SESSION 6A

DEVELOPMENTS IN CROP PROTECTION FOR THE 1990s

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Food Consumption, Free Trade, and Demand for Agrochemicals.

As world agriculture enters the 1990s it is riven with strife and uncertainty. An emerging consensus is that protectionist national farm policies funded by taxpayers, buoyed up consumers, have failed. The abandonment of laws of competition is now alleged to be the principal cause of the growing tension in international trade in agriculture. Excess capacity in farming abounds in the industrialised economies characterised by overproduction though there are incorrigible Malthusian cynics who will disagree. Declining and unstable prices,threats of trade wars, neomerchantilist tactics, burgeoning costs of public support for farming, now over $250 Bn a year world wide, are all heaped at the door of failed national farm policies. The charge is that agricultural protectionism has gone too far. Stagnating demand for food in affluent industrial economies as life styles and dietary attitudes change exacerbate the problems of overproduction. World export levels for grain have stagnated in the 1980s and debt-ridden countries with poorly developed and underfunded, food producing farm sectors have been unusually constrained throughout the 1980s from importing adequate food supplies. In the developed world policy makers and their economic analysts underestimated the potential impact of new technology on farm output. Fuelled by high prices, well above world prices, open ended markets propped up by generous taxpayers support, output raced ahead of stagnating consumer demand. Looking to the future, a declining ageing, more diet and health conscious population, in the industrially mature economies, will require lower daily calorific energy requirements. More sedentary and leisure orientated lifestyles will reinforce this trend. In the EC the population will slowly decline below 324 million leading to a decline in the amount of food consumed. Indeed this trend has been evident in some EC countries for some time, but since farm gate prices have been set well above market clearing prices, surplus production has been a regular feature of EC farming for too long. This problem would have been worse were it not for taxpayers support used to subsidised exports. Of course the US does likewise but the levels of producer and consumer subsidies are generally lower. Now the "free traders" intend to challenge the protectionists, in pursuit of a more efficient system of production and trade in agricultural products. In response to GATT proposals on trade liberalisation the commission in Brussels has hinted that the level of support could be reduced by as much as 30 per cent over the next decade. The US has engaged in similar posturing but it is those countries which have the lowest levels of support for farming, in particular Australia and New Zealand and possibly some South American countries who have most to gain. Removal of the 1986-1988 support levels would grievously harm UK/EC producers. Output from the agricultural sector would decline by about 20 per cent, by 24 per cent in Japan, and by between two to eight per cent in the US. The gainers from a shift towards the elimination of public support for farming would clearly be Australia and New Zealand, agricultural output would increase by about 12 per cent in total. Outside OECD countries, in Latin America the increase in output could be about six per cent. Food processing output would decline by a fifth in the EC but in the US it could increase by up to two per cent. Of course depending on the assumptions, the range of economic models used, not surprisingly produce a wide range of results. Yet there is a common thread amongst these simulated results, the EC would fare worst under policies to liberalise protection. Farming and food processing would be reduced by about 20 per cent. If such a policy measure were to be adopted, farm and food output would be reduced by about 10 per cent in OECD countries. Since the EC would bear the greatest brunt of policy shift, the agricultural supply industry would be faced with severe economic adversity. If lower levels of agricultural protection were to coincide with statutory legally enforced controls on inputs judged to be detrimental to the environment, and there is a strong probability that policy makers could be tempted to adopt such measures to promote extensive farming systems and also to seek and possibly justify policies to pay farmers to safeguard the countryside. Fertiliser is a substitute for land, especially for the smaller ambitious farmer and price support stimulates the use agrochemicals. In the US it has been estimated that a one per cent increase in the value of land leads to a 1.4 per cent increase in the use of fertiliser.

Intensive farming might not have been possible were it not for the agrochemical industry. It increased the supply of food at generally falling real consumer prices, but the agricultural triumph of the past 40 years could not go on for ever, the changing nature of the consumer and society now requires that production is reduced and the countryside should be put into "mothballs" and the "ecosystem" preserved in environmentally sensible wrapping. Of course posturing by incorrigible food security advocates will still seek to seduce politicians into doing otherwise. This would merely prolong the costly waste of resources used to produce food for oversaturated markets.

It has long been known that farm support policies benefit land owners most since these are more likely to be capitalised into land values compared with wages (incomes) and returns to capital. Not surprisingly rental values of agricultural land unless other uses could be found, would fall by at least 50 per cent in the EC Japan the US and Canada. So much for the notion that land values are unaffected by taxpayers support for farming and or by the level of farmers incomes over the longer term. Consequently real agricultural incomes would fall by about 13 per cent in OECD countries, and though they would remain unchanged in the US they would plummet by 20 per cent in the EC. On the positive side EC domestic food prices would fall by about six per cent and real household income would rise by over one per cent. For the countries where farm output is expected to rise there would be an added bonus, world prices for wheat and coarse grain would rise by between eight and 24 per cent and for meats by around 20 per cent. Many UK/EC farmers and agricultural suppliers will look upon the distribution of the welfare gains from liberalisation with astonishment, the EC would be emasculated as a producer of farm products for domestic needs, and export markets won at great cost to the taxpayer lost. It is unlikely that government will abandon farming, the conservation issue is too important, but price support for production will be whittled away over the next decades and some conventional farm resources withdrawn. If these include agrochemicals, taxpayers will raise few eyebrows, and a new dawn awaits those who have the wit and insight into new farm technology for a greener consuming society.

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The Environment the Farmer and the Taxpayer.

