period. The first and often the most important 'barrier' may therefore be outside the plant.

The study of the patterns of phytotoxicity indicated that different compounds accumulated in different regions of the plant and that the same compound might accumulate in different places in different plants. The difficulty in interpreting data of this type must not be minimised,but the observations with a limited number of labelled compounds showed that the correlation between patterns of phytotoxicity and accumulation was good. If the zones of accumulation indicated the position of barriers, then these occurred in almost every part of the plant and were more formidable in the apple than in the cucumber.

In the roots of apple and cucumber there appeared to be at least two barriers, one controlling entry into the root and a second controlling translocation to the base of the stem. If the system were further subdivided the position of these barriers should become clearer. The barriers in different plants differ in their nature because entry of the pyrimidines into the roots of cucumber was relatively non-selective whereas entry into apple roots was highly selective. In contrast, translocation to the stem was much more selective in the cucumber than in the apple.

The fact that the pyrimidines accumulated in the roots of apple and vine, where overall translocation was relatively poor, but not in the roots of cucumber and wheat, where translocation was good, may be significant. Most of the accumulated material could be eluted into water and was therefore potentially available for translocation. It was likely that the compounds were partitioning in to cell components for which they had a particularly high affinity and that the overall concentration in the tissue was consequently much higher than that generally available for translocation. The tannin containing cells, which were common in the region of the vascular tissue of apple and vine, but not of cucumber and wheat, provide possible sites for this accumulation.

Although all four pyrimidines accumulated in the roots of apple, the rates of accumulation differed (Table 2). If this reflected differences in the rate of penetration of the cell membranes, corresponding differences might also be expected in the rate of penetration of the endodermis. In this connection it should be noted that compound A., with the lowest rate of accumulation also had the poorest translocation through the roots of both species (Table 1).

When compounds were fed directly into the cut end of a short piece of stem, it might have been expected that the barriers to translocation would be minimal, particularly in a stem like the vine with its large vessels. It was therefore surprising to find that considerable reductions in concentration occurred during the passage of relatively mobile compounds along a short length of stem. The rapid build-up in concentration of the effluent to its final maximum (Fig 4) suggested that the influence of the vessel walls was probably slight and that the losses were due to continuous accumulation in some other tissue. The slower build-up in the concentration of the effluent from the apple and elm suggested a gradual saturation of adsorption sites in these species. It is not clear whether this accumulation was solely in the walls of the conducting elements of the xylem, or whether it extended into the surrounding tissue. The failure of the pyrimidines to pass through a short length of apple stem indicated the possible strength of the barriers to translocation in this region.

In the leaf a chemical may move along one or more of three possible pathways; viz. it may move with the transpiration stream to the leaf margin; or into the symplast of the leaf cells; or via the symplast into the phloem and thence to other parts of the plant. Relatively few of the miscellaneous compounds, and none of the compounds examined in detail by the author, were translocated in the phloem. The general features of movement in the phloem have recently been reviewed by Crowdy (1972). The observation by Crisp (1971) of the preponderance of 'acidic' compounds among those compounds which are moved in the phloem way give a clue to some of the physical requirements of the system, but it appears that the method of entry into the phloem, and the type of compounds which can enter, is still a matter of debate.

Movement of the experimental materials along the leaf or into the leaf cells appeared to follow roughly the same pattern as in other parts of the plant. Relatively free movement of the pyrimidines and benzimidazoles occurred in cucumber leaves whereas little or no movement took place in apples. However, within the leaf of the cucumber, where relatively free movement occurred, Upham and Delp (1973) found differences in the extent of movement of different compounds, indicating that even here selective barriers still exist.

It appears that almost every tissue of the plant exerts a selective effect on both the type of chemicals and the quantity which pass through it. Some plants seem to have a built-in factor which makes translocation of certain types of compound difficult e.g. the pyrimidines in apple. However the fact that some compounds are still translocated relatively freely in apple indicates that even a built-in factor may not be insuperable.

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THE STRATEGY OF GLASSHOUSE PEST CONTROL

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Summary The main factors currently limiting the efficiency of pesticides for the control of glasshouse pests are discussed. The strategic response to these difficulties must be the use of biological control for those pests in which pesticides have readily selected resistant strains.

Some of the problems of integrating management programmes for these natural organisms, which must operate very precisely on such high-value crops, with the chemical control of diseases and minor pests, are outlined.