The ever growing criticism of farming policy is that agricultural protectionism has failed. It has lead to costly high priced overproduction and possibly endangered the rural environment. Intensive livestock production has led to large quantities of polluting residues and in many cases poor storage and inefficient disposal systems lead to contamination of water supplies. Intensive livestock systems have raised concern about food quality. The question now being raised is why not couple measures to reduce farm output with measures to safeguard the rural environment. It is now doubtful if farmers can be persuaded to reduce production quickly enough by price reductions. These would have to be swingeing to achieve a withdrawal of agrochemicals, one of the most productive components in modern farming, and consequently would bankrupt too many farmers. For a number of years what has been called a "cross-compliance" programme has been discussed in the US whereby receipt of "subsidised prices" is conditional upon the adoption of environmentally friendly farming methods. A second policy allows for "additional subsidies" to be paid when extra conservation targets are required. Critics will cry that such methods cannot be monitored as they have in the case of "Set-aside and extensification" policies. There is a school of thought that argues, that output reduction policies (set-aside and extensification) are technically inefficient because they ignore potential complementarities between agricultural output and the rural environment. It is further argued that policies that provide incentives to farmers to adopt environmentally friendly production can be construed as technically efficient. This is essentially the "cross compliance" approach and if this policy were implemented it could remove the need to compensate farmers for the loss of output. However this notion is dependent upon the estimation of the value of environment goods to the taxpayer since they would be relied upon to fund such a programme. If this estimate were to match the present level of public support for farming, then it could be business as usual but in a changed role, from food producers to conservators of the rural heritage, if that was what voters can be persuaded to support. Whether this approach conforms with the "polluter pays" principle, which includes the use of economic and legislative measures is open to question. Taxes have been proposed as a means of persuading farmers to reduce nitrogen and phosphate emissions but they would have to be high, approaching 100 per cent. In the Netherlands one proposal is that farmers pay a levy on phosphate inputs over a given level, reduction would be phased over a decade, reaching a threshold of 70 kg a hectare by 2000. Permits and licenses to keep intensive livestock enterprises and for the application of agrochemicals are also much discussed options. All these policy options would reduce global levels of output and inputs if implemented, but more importantly farmers incomes and those of their suppliers.

Prospects for Agrochemical use on Arable Farms.

The great expansion in output in the arable farming sectors of the UK/EC over the past 25 years has plainly been associated with higher inputs of agrochemicals. EC (12) output of cereals increased by over 50 per cent in a decade and this was reflected at the farm level through higher yields per hectare. Between 1970 and the mid 1980s the yield of winter wheat in the Eastern Counties of England increased by 70 per cent, or about three tonnes per hectare. However real output per hectare declined by about five per cent, but real gross margin declined even faster, by 18 per cent. The reason for this paradox is that as increasing output is faced by a wall of inelastic demand for cereals in the UK/EC (and many other industrial countries) the farm gate price declines. In the UK, real farm gate prices for wheat have declined by about 40 per cent between 1973 and 1990. Worse still since the real costs of factor inputs, machinery, labour, and in particular land and capital, have remained stubbornly high, the real net margin per tonne has relentlessly declined. These trends will continue for as long as production exceeds demand by such a wide margin. An interesting feature of agrochemical use is that the real cost of fertiliser per tonne of winter wheat produced on farms in the eastern counties, though it increased by about five per cent in the mid 1980s compared with a decade earlier, declined in the late 1980s to £12.5 per tonne, two per cent lower, compared with the early 1970s. However the real cost of spray chemicals followed a different path. Up to the mid 1970s the cost per tonne was half that of the 1980s. The cost per tonne grew steadily in the late 1970s reaching a peak in the early 1980s, thereafter it remaining more or less constant at

£13.6 a tonne. Rapid technical progress boosted yields over the past two decades but plainly not without the assistance of higher inputs of nitrogen and spray chemicals. The net effect of the changes in inputs was that the real cost of fertiliser and sprays increased by about three per cent over the past 15 years to just over £26 a tonne in 1984-89 (Table 2).

However when judged in terms of economic efficiency the "average value product" of fertilisers has declined by 22 per cent and that for spray chemicals by 27 per cent. More importantly, however, the marginal value products of these inputs have declined at a slower rate, buoyed up by improved technology. Consequently the ratio of marginal cost to marginal value product has always remained greater than unity, the acid test for allocative efficiency of resources. This confirms that winter wheat growers were underallocating agrochemicals at average yields and price per tonne over the decade 1978-1989. The question now uppermost in farmers minds, is if real farm gate prices continue to fall at what level should they contemplate withdrawing agrochemicals to ensure that they continue to produce that level of output which maximises profits.

An interesting feature of this line of argument is that over the past 20 years the real expenditure index for fertilisers applied to winter wheat rose steadily up to 1986 but then declined resulting in an overall increase of 20 per cent between the mid 1970s and 1989/90. The volume index rose by 40 per cent but this too is now on the decline. Risk averse farmers are already responding to perceived future trends in real farm gate prices and the necessity of adjusting total costs of production. Plainly some factor costs will remain stubbornly if perversely high, especially annual land costs, and interest on working capital. The pattern for spray chemical costs was somewhat different. The real expenditure index rose without pause between 1975 and 1989 by 92 per cent, but the volume index by rather less, 74 per cent. To exploit fully and then sustain higher yielding varieties the input volumes (and expenditure) of agrochemicals increased especially on specialist cereal and intensive arable cropping farms. Plainly, if agrochemical inputs are reduced output would decline. In a period of over production this is what policy makers would hope farmers could be persuaded to do. However, the farm gate price for wheat would have to decline by between 15 and 20 per cent before profit maximising winter wheat producers should contemplate such a step. If in partial response to

GATT proposals EC protection levels are lowered, then under existing farm technology many producers will be forced to withdraw agrochemical inputs.