The need for continuous evaluation of the impact of new pesticides and cultural improvements on these integrated control procedures is stressed.

Sommaire On débat les facteurs principaux qui restreignent l'efficacité des pesticides pour le contrôle des insectes nuisibles dans les serres. La réponse stratégique à ces difficultés doit se trouver par l'usage d'un contrôle biologique des insectes chez lesquels les pesticides ont aisément sélectionné des souches résistantes.

On ébauche quelques uns des problèmes associés à l'intégration de programmes de maîtrise de ces organismes naturels, qui doivent opérer avec précision sur des récoltes d'une valeur si importante, avec le contrôle chimique des maladies et des insectes nuisibles mineurs.

On insiste sur la nécessité d'évaluer continuellement l'impact des pesticides nouveaux et de l'amélioration des cultures sur ces procédés de contrôle intégré.

INTRODUCTION

For many years it has been customary to provide 'controls' for specific pests which, while biologically efficient, take into account only phytotoxic risk to the host plant and relative cost. Recently, and increasingly, it has become necessary to consider much wider issues and to develop the concept of what we now call integrated control. It is the purpose of this paper to draw attention to the factors now affecting pest control within glasshouses and to outline the strategic considerations which should govern the selection of particular techniques.

LIMITING FACTORS IN GLASSHOUSE PEST CONTROL

(a) Resistance

Since the early 1950's the selection of strains resistant to pesticides has increasingly limited the choice of the control procedure. Following tolerance to OP acaricides by the Glasshouse Red Spider Mite (Tetranychus urticae) strains resistant to OC compounds soon appeared and at frequent intervals during the past decade growers in different countries have complained justifiably that mites on their nurseries were tolerant to all the acaricides commercially available. The only exception was petroleum oil which, of course, kills mites by physically blocking the breathing pores - though even this material has limitations to which I shall refer later. Resistance has since appeared in other pest groups including whiteflies (Trialeurodes vaporariorum), the peach-potato aphid Myzus persicae and the chrysanthemum leaf-miner Phytomyza syngenesiae.

A vast research effort has been concentrated on resistance during the past twenty years but it is a salutary fact that while the genetic mechanisms controlling its inheritance and the biochemical pathways by which different types of resistance become effective are widely understood, it remains difficult to advise the grower how to circumvent resistance. Prof. A.W.A. Brown has said that 'resistance is a one way street' - this useful phrase is nowhere more true than under glass where growers can frequently point out certain areas of their houses in which resistant mites are consistently found from year to year.

The inevitability implicit in Prof. Brown's statement appears to be supported by the occurrence of resistance wherever control of the pest demands an intensive routine spray programme. Avoidance of resistance by alternating active ingredients or utilising mixtures of pesticides with different modes of action has not been studied in any convincing manner by research workers though grower experience would suggest that the inevitability of the process is, at the most, delayed.

In these circumstances, a purely chemical solution to the problem depends on the ingenuity of the chemical industry to produce new materials with novel modes of action. However, their very high development costs must lead to a reduction in the flow of alternative products which the grower has come to expect during the past decade.

(b) Phytotoxicity

Spray damage to plants has, of course, always been a matter of some concern but recent trends have markedly increased the problem. In Europe the competition between glasshouse produce and that grown outdoors and transported from more amenable climates has tended to make production under glass more profitable 'out of season'. This has been achieved by very early planting in low winter light - a factor which has been counteracted to some extent by supplementing the glasshouse environment with carbon dioxide. This practice improves plant growth at the expense of producing soft, vegetative growth which is readily subject to damage by pesticide sprays. Since there is such a marked correlation between phytotoxicity and both the light intensity and its duration at, and immediately after, the time of application, it is difficult to predict damage or perhaps, what is more important, guarantee that a given treatment will be harmless.

Work on biological control has revealed other, previously unsuspected, phytotoxic hazards. The use of Phytoseiulus persimilis to control red spider mite on cucumbers enabled comparisons between sprayed and unsprayed crops to be made. Both small-scale replicated experiments and commercial glasshouse trials confirmed that even though the foliage showed no phytotoxic symptoms, crops sprayed with petroleum oils and other acaricides consistently yielded 10% less than those unsprayed. Some cucumber growers who were accustomed to applying more than twenty sprays per season, the 1962 U.K. average was 13, claim yield increases of more than 20% when chemicals were not used. Similar unquantified effects have been observed in the flower quality of unsprayed year-round chrysanthemums and even in the rooting of cuttings taken from unsprayed stock plants.