Not surprisingly for potentially lower yielding spring barley, although the real expenditure and volume indices for fertiliser rose gradually between 1975 and 1985, these too declined and by 1989 registered little change over 15 years. The spray chemical indices rose by over 70 per cent yet in terms of economic efficiency the average value product generated declined by 16 per cent; a clear signal to yield maximisers of the futility of attempting to produce their way out of economic adversity. For winter barley production the trend in the real expenditure and volume indices for fertiliser were similar to that for spring barley. However the volume index for spray chemicals rose by rather more, 26 per cent. As the real farm gate price for feed barley continues to decline, so do the average and marginal value products for fertiliser and sprays. At present, barley producers achieving average yields and prices are operating much closer, compared with winter wheat producers, to the point where an extra increment of expenditure on agrochemicals would be only just matched by the expected incremental increase in output. Under existing technology a decline of about 12 per cent in farm gate feed barley prices would force a withdrawal of agrochemical inputs. This is precisely what "price levers" are intended to achieve. For oil seed rape, although the real expenditure and volume indices for fertilisers inputs increased by between 20 and 30 per cent during the decade 1975 to 1985, these later declined. The net effect is that real expenditure per hectare for fertilises inputs is now similar to the early 1970s. Yet the yield index has increased by 20 per cent (Eastern counties of England 1972-1989) and this has been accompanied by a sustained increase in real expenditure on sprays which doubled between 1978 and 1989. The volume index increased even more. This crop shares the same syndrome as cereals. Despite increased yields per hectare, the average and marginal value products of fertiliser and sprays are remorselessly declining. This confirms that profit maximising rape seed growers would also have to consider reducing agrochemical inputs if farm gate prices were reduced further.

Production and Consumption Trends - Is There a Production Crisis?

Despite the 1988 US drought and the soil moisture deficits in many parts of the EC in 1989-1990, world wheat production in 1990-1991 is expected to reach a record of 564 million tonnes. Consumption is expected to be in the region of 555 million tonnes. Despite an expected reduction of about 30 per cent in the dollar price per tonne, world trade in exports is expected to remain stagnant at 98 million tonnes, eight per cent lower compared with 1986/87. Consequently world wheat stocks will once again rise to the accepted safe level of around 18 per cent of annual consumption, confirming that wheat production is returning to its normal state of oversupply. In sharper perspective, the EC could contribute over one quarter possibly more in future, of world wheat exports leaving a mere 70 million tonnes to be shared amongst the other major world grain producers. It is this prospect that fuels much of GATT debate on world trade and protectionism. Indeed total world trade in wheat and coarse grain has remained static over the past decade at between 193 and 200 million tonnes annually. The world crop of cereals in 1990 is expected to be in the region of 1403 million tonnes, including rice (milled) 1700 million tonnes, or about 320 kg a head world wide, hardly the crisis situation that some commentators still persist exists, filling farmers with false optimism. There are plainly problem in distribution hindered in some circumstances by high indebtedness and lack of foreign exchange to import grain. The resurgence of EC intervention stocks for beef and to a lesser extent dairy produce and later grain is a further manifestation of the continuing excess capacity in EC/OECD farming. This is exacerbated by the discouraging trends in food consumption per capita.

Food Consumption Trends.

The consumption of fresh milk products in the EC is stagnating at 27 million tonnes about 80 kg/hd and butter consumption is on the decline. In the UK it has more than halved since 1960 to 5.1 kg/hd in 1988 (Table 1). Consumption of cheese is slowly expanding, and there are wide variations in the amounts consumed, but this is unlikely to offset the total decline in consumption of dairy produce over the next decade. These trends will prompt a revision of the present level of milk quotas which would later be reflected in a decline in the demand for animal compound feed. Similar trends are observed in the UK/EC meat sectors, EC sheep meat consumption at 3.8 kg/hd has changed little, but has almost halved in the UK since 1960 to 6.2 kg/hd in 1988. Beef and veal consumption is fairly even across the EC at around 23 kg a head and has changed little in the past 5 years. However in the UK it is declining slowly, it was just under 20 kg in 1988. The net human consumption of cereals in the EC is stagnant at 27 million tonnes a year (total production 162 mt in 1989), about 85 kg/hd per annum. UK human wheat consumption at about 73 kg/hd per year is still one of the highest world wide, but is slowly declining. With the possible exception of vegetables, the consumption trends for most other EC indigenous food products are discouraging from a production viewpoint.

Looking to the future it is the trends in consumer behaviour which will influence farmers livelihoods. The consumer is now setting the agenda for food production and most researchers are generally agreed that future growth in real disposable income cannot be relied upon to sustain, still less increase food consumption especially red meat consumption. The income elasticity of demand for food has declined steadily over the past century and is now close to 0.05 at the farm gate. From mid 1970 to the late 1980s, despite the decline in real red meat prices, the marginal impact of taste change was associated with a decline of almost three per cent a year. Demographic trends in the advanced industrial nations will plainly continue to have a major influence on food consumption in the 1990s. Consumers will also seek to have a greater say in the determination of policies that influence the quality of food they eat. Plainly these are factors farmers and the agricultural industry cannot now afford to ignore. If for whatever reason consumers wish to consume greener food then farmers should be ready to slake the thirst of green and hopefully well informed consumers.

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TABLE 1. CHANGES IN HOUSEHOLD CONSUMPTION OF CEREALS AND DAIRY PRODUCE (Kg per head per year)

	1934-39	1960	1980	1988
Bread	-	67.0	45.9	44.6
Flour	-	10.0	8.4	6.0
Cakes and Biscuits	-	17.7	13.4	14.2
Breakfast Cereals	-	4.0	5.8	6.6
Rice	-	1.0	1.5	1.4
Other Cereal Products	-	3.4	6.7	7.3
TOTAL CEREAL PRODUCTS	95.3	103.1	81.7	80.1
Beef and Veal	24.9	21.4	20.5	19.8
Lamb and Mutton	11.4	11.1	7.5	6.2
Pork	5.6	8.7	12.6	13.4
Bacon and Ham	12.0	11.3	9.0	8.1
Offal	1.9	2.2	2.3	1.9
Poultry	2.3	5.3	13.4	18.0
Liquid Milk	98.5	147.1	133.3	131.9*
Butter	11.2	8.9	6.3	5.1*
Cheese	4.0	4.6	6.0	7.6*
Potatoes	-	-	60.4	56.7
Sugar	-	-	16.5	10.2