The trend in W. Europe for a dramatic increase in flat dwelling is almost certain to increase the demand in both quantity and variety of ornamental pot plants. These subjects, which often have coloured foliage or require treatment when in bloom, are very vulnerable to damage thereby restricting the range of suitable pesticides.

(c) Labour

The third trend in glasshouse culture which is imposing increasing limitations on pest control practice is the reduction in the labour force. Increasingly, business management techniques are used to control larger nurseries under the guise of efficiency and financial accountability. I am not criticising these techniques as such but the accountant is rarely a biologist and it is regrettably becoming painfully apparent in large-scale horticulture that management decisions, admirable in their own right, are often imposing unreasonable constraints on the biological system. As the labour force is reduced yield per plant falls only to be compensated by larger growing areas. Pest control is only possible by quick, ultra low volume applications which,with the relatively immobile glasshouse pests living largely on the lower leaf-surfaces, give indifferent control. The recommended application frequencies take little account of these limitations and are rarely related to the time-scale of the life-cycle in the particular cropping situation. As a broad generalization I think it should be appreciated that unless the pesticide is volatile or translaminar in action, low volume application is inefficient, indeed ineffective, since almost all the pesticide is deposited on the upper leaf surfaces which are rarely traversed by the pests when these are present in low numbers.

These three limitations on pesticide usage demand a less haphazard approach to pest control with a much reduced and more selective programme in the future.

THE STRATEGIC RESPONSE

Any programme considering a reduction in spray application must be based upon a sound knowledge of the interaction between the pest and its host-plant. It is, of course, essential to establish the economic damage threshold for the pest so that a chemical control programme can be designed simply to maintain the population below a damaging level. Given an efficient material, this approach can reduce the number of acaricide applications on cucumbers from 13 (national average in 1962) to 5.

Other aspects of the interrelationship between pest and plant which have to be considered include those behavioural changes on the part of the pest which have sudden and important effects on control. The apical migration of low numbers of the peach-potato aphid to the swelling buds of chrysanthemum or that of glasshouse red spider mite to the youngest leaves of cucumbers at about the summer solstice are typical examples of the need to control seemingly insignificant populations at critical times.

It seems entirely appropriate to seek non-chemical control methods for those pests which have shown sufficient genetic plasticity for the rapid selection of tolerant strains by conventional pesticide treatments. Techniques are now sufficiently well established by our work at the G.C.R.I. to argue that there is no substitute for the concept that successful biological control by introduced natural enemies must be so arranged that the pest population, and hence its damage, changes predictably and uniformly throughout the crop. This is possible only if the pest is introduced first in a manner designed to give the desired uniformity. Control will then proceed without 'patchy' control such as is so frequently seen in many attempts to control whitefly with *Encarsia formosa*. Even if the pest reaches excessive numbers on only a few plants, control will never be achieved however many parasites are present for the closely packed scales collectively produce a protective 'rain' of honeydew which deters the adult parasites from successful oviposition. Similarly, the key to efficient predator control is known to be the management of pest distribution so as to encourage rapid and widespread searching by the predator.

On all glasshouse crops so far studied Phytoseiulus is capable of giving complete control of glasshouse red spider mite largely because it reproduces more rapidly than its host, but with parasites, control is less certain for, in general, their rate of population increase is very similar to that of the host. Control, therefore, may often be achieved more certainly if the rate of pest increase can be reduced slightly as my colleague Wyatt has effectively shown with aphids on chrysanthemums. Many of the cultivars grown have different susceptibilities to peach-potato aphid. On most aphid-prone cultivars such as 'Tuneful', parasite control by Aphidius matricariae is less certain but some admixture of less susceptible cultivars easily and certainly swings the balance in favour of the parasite even though the degree of plant resistance is very low.

These different but interacting approaches to pest control, combined with the need to consider the control of minor pest species which may assume importance when a spray programme is relaxed together with the side effects of chemicals applied for disease control on natural enemies, demands the adoption of an integrated approach.

THE STRATEGY OF INTEGRATED CONTROL

Under glass, any biological control component must be artificially introduced if success is to be ensured. The necessary organisms have to be mass-produced by some commercial concern to whom the exercise must show an attractive return on capital. The quality and reliability of their product is, however, of paramount importance. At present, production is achieved by specialist growers who rear the organisms in glasshouses. In the absence of skilled entomological guidance the output of these units is at times suspect and may put the control on a particular nursery at risk. Steps must be taken to minimize these dangers, presumably through the specialist advisers in A.D.A.S.