Sources: National Food Survey, 1986, MAFF, HMSO, London
Dairy Facts and Figures, 1980-89

*Estimates

TABLE 2. WINTER WHEAT

		£ per Tonne**			
	Yield per Ha	Cost of Fert.	Cost of Spray	AVP	
				Ferts.	Sprays
1970	4.11	14.2	4.7	12.2	36.2
1978	5.65	12.4	13.6	13.0	11.8
1984	8.36	11.6	10.4	13.0	11.9
1986	7.17	13.3	11.4	9.0	10.5
1988	6.46	10.7	13.8	10.1	7.8
1989	7.62	10.6	13.9	10.0	7.7

TABLE 3. SPRING BARLEY

1973	4.02	12.3	5.3	14.2	33.3
1978	4.13	13.9	8.1	10.6	18.2
1984	5.30	11.3	5.8	11.0	21.2
1986	5.10	11.1	6.9	11.8	19.2
1988	3.88	10.8	11.2	10.5	10.2
1989	4.26	11.3	9.7	11.6	13.5

*AVP = Average Value Product

** These estimates differ from those quoted in the text which are based on five year moving averages.

NEW METHODS IN DIAGNOSIS AS AIDS TO CROP PROTECTION

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ABSTRACT

Accurate diagnosis is fundamental to efficient crop protection and the need for rapid and accurate methods has increased as treatments have become more specific and control strategies more complex. Diagnosis based upon immunological and nucleic acid characteristics is already widely used for viruses and their use will extend to many other pathogens and pests in the next ten years. Such methods will also be important in monitoring the fate of crop protection chemicals, biocontrol agents and genetically manipulated plants and micro-organisms in the environment.

INTRODUCTION

The identification of causal organisms is fundamental to efficient crop protection. As the methods and materials available to combat pests and pathogens have become more numerous and increasingly integrated with crop management systems the requirement for accurate diagnosis has become even more important. No longer is the nineteenth century recognition of 'blights' 'mildews' or 'murrains' an adequate description of the variety of damaging organisms now known to attack crops.

Diagnostic methods should fulfil a number of requirements. The relative importance of these requirements will differ for each organism and depend upon the biology of the pest or pathogen and the crop protection methods available to prevent or minimise the damage they might cause. Perhaps the most important requirement is that the method used should be reliable. There is little point in attempting to identify a pest or disease agent if one has no confidence in the result. It should also be reproducible in different conditions, at different times of crop growth and different stages of pest or pathogen development. It is also often important that the identification should be rapid. Not only does this permit prompt action if this is indicated but many tests can be done. Rapid is of course a relative term. To do in one week what previously took eight might reasonably be described as rapid but may still be too long for appropriate control measures to be taken; the benefit of such a method might be questioned. Therefore, overriding all these requirements is that the method should be appropriate to the need. Appropriateness is very closely linked with the practicability and cost of control. At the extreme the identification of a problem may cost more than the value recouped by its control. However, many diagnostic methods begin as research tools and become practical methods as a result of the economies of scale. Obviously commercial realities will dictate which targets are seen as important enough to sustain the investment in developing a diagnostic method. For some purposes it may be sufficient merely to confirm presence or absence, as for example in quarantine. In crops there is usually an additional need to determine the incidence of the pest or pathogen. The need for the method to be robust, or to use current jargon 'user-friendly', will depend upon its application. Tests by the farmer on the kitchen table need to be robust compared with tests done in a well-equipped laboratory.

One of the most sophisticated diagnostic tools, capable of handling much information simultaneously, identifying many pests and pathogens almost instantaneously and quantifying them almost equally quickly, is man. Much resource has been devoted to acquiring these skills and they should not be dismissed lightly. However, humans have their limitations. The identification of some important pest and pathogen species requires additional help, such as a microscope, and even then some important biological differences e.g. pesticide resistance cannot be identified without further time-consuming assays. Different pathogens often cause indistinguishable symptoms and some cause none at all until infection is well established and the optimum time for control has passed. Recent developments can help resolve these difficulties. At the routine level they can be a substitute for a chore, at a more detailed level they can supplement other information and become part of the increasingly sophisticated decision-making process required for effective crop protection.

New diagnostic methods have often been seen as adjuncts to existing methods. They can and have already become rather more than that. The consequences of the use of fertilizers and crop protection agents have become associated in the public mind with pollution and the contamination of food and drinking water. Methods to monitor nitrates or pesticide residues are essential to ensure compliance with legal limits and to help identify sources. The new techniques can increase the accuracy, speed and sensitivity of such monitoring. Diagnostic methods can be used as research tools to investigate interactions at the molecular level between host and pest or pathogen, or between pathogen and vector, or as aids to epidemiological studies and consequent refinement of treatment regimes or forecasting methods. The new methods offer opportunities for anticipating and thus avoiding problems. The detection and quantification of pathogens in soil can ensure that a resistant cultivar is chosen or an alternative crop is sown. Other effects of pests and pathogens result from metabolic changes in the host or the production of metabolites, such as mycotoxins, by the invading organisms. Such changes are now amenable to rapid detection.

In this paper, we review the properties of organisms that can be used in diagnosis and their relative advantages and disadvantages, the methods used to exploit these opportunities with examples of their use across a wide range of crop protection problems and how we expect these new methods to affect crop protection in the next 10 years.

IMMUNOLOGY

An antigen is any substance capable of inducing an immune response when it is introduced into an appropriate animal resulting in the production of an antibody. Antigens also have the property of specifically binding with corresponding antibodies. It is these properties that are exploited in immunological detection methods. The binding property is associated with specific parts of the molecule called epitopes which for proteins usually consist of 5-7 amino acid residues. However, single epitopes cannot induce an immune response on their own, they need to be linked to a larger, carrier molecule. This antigenic property can be conferred on other small molecules of whatever chemical grouping by similarly linking them to a carrier (Van Regenmortel, 1982). Thus the possibilities of using immunological methods to diagnose and detect molecules of significance in crop protection is almost limitless.

To provide the materials needed for serological tests and assays, two approaches are possible. The well-established route is through the production of polyclonal antibodies by injection of the highly purified antigen into an appropriate animal. The serum obtained from the injected animal will consist of a range of antibodies generated by epitopes on the antigen. As some of these epitopes are common to closely, and sometimes distantly, related organisms a range of reactions is possible in tests. If the injected preparation contains impurities, eg. host plant material, then antibodies will be generated to them and subsequent tests will be inaccurate because healthy plants will give reactions.

More recently the development of monoclonal antibodies (Kohler and Milstein, 1975) has revolutionised immunology by allowing the production, in virtually limitless quantities, of antibodies specific for single epitopes. This is done by fusing spleen cells from, or in, immunized mice or rats with a myeloma cell line to produce hybridomas in the animals or myeloma cell lines, each of which produce unlimited amounts of specific and uniform antibodies.

The relative advantages and disadvantages of the two methods of antibody production differ depending on the use to which they are put. Broad spectrum assays are often best provided by polyclonal antibodies. However, the specificity of monoclonal antibodies is valuable for specific tests and by combining monoclonals of known specificity, 'custom-built' polyclonal sera can be prepared with a precisely defined spectrum of reactivity.

While monoclonal antibodies are relatively expensive to produce, limitless quantities are potentially available with precisely defined properties so they are often the method of choice when many assays are required. Polyclonal antibodies by their nature and by the need to use a separate animal for each fresh preparation of antiserum are more variable and care is needed to ensure consistency of results using sera collected from the same animal at different times or from different animals.

Methods

Serological methods have been used, especially for the identification of plant viruses, for many years, but not until the adaptation of the enzyme-linked immunosorbent assay (ELISA) for use with plant viruses did immunoassay become widely available outside specialist laboratories (Clark & Adams, 1977). Since then ELISA has become the standard procedure although there have been many adaptations and modifications. The literature abounds with descriptions of 'direct', 'indirect', PAS, immunoblot, Fab-ELISA, dot ELISA, dot-immuno-binding, dipstick assays and amplified systems. In addition fluorescence assay in which a fluorescent material substitutes for the enzyme, or radioimmunoassay in which a radioisotope is the detecting material have been used although less frequently than the chromogenic enzyme systems. The appropriateness of a particular method depends upon the material to be assayed, the antibodies available, the specificity and speed required and the resources available. For polyclonal antibodies the detection method used can influence the result; for monoclonal antibodies different methods may affect the sensitivity, but not the specificity, of the assay.

Immunological detection methods are quick; answers are often possible in hours and with amplified systems in minutes. Results are usually manifest as a colour change, which is often sufficiently marked to be recorded by eye, and its intensity is proportional to the presence of the reacting antigen. They are suitable for use where facilities are limited and can often be prepared as simple 'dipstick' tests (Miller *et al.*, 1988) which require a minimum of manipulative skill and interpretation. A variation on immunological diagnosis is the combination of serology and electron microscopy in the method known as immunospecific electron microscopy (ISEM) (Roberts & Harrison, 1979) which is especially useful for viruses that infect phloem and are present in low concentrations.

NUCLEIC ACID TECHNOLOGIES

The principal advantage of nucleic acid-based methods of detection is that they can exploit all of the information, and therefore all of its variability, that is coded for in the base sequence of the plant, pest or pathogen genome. Nucleic acids and their variability can be exploited in several ways.

Hybridization

The pairing of nucleotides between strands of nucleic acid is very specific and this property has been used to detect genetic material from specific parts of the target genome. The detecting, labelled nucleic acid is described as a probe. Probes are currently usually of DNA because RNA-based probes are less stable and likely to be digested by RNAse. The methods used to detect hybridization between target nucleic acid and probe are many but all depend on denaturing i.e. separating the two strands of the test nucleic acid, bringing the denatured nucleic acid in contact with the probe and determining the degree of complementarity by measuring the amount of probe that has hybridised with the test sample.

The measurement, or demonstration, of hybridization depends on the label attached to the probe. So far radioactive labels have predominated because of their greater sensitivity than chromogenic-based probes. However, while such probes can be used reliably and safely in well-equipped laboratories they are not suitable for use elsewhere. Only when reliable and sensitive chromogenic detection systems are available will nucleic acid hybridization become widely used. However, in some circumstances, as for viroids which contain no antigenic material, nucleic acid-based detection is the only option available. Changes in antigenic properties can occur, especially of pests such as aphids and nematodes as they pass through different growth stages during their development, and in these circumstances detection based on nucleic acids, which do not change, is more reliable than immunology.

Restriction fragment length polymorphisms (RFLPs).

Another use of nucleic acids in diagnostics is to chop up the DNA of the species of interest using enzymes (restriction enzymes) that recognise a specific nucleotide sequence, separate the fragments by electrophoresis and look for differences in the patterns that result that can be linked to a biological property, such as host range, pesticide insensitivity, severity. It is a too lengthy and expensive technique to be used routinely but is of value in fundamental studies of host/pathogen interactions and taxonomy which will influence future crop protection methods. However, the identification by RFLP analysis of the biological properties conferred by particular regions of nucleic acid could lead to the development of specific probes.

Double-stranded (ds) RNA

In general plants and fungi do not contain detectable amounts of high molecular weight ($>0.1 \times 10^6$) ds RNA (Dodds *et al.*, 1984). Therefore, the presence of dsRNA in a plant or fungus probably indicates the presence of a multiplying RNA-containing virus, or virus-like agent. As the great majority of crop infecting viruses have RNA as their infectious principle the method has potentially wide application. In practice it is only useful for those agents not amenable for immunological methods or visible by electron microscopy. It is unlikely the dsRNA method will become a routine method of general applicability. However, it is a first step in identifying and characterising a causal agent and can allow studies of the disease and its epidemiology before much is known about the agent.