Integrated control depends on the selectivity of any chemicals used in the programmes to the natural enemies involved. Ideally, specific selectivity is required as with pirimicarb for aphids or dimethirimol for cucumber mildew but more usually selectivity must be sought by separating the chemical and biological components in time or space. Examples of the former include the use of pre-planting drenches of parathion on cucumber bales to prevent 'French Fly' (Tyroglyphus sp.), post-planting BHC or diazinon drenches for control of onion thrips (Thrips tabaci) during cropping, the use of dimethoate granules on tomato seedlings to control Tomato leaf-miner (Liriomyza byroniae) and benomyl drenches for control of fungal diseases. These techniques can be used in the presence of Phytoseiulus and Encarsia. Other examples abound and one will be referred to later by Scopes, namely, mists of dioxathion applied to chrysanthemums to kill the hatching larvae of Chrysanthemum leaf-miner in the upper leaves without affecting Phytoseiulus or Aphidius.

While the pest management systems currently under development are designed to operate with a minimum of grower skill it is important for him to develop a sympathy and understanding of the techniques. He must learn to live with low pest populations and preserve his natural enemies from destruction by thoughtlessness, i.e. removal of parasitized pests on trimmings or injudicious 'damping down' soon after natural enemies are introduced. The grower must also develop an awareness of the biological reasons for control rather than the present 'spray on sight' syndrome. The widespread adoption of biological control on cucumbers has led to attacks by the Clover mite (Bryobia rubrioculus), a mite normally associated with clover and grassland.

This species does not hibernate under glass and so invades the crops from outside. Treatment of the outer wall and soil surface with dicofol should prevent such invasion without recourse to control on the crop. Similarly, many whitefly outbreaks follow survival on weeds outside the houses during mild winters and so it is important to use weed-killers or to maintain cut swards in the immediate nursery environment. All too frequently, trimmings infested by pests are left in untended heaps or pits - routine treatment of these with pesticides is imperative.

The increasing practice of purchasing young plants from specialist propagating units demands that there be a responsible attitude to pest problems and a willingness to integrate the competing demands of the propagator and grower. Diazinon sprays for control of tomato leaf-miner on tomatoes can affect the artificial establishment of whitefly for "pest in first" techniques and so dimethoate granules should be used instead. Perhaps one of the most interesting possibilities for integration concerns manipulation of the culture to reduce pest populations so as to avoid the difficulties of introducing pesticides. We have shown, with the cooperation of students at Bath University, that the performance of Encarsia is so affected by low light intensity and short days that it cannot be effectively released on tomatoes before April.

As whitefly almost certainly becomes established in January and February it would be impossible to have a planned introduction of the parasite by April without extensive sampling to establish the size of the whitefly population. This is clearly impracticable. If a classical 'pest in first' approach is to be made by introducing whitefly in the second or third week of March any adults maturing from populations already established by natural invasion from outdoors should be eliminated. At tomato cropping temperatures whiteflies take 37 days to develop from egg to adult and so adult emergence must be prevented throughout this period - namely from 37 days before it is intended to liberate Encarsia. It is known that tomatoes form about 2 leaves every week at this time of year so that in the 37 day period about 10 leaves will form. However, it is only necessary to remove pupae so that if, during the critical period, leaves 6-8 counted from the growing point are removed, any earlier infestations will be eliminated.

Such approaches stress the need for growers to appreciate the objectives of integrated control programmes rather than to blindly follow some recommendation. It must also be understood that objectives change when using these techniques. Successful predator control will literally eliminate red spider mite populations within a glasshouse and if this degree of control is achieved when mites would normally be switched into diapause by declining daylength or senescent plants then no mites will hibernate. There will then be no invasion of the next crop when the house is re-heated in late winter. Hence a further 'classical' introduction of predator would be unnecessary and wasteful.

The situation questions the permanence of pest management programmes. It is important to remember that the main reasons for reducing the frequency of pesticide applications were to reduce the selection pressure and phytotoxicity hazards. Virtual elimination of glasshouse red spider mite would permit a return to spot-spraying at least for a season or even longer if it was combined with predator release on isolated outbreaks.