APPLICATIONS OF NEW DIAGNOSTIC METHODS

Diagnostic methods, however sensitive, are not ends in themselves. They can be valuable tools in research and in practical crop protection. Illustrated below are some examples of how the new methods of diagnosis have and will contribute to more effective crop protection.

Pests

In general, the identification of pest species presents less of a problem than of pathogens and consequently little use has been made of immunological or nucleic acid-based methods in crop protection. However, the problems presented by the development of pesticide resistance in populations of pests stimulated interest in these methods and it is now possible to identify characteristics that are significant in crop protection (Loxdale & den Hollander., 1989). By identifying the basis of population shifts, especially biological characteristics of relevance to crop protection, these methods could be providing the basis for diagnostic tools of use in more targeted crop protection practices in the next ten years.

Immunological and nucleic acid-based methods for detecting and monitoring insecticide resistance in field populations of the aphid pest and virus vector *Myzus persicae* are now well established and in everyday use. With the immunoassay, up to 2000 aphids can be tested per day (Devonshire, 1989) and similar methods are likely to be applied in future to other crop pests. The knowledge that results will be of fundamental importance in understanding resistance mechanisms and developing strategies that avoid the development of resistance.

Nematodes

The identification of some nematodes, based as it is on microscopic morphological characteristics, is "at best difficult, and at worst pure guesswork" (Burrows, 1988). Consequently much effort has been directed at obtaining simple, accurate and quick methods of identification based on immunological (Jones *et al.*, 1988), or nucleic acid (Burrows, 1988; Besal *et al.*, 1988) methods. As the range of species that are detectable by these methods increases and discrimination between races and pathotypes within species becomes possible, the use of monoclonal antibodies and nucleic acid probes will increase. This will provide support for plant health and quarantine assessments and allow the more rational use of nematicides and host cultivars in integrated management programmes.

Fungi

Increasing numbers of commercial kits based on monoclonal antibodies are being advertised for fungal diagnosis and in the next 10 years their use is likely to increase. However, diagnosis is still for many pathogens relatively easily done by man and the area of greatest use is likely to be where several fungi may cause similar symptoms e.g. *Pseudocercosporella herpotrichoides*, *Rhizoctonia cerealis* and *Fusarium* spp on the stem base of cereals (Dewey, 1988) or *Septoria tritici* and *S. nodorum* on wheat (Petersen *et al.*, 1990). A further use is in the quantification of inoculum which may give a better assessment of the potential for disease spread and yield loss than current subjective assessments.

As it has for some insect species, the development of pesticide insensitivity has resulted in a need to identify resistant fungal isolates that can now be met only by time-consuming bioassays. The presence of pathotypes with different epidemiologies, such as the R- and W- pathotypes of *P. herpotrichoides*, poses similar problems and illustrates the need for methods that allow rapid identification of characteristics that are not reflected in symptom appearance.

It is likely that the identification of fungi will benefit most from the new methods in diagnosis in the next 10 years. Nucleic acid based methods have been used to investigate RFLPs and total DNA of *Phytophthora* spp (Panabières *et al.*, 1989) and *Fusarium oxysporum* f.sp. *pisi* races (Coddington *et al.*, 1987) and DNA probes have been produced for sorghum downy mildew (Yao *et al.*, 1990).

Bacteria and Mycoplasmas

Bacteria are relatively complex organisms and serological tests have suffered from the poor specificity of many polyclonal antibodies. The use of monoclonal antibodies has the potential to improve specificity and provide useful tests for bacterial identification. There are still some problems of specificity because of the ubiquity of epitopes within bacterial groups; for example, accurate distinction between *Pseudomonas* spp. can be difficult. However, monoclonal antibodies have been prepared to *Corynebacterium sepedonicum* (De Boer & Wieczorek, 1984), *Erwinia* spp. (De Boer & McNaughton, 1986) and *Xanthomonas campestris* pv *campestris* (Alvarez *et al.*, 1985), and several diagnostic kits for bacteria are available commercially. These are usually ELISA-based tests which are more rapid than traditional methods and can permit early detection of bacteria often in the absence of symptoms. When specificity becomes equal to or better than traditional host inoculation methods such kits may also have potential in quarantine, plant health and seed certification (Candlish *et al.*, 1988). Other immunological approaches such as immunosorbent immunofluorescence and immuno-isolation methods have been proposed by Franken and Van Vuurde (1990) particularly for the detection of bacteria such as *Pseudomonas syringae* and *Clavibacter michiganensis* in seed.

Immunoassays have also been used for MLOs and fastidious xylem-inhabiting bacteria (Jones *et al.*, 1988), but because plant infecting mycoplasmas cannot be grown in culture, interfering plant substances make specific assays difficult.

Nucleic acid hybridization methods are being developed for plant pathogenic bacteria (Denny, 1988; Schaad *et al.*, 1989; Ball & Reeves, 1991). The use of bacterial plasmids has been suggested as probes for xanthomonads (Gilbertson *et al.*, 1989) and in RFLP analysis for pseudomonads (King, 1989).

Viruses

Because of their simple structure and the impossibility of identifying them morphologically, virus identification and detection has for long depended on immunological assays and the newer nucleic acid-based methods were first used for viruses (Robinson, 1988).

The opportunities now available for sensitive, specific virus assays have also created difficulties as well as opportunities. Tests that are too specific may require that a panel of monoclonal antibodies is used to ensure that all relevant variants of the virus are detected, or that a ‘synthetic polyclonal’ is created by mixing monoclonal antibodies of known specificity. Nucleic acid hybridization allows access to greater variability of the virus but their wider use depends on the development of safer detection systems than radioactivity.

Because immunological methods are now used routinely to diagnose viruses, it seems less likely that there will be much expansion in their use compared with their use for other pests and pathogens. The availability of monoclonal antibodies is still restricted but this will improve, and, in part, will replace polyclonal antibody-based tests and, in part, provide the specificity required to cope with particular disease problems. Two of these uses will be in separating virus variants with different host ranges than the type strain, and for detecting viruses that cause no symptoms but are often ubiquitous, such as the cryptic viruses. There is also scope for increased use in plant health, quarantine and seed certification schemes, and both nucleic acid and immunological methods will be used to detect viruses in vectors as an aid to studies of epidemiology and in forecasting.

The new diagnostic methods will continue to be modified and an additional role may be in detecting genetic material or its translation products in transgenic plants. Resistance based upon the insertion of virus coat-protein or anti-sense RNA, may be the only character by which one 'cultivar' differs from another and some method of verifying this difference will be required.

Other uses in crop protection

In the next 10 years genetic engineering will begin to have an influence on crop protection practices either by the production of transgenic plants with specific characters or the use of engineered organisms as biocontrol agents. These applications will require careful monitoring before their general release is sanctioned and the new diagnostic methods will be the only way of doing so quickly. Environmental concerns are, and will become even more, important. Pesticide residues in crops, drinking water and soils are already of concern. Monitoring these residues will require sensitive, reliable detection such as can be provided by the new molecular methods. Contamination from harmful natural products such as mycotoxins are already the subject of statutory limits and immunology is increasingly used for their detection.

FUTURE DEVELOPMENTS

Investment in biotechnology has resulted in rapid increases and frequent improvements in the range of techniques available. Diagnostic methods in medicine, forensic and veterinary science are already benefiting from the new technology and applications to crop protection problems are being developed. The most significant advance is the polymerase chain reaction (PCR) used by Saiki *et al.* (1985) and described by Mullis and Faloona (1987). PCR amplifies sequences of base pairs from nucleic acids by the action of DNA polymerase enzymes and thermal cycling to denature and reanneal the DNA strands. There are innumerable potential uses of PCR. Most of the studies relevant to crop protection are currently awaiting patents and are not yet published, but there is likely to be a rapid increase in the use of such techniques for diagnostic purposes when the power of the technique is more widely recognised.

CONCLUSIONS

In many areas of crop protection the powerful technologies of immunology and nucleic acid sequencing and hybridization have only just started to have an influence. In the next 10 years this will increase considerably. Nucleic acid hybridization will be based on non-radioactive assays and be used routinely for many assays. Immunological tests, usually based on monoclonal antibodies will be widely used for fungal and bacterial diagnosis and to distinguish host species variants, resistance to fungicides, and pathotypes.

Pest species will often be identified by immunological and nucleic acid - based tests to determine characteristics of significance in crop protection and those species that are virus vectors will be routinely monitored for the presence of viruses, often in conjunction with quantitative monitoring. Composite guidance will then be given on the risk of damage and the need for control based on numbers, virus-transmitting characteristics and ease of control.

However, despite these changes, the new diagnostic techniques are themselves only part of the information required for efficient, effective and rational crop protection strategies. They are a means to an end not an end in themselves, their ultimate value will depend upon their close integration into crop protection systems.

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DISEASE CONTROL IN COMBINABLE CROPS: MEETING THE CHALLENGE OF THE 1990s

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ABSTRACT

Over production, environmental considerations and consumer preferences will place considerable constraints on the use of fungicides in the future. This paper considers the potential for changes in fungicide use during the next decade with reference to the major combinable crops. It concludes that reductions in foliar applied fungicides are feasible and will be made possible by developments in breeding and seed treatments.

INTRODUCTION

Anticipating trends and changing circumstances is always difficult. In crop protection, where there is an annual ebb and flow of disease pressure in response to changing seasons, prediction is particularly difficult. However, there is no doubt that UK agriculture is changing. Some effects of the recent economic pressures are already clearly visible. Further economic pressures are likely as a result of changes within the British economy. Similarly, we can also identify increasing consumer-related pressures on the industry.

In this paper we shall try to identify the effects that these pressures are likely to have on approaches to disease control during the next decade. We will only consider combinable crops - cereals, oilseed rape, linseed, peas and field beans in Great Britain. The wider range of arable crops in the UK has been well covered in a recent review by Yarham and Giltrap (1989).

Table 1 lists the main combinable crops and shows their areas, average yields, values and gross margins (data from the 1988 and 1989 MAFF June census; MAFF Publications Branch and pers. com. J Redgate, ADAS Business Management). Cereals are the primary combinable crops in Britain and in view of our soils and climate are likely to maintain that position.

The proportions of each crop grown in each ADAS Region, Wales and Scotland are given in Table 2. These crops are clearly concentrated in eastern and southern regions but there is a concentration of spring barley in Scotland to meet the specific demands of the malting industry.

TABLE 1. Areas sown and returns on the major combinable crops (1989 MAFF Census).

Crop	Area (ha)	Yield (t/ha)	Value (£/ha)	Gross Margin (£/ha)
Winter wheat	2 083 000	6.52	646	420
Winter barley	881 000	5.33	544	354
Spring barley	772 000	3.80	404	261
Oilseed rape	321 000	2.95	711	456
Linseed	17 300	1.83	608	381
Peas	85 600	3.45	554	344
Beans	129 000	3.26	509	378

TABLE 2. Percentage of the total area of each crop grown in the ADAS Regions, Wales and Scotland (1988 MAFF Census).

Region	WW	WB	SB	OSR	Lin*	Pea	Bean
Eastern	40	25	21	37	33	37	52
Midlands	14	19	11	15	15	12	14
Northern	14	20	14	19	11	15	10
South East	15	12	9	13	32	17	18
South West	11	14	9	4	9	11	5
Wales	1	2	4	<1	<1	<1	<1
Scotland	5	8	32	12	<1	8	0

* 1989 census estimates (first year linseed area included)
(WW = winter wheat; WB = winter barley; SB = spring barley; OSR = oilseed rape; Lin = linseed)

FACTORS INFLUENCING DISEASES AND THEIR CONTROL

A number of independent factors influence farmers' approaches to disease control. Most are interrelated to a greater or lesser extent and many are under the direct control of the individual farmer. Some of them are considered below.