It may also be necessary to have a 'break' in biological control on chrysanthemums to prevent excessive increase in aphid hyperparasites and if this were done in early autumn much of the caterpillar problem caused by emigrant Noctuidae attracted to the lights used to maintain vegetative growth would be avoided without recourse to selective spraying with Bacillus thuringiensis or bromophos.

CONCLUSIONS

It seems likely that the increasing costs of developing new pesticides will reduce the flow of new glasshouse pesticides to a trickle. The reduced labour force available to growers demands effective control techniques which are labour-intensive only when other aspects of culture are at a minimum. The biological control component of the integrated approach fills this need but full exploitation of the approach demands integration by all those involved in glasshouse culture both in their philosophy and organisation.

The propagator, the grower, the adviser, the chemical manufacturer and the research worker must integrate their interests and objectives to the common goal. All must appreciate that integrated control involves the culture and nursery management as well as control of the entire pest and disease complex affecting a given crop. The impact of any changes in any one of these components must be considered and evaluated before it is put into operation.

In these days of project costing and cost/benefit analysis it must be appreciated that any pest management system is a continuum. The task is never complete. New, minor or older forgotten pests like Tomato Moth, Tomato Russet Mite and Greenhouse Leaf-hopper, may reappear and need to be assimilated in the programme. New chemicals will appear and create new problems. Growth controlling substances, fruit ripening compounds and fungicides will need continual evaluation. Such evaluation is not easily achieved in the laboratory as the side-effects are legion - residual, contact, vapour and food-chain toxicity as well as behavioural aspects. Compounds must therefore also be tested on normal crops treated according to the existing integrated control programmes. This task is not cheap in labour or resources but it must be achieved if we are to reverse out of the one-way street and prevent pest control becoming the limiting factor on glasshouse crop production.

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GLASSHOUSE CROPS DISEASE CONTROL - CURRENT DEVELOPMENTS AND FUTURE PROSPECTS

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Summary The tomato and mushroom crops are economically the most important. Very little information is available on losses due to plant diseases, but it is estimated that there is a total annual loss of between £6.5-9 million to the glasshouse industry. Half of this is accounted for by diseases of the tomato crop and in particular tomato mosaic. Recent advances in disease control include the use of systemic fungicides but tolerance of pathogens is an increasing problem; the use of heat therapy and meristem culture has considerably reduced the virus disease incidence in vegetatively propagated flower crops; the effects of tomato mosaic have been minimised by cross protection; disease resistant varieties have been of particular benefit to tomato growers. Further advances in disease control can be made by better use of existing information and facilities. Not enough use is made of the environmental control available to many growers. Often the best method of disease control is extremely costly in labour and work is required to reduce this cost without sacrificing efficiency.

INTRODUCTION

The intensive cropping of land inevitably results in the development of pest and disease problems. Glasshouse growers have long been aware of the dangers of disease epidemics. Recent research into the epidemiology and control of various diseases of glasshouse crops together with the introduction of more effective fungicides and resistant varieties have all helped to minimise the losses from plant disease. However, diseases are still a major factor to be considered and many problems await solution.

DISEASE INCIDENCE AND CROP LOSS

Little has been published on the incidence of diseases of glasshouse and mushroom crops and there is practically no information on the losses resulting from the major diseases. Some basic information is available from experimental work which gives indications of the potential losses. Thus Broadbent (1964) found that yield losses due to tomato mosaic could be as high as 23% and Smith et al (1969) showed that tomato leaf mould (Cladosporium fulvum) only began to affect yield after the attack had been severe for about 6 weeks. Information is also available on plant losses resulting from vascular wilts of carnation (Fletcher 1963, Fletcher 1972, Last and Ebben 1963) and root rots of tomato and cucumber (Last et al 1969, Ebben and Last, 1973). Surveys have not been made to enable this information to be translated into total crop loss as is the case with some cereal crops (James 1969). Ordish (1951) estimated crop loss due to pest and disease of glasshouse grown tomatoes and cucumbers to be approximately 30% and 12% respectively of total yield. In this paper I have attempted to estimate the total crop loss caused by the major diseases of the major crops. These figures are based on the results of experiments where work is available, together with information gathered by the Agricultural Development and Advisory Service. The statistics for acreage and gross monetary returns of each of the major crops are based on the Ministry of Agriculture, Fisheries and Food returns for 1972 (Table 1).

Table 1

Greenhouse Crops and Mushrooms - statistics based on MAFF 1972 figures

Crop	Acreage	Estimated Gross Value £ millions
Tomato	2579	20.4
Cucumber	443	4.7
Lettuce	2501	5.8
Carnations	177	3.8
Chrysanthemums	827	6.5
Roses	123	1.8
Pot Plants	268	6.2
Bedding Plants	160	3.5
Forced bulbs	144	3.5
Mushrooms	1078	15.9

With the exception of mushrooms, the gross value of the tomato crop considerably exceeds that of all other crops. Chrysanthemums, pot plants and lettuce are next in order. The acreage figures do not always reflect the number of producers involved or the size of units; for instance there are many producers of tomatoes, lettuce and chrysanthemums but relatively few of mushrooms and roses.

Main Disease Problems

A large number of diseases affect glasshouse crops, some of which cause considerable loss, others are less common but may still be locally severe. Some diseases are now adequately controlled but sufficient information is not available to enable us to control others. The major crops and the disease problems of commercial significance are shown in Table 2.

Inevitably the figures will vary from season to season but for the main diseases some measure of the range has been indicated. These figures do not take into account the large expenditure already made by growers on routine disease control measures such as soil sterilisation and fungicide applications. Figures for the cost of disease control must be added to those in Table 2 to arrive at the total cost of plant diseases to the glasshouse industry.

Table 2

Estimated loss caused by the major diseases of glasshouse and mushroom crops

Crop	Disease and Pathogen	Estimated Loss	
		Percentage Yield	Monetary
Tomato	TMV - Tobacco mosaic virus	10-15	£2-3 million
	Root Rots - *Pyrenochaeta lycopersici* *Phytophthora* sp.	5-10	£1-2 million
	Grey Mould - *Botrytis cinerea*	2-5	£400,000-1 million
	Wilts - *Fusarium oxysporum* and *Verticillium* spp.	0-5	£100,000
	Leaf Mould - *Cladosporium fulvum*	0-1	£20,000
Cucumber	Root Rots - *Phomopsis sclerotioides* *Pythium* sp.	5-10	£235,000-470,000
	Stem Rot - *Mycosphaerella melonis* and *Botrytis cinerea*	1-3	£47,000-141,000
	Wilts - *Fusarium oxysporum* and *Verticillium* sp.	0-5	£23,500
	Powdery mildew - *Erysiphe cichoracearum*	0-5	£23,500
Lettuce	Grey mould - *Botrytis cinerea*	1-3	£57,000-171,000
	Downy mildew - *Bremia lactucae*	1-3	£57,000-171,000
	Tip burn - Physiological	3-5	£171,000-285,000
Mushroom	Bacterial diseases	5-7	£795,000-1,115,000
	Virus diseases	5-10	£795,000-1,590,000
	Competitors	1	£159,000
Carnations	Wilts - *Phialophora cinerescens* *Fusarium oxysporum*	3-5	£114,000-190,000
	Stem Rots - *Fusarium culmorum*	1	£38,000
	Viruses	1	£38,000
Chrysanthemums Roses Bedding Plants Forced bulbs Pot Plants	No single disease accounting for appreciable overall loss		

Tomato mosaic is the most important tomato disease and disease loss for the tomato crop is greater than all the other glasshouse crops added together. Considerable losses also occur in the mushroom crop. Many of the glasshouse crops are affected by a wide range of diseases, none of which are individually nationally important but all of them are potentially important to the individual grower. If all the possible losses in Table 2 are added the total estimated monetary loss for the industry due to disease is between £6.5-9 million per annum.

Objective measures of crop loss are needed in order to get a more accurate assessment of losses and to enable priorities to be set for research work.

CURRENT DEVELOPMENTS AND RECENT ADVANCES

Major advances in disease control have been made in the fields of fungicides, techniques and plant breeding. In the UK the Glasshouse Crops Research Institute has played an important role in each of these fields.

Fungicides

Systemic fungicides are now widely used in glasshouse and mushroom crops. Considerable advance in the control of wilt caused by Phialophora cinerescens in the carnation crop has been made by the use of benomyl. This and related materials have also been used in commerce to successfully control wilts in tomatoes and pelargoniums. Unfortunately these materials are not quite so satisfactory for the control of Fusarium wilt. Some leaf diseases are also well controlled by the benzimidazole group of fungicides eg tomato leaf mould. The use of benomyl during the past three years applied to or in the casing of mushroom crops has practically eliminated the major fungal diseases caused by Verticillium psalliotae, Mycogone perniciosa and Dactylium dendroides. Control of Botrytis cinerea with benomyl although initially successful, may now not be satisfactory on some nurseries where tolerant strains of the fungus have arisen. Tolerance to this fungicide was first reported by Schroeder and Provvidenti (1969) for Erysiphe cichoracearum and since then there have been reports of tolerant isolates of Botrytis cinerea from various glasshouse crops (Bollen and Scholton 1971, Miller and Fletcher 1974). Five out of eleven isolates of Botrytis cinerea from lettuce crops in the Yorkshire and Lancashire Region were tolerant to benomyl in 1972 and ten out of sixteen in 1973 although none of them were associated with a disease problem. Tolerance of Sphaerotheca fuligena to dimethirimol is also of widespread occurrence (Bent et al 1971). So far there is very little information on the survival of tolerant strains in competition with sensitive strains in the absence of the fungicide. More information is needed on the ecology of these strains and also on the best use of systemic fungicides to avoid the build-up of tolerance in the pathogen population.

Techniques

Virus diseases have reduced yields and quality of a number of flower crops including carnations and chrysanthemums. A complex of carnation viruses has been shown to considerably affect yields and quality (Hakkaart, 1964, Hollings et al 1972). Work in various countries has shown that virus free plants can be successfully produced from diseased clones of both chrysanthemums and carnations. This work has been of considerable significance for the glasshouse industry since it has resulted in the production of virus free propagation material. Furthermore, the methods involved in the production of the clones ensures that vascular wilts are eliminated. The development of the Nuclear Stock Association (Ornamentals) in the UK and the use of high quality propagation material by the propagators has resulted in a considerable decline in disease incidence in both carnation and chrysanthemum crops. This development must be counted as one of the most significant in the control of diseases of these flower crops.

Because of the relative absence of disease in these flower crops it is always tempting to relax standards especially when choosing propagation material. Such practice can often lead to the rapid build-up of virus problems and the advantages of clean stocks are then sacrificed. It is therefore essential to continue the present policy of using the best quality propagation material that is available. It is to be hoped that the inclusion of pelargoniums in the Nuclear Stock Association Scheme will result in similar improvements in clones of this crop.

Economically tomato mosaic is still the most important disease of the tomato crop. Progress has been made by the plant breeders and already there are a number of promising varieties containing all the known factors for resistance. However susceptible varieties still form the bulk of the acreage. For this reason the technique which utilises early inoculation of crops with a mild strain of TMV has been of widespread interest. This technique was developed on a commercial scale by Rast (1972) and in his experiments in the Netherlands and similar experiments by Agricultural Development and Advisory Service pathologists in the UK (Upstone 1973) it has been shown that yield losses due to normal strains of TMV can be reduced. Present indications are that yield may be improved by about 5% and quality improvements may also occur. This technique should enable tomato growers to reduce loss caused by TMV at least until suitable resistant varieties are available.

Plant Breeding

In the UK tomato varieties resistant to Cladosporium fulvum, Verticillium and Fusarium wilt diseases and TMV are in commercial use. Some tomato varieties eg Eurocross BB are resistant to many strains of the pathogen but although this resistance has broken down in some parts of the country the virulent strains have not become widespread. Resistant varieties provide a valuable tool for growers although they should not be used to the exclusion of other control measures. TMV resistant varieties must be protected as far as possible from exposure to TMV in order to prevent their breakdown as a result of the origin of new virus strains. (Pelham, Fletcher and Hawkins 1970). The incorporation of genes for resistance into a wide range of commercial varieties of all glasshouse crops would simplify the task of disease control. Considerable advances in this direction have already been made with the tomato crop. Disease resistance breeding in other glasshouse crops has not been as intensive or as successful. Every year lettuce varieties resistant to downy mildew (Bremia lactucae) are introduced only to be quickly followed by new virulent strains of the pathogen.

FUTURE PROSPECTS

Future prospects for improved disease control depends to a large extent upon new information from research and development. But although more information is needed for the control of some diseases many can be controlled by established methods. These often require a large labour force and are costly. One major aim for the future should therefore be to reduce the costs of disease control methods without sacrificing efficiency. This is particularly necessary in the fields of soil sterilisation and fungicide application.

Various methods of steam treatment of soil have been examined with labour costs in mind. Comparisons between Hoddesdon pipe and sheet steaming have been made (Dawson, et al 1967). The sheet method, in which steam is blown under a plastic sheet, has the advantage of a low labour requirement. However its efficiency varies considerably from site to site. Dawson (1970) reports that a depth of 6 inches heat penetration was not consistently achieved during a five to six hour treatment period. Fletcher (1969) found good heat penetration to a depth of up to fifteen inches after six hours and eighteen inches after 8.25 hours treatment. Why is there such a large variation from site to site? In an investigation in the Yorkshire and

Lancashire Region in 1971-1972 it was found that the soil moisture content was one of the main factors affecting heat penetration. Samples of soil were taken before treatment and the water content determined as a percentage of the field capacity. Moisture content of the mineral soils varied from 58 to 74% of field capacity with approximately 10% difference between the top 6" and the second 6". Peat loams varied from 64% to field capacity and were generally at field capacity in the lower 6 inches. On mineral soils the penetration varied with moisture content and was best in drier soils.

Sheet steaming is relatively cheap, but results with the method are very variable. Perfectly satisfactory results are achieved on some sites eg in the Lea Valley, but in other parts of the country with the same method results are variable. The soil moisture content may be one important factor but more information is required in order to make the method more reliable on all sites.

High volume application of fungicides is also a costly operation although in comparison with other methods of application is generally shown to be the best. In experiments at Fairfield Experimental Horticulture Station on the control of Botrytis cinerea on tomatoes high volume sprays have been shown to be better than low volume applications, smokes and dusts. There is a need for the development of other methods of application which do not involve the labour requirement of high volume spraying but are equally effective.

A second field for further development is that of environmental control. Although glasshouse growers have a greater degree of control over both the aerial and soil environments than any other group of growers this is not used to full advantage for disease control. Many of the important airborne fungal pathogens of glasshouse crops are spread by means of spores eg Cladosporium fulvum, Botrytis cinerea, Bremia lactucae, Mycosphaerella melonis and Fusarium culmorum. Most fungal spores require high relative humidity or free water on the plants surface before germination and infection occurs. If the relative humidity in the crop is kept below the critical level for disease development then disease incidence is greatly reduced. This was well illustrated by the work on tomatoes at the National Institute of Agricultural Engineering by Winspear, Postlethwaite and Cotton (1970). In an experiment where humidity was either regulated to not exceed 90% or 75% RH or not regulated they showed that the incidence of both Cladosporium fulvum and Botrytis cinerea was least in the 90% RH and most where RH was not regulated. Very little information is available on the heating costs involved in the regulation of relative humidity and some heating systems such as those utilising piped steam or hot air cannot be easily used for this purpose. There is a lack of information on the precise environmental conditions necessary for the development of epidemics in commercial crops and it is also extremely difficult to accurately measure relative humidity in a greenhouse. Some simple apparatus is needed which would enable growers to know the length of time when the relative humidity exceeds the critical level. Cotton (1969) has shown that in a tomato crop the relative humidity between the rows is approximately 10% less than on the leaf surface. Most fungal spores require a humidity of over 90% to germinate so a measurement taken between the rows of between 80 and 85% would probably indicate suitable conditions for spore germination and crop infection. An instrument recording this information would help research workers to study the development of epidemics in commercial conditions and perhaps enable them to predict their development with greater accuracy enabling the most economic use of the heating system and of fungicides.

Finally it is to be hoped that the development of new fungicides and the breeding of resistant varieties will continue in the future. Already we have seen the problem of the development of tolerance of some pathogens to some fungicides and the breakdown of some resistant varieties by new races of pathogens. Tolerance to systemic fungicides could become an increasing problem unless we soon find a way to use these materials to prevent its occurrence. It is doubtful whether the economics of fungicide development will allow manufacturers to keep producing new materials in order to stay one step ahead of the pathogens. Similarly with resistant varieties care should be taken not to unduly expose them to pathogens. This is particularly so with TMV resistant varieties where there is considerable risk in the practice of comparing these with susceptibles in the same house because of the chance of the evolution of new strains of the pathogen. Growers will be wise to follow the advice to grow such varieties in separate blocks in isolation from susceptibles.

Effective disease control in the future is largely dependent upon the best use of information already available and the development of low cost techniques which are as effective as some of the older, well tried methods.

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