Political constraints

Current indications are that political pressures to reduce over production in the European Community (EC) are likely to continue. Schemes such as set-aside have evolved in order to remove excess areas of land from production. Further economic pressures on cereal producers are likely to follow as the Uruguay round of the General Agreement on Tariffs and Trade endeavours to reduce market distortions within the EC and force European grain prices closer to world prices. In the meantime internal changes within the EC will reinforce market requirements for grain of high quality.

We can postulate that these pressures will concentrate arable production into the more favourable areas of Britain (see Table 2) and that some individual farmers in these areas may find it necessary to maximise production through an increase in inputs.

There are also increasing pressures mounting from consumers and from the environmental lobby in response to the perceived threats to the environment of intensive agriculture. These pressures will force reductions in pesticide use. Much current strategic R&D is aimed at determining a) the consequences of enforced pesticide reduction and b) the effective management of disease by the more efficient use of pesticides.

Climate effects

There is now general agreement that owing to global warming some modification of our climate is likely (Warrick & Barrow, 1990). We cannot predict precisely what these changes will be, but there are suggestions that Britain is likely to experience greater extremes with a generally enhanced instability during winter months. Some predictions suggest that winter and spring rainfall may increase in mid-latitudes (Parry et al., 1990). Changes in climate that increase spring and early summer rainfall will increase disease. However, it is unlikely that these changes will be discernible during the next decade against the background of normal seasonal variations.

Another possible effect of climate change are milder winters. The increases in barley yellow dwarf virus (BYDV) in spring and winter cereals in 1989 and 1990 were due to prolonged aphid activity in the autumn and early flights into crops in the spring. Development of barley mildew during recent mild winters also illustrates some of the problems likely to occur if such weather patterns become common place.

Many of the most important diseases of Britain's combinable crops are dependent on high humidity or rain (Table 3). If late winter or spring rainfall increases we suggest these diseases might become more severe, irrespective of summer droughts. This will require greater skill in crop management, as there will often be relatively fewer "spray days". Advances in spray application technology are unlikely to ameliorate such difficulties. However, improvements in formulation chemistry may offer some prospects for improving the persistence and tenacity of fungicides.

Cropping patterns

Any consideration of disease potential and risk needs to take account of the position of individual crops in the farm economy. Many farmers are now geared entirely to arable crop production and have no alternative but to continue with intensive production systems. It is in these situations and where the diversity of genetic variation is limited that disease risk is highest, as recently noted with yellow rust in the winter wheat cultivars Slejpner and Hornet. The risk of diseases such as take-all, eyespot and sclerotinia are entirely dependent on soil-borne inoculum so that their severity is influenced by the number of susceptible crops within the rotation.

TABLE 3. Combinable crop diseases dependent on wet weather and likely to increase if springs become wetter.

Crop	Disease
Winter wheat	Septoria species Yellow rust Eyespot
Winter barley	Net blotch Rhynchosporium Eyespot
Oilseed rape	Light leaf spot Alternaria
Beans	Chocolate spot Downy mildew
Peas	Aschochyta Botrytis

Disease risks

Examination of the major disease problems affecting combinable crops indicate that some have been amenable to control by breeding. Classic examples are the cereal rusts and mildews but the benefits have often been short-lived, the resistance being overcome by pathogen variability. A similar, but more recent example is the occurrence of resistance-breaking strains of barley yellow mosaic virus. These examples confirm that before significant progress can be made there is a need to identify durable resistance in new cultivars. Other diseases have been less amenable to control by plant breeding, eg: sclerotinia, chocolate spot, ascochyta and take-all. For many of these there is no alternative but to have recourse to fungicides.

Disease development

Recent research (Thomas et al., 1989) has shown that although effective control of Septoria tritici on wheat can be achieved by programmes of fungicide sprays applied throughout the growing season, yields are reduced only by disease attacks on the final two or three leaves (ie, the flag and the one or two leaves below it). Fungicides need only be used if suitable conditions allow infection of these leaves. Furthermore, the incubation period of this fungus is relatively long (eg. Shaw, 1990). Therefore, if disease has not become severe by early June it is unlikely that significant yield-reducing epidemics will be able to develop before the crop is mature. Similarly, fungicide applications later than the end of flowering are unlikely to be cost effective in many situations (Cook & Thomas, 1990).

Experiments studying disease development (Thomas et al., 1989) have also provided other insights into the relationships between disease, crop growth and disease-induced yield losses. There is, for example, a steady decline in yield response to application of fungicides for disease control after the middle of May, irrespective of the disease present. The available evidence for yellow rust, brown rust and mildew of wheat suggests that treatment applied during flag leaf emergence is an essential element of spray programmes. Data from ADAS experiments in 1989 illustrate these points (Table 4). Spray programmes commencing at successively later growth stages have been used to determine optimum spray timing for individual diseases. In general yield declines successively as the spray start date is delayed from the second node stage (ie when the second leaf below the flag leaf was emerging). At each of the sites disease incidence was well related to yield loss accounting for 78, 66 and 74 per cent of the variance for yellow rust, S. tritici and mildew respectively.

TABLE 4. Effects of spray programmes on yield and disease development at three sites in 1989.

Spray at	Terrington		Adisham		Rosemaund	
growth stage:-	Yield	%yr	Yield	%st	Yield	%m
30	8.84	0.2	-	-	12.10	7.8
31	8.76	0.0	-	-	12.28	0.8
32	7.77	0.8	8.13	5.3	11.86	2.5
33	7.73	0.9	8.05	6.8	12.02	2.7
37	7.79	0.2	7.40	7.7	11.11	0.1
39	8.11	0.2	7.53	11.7	-	-
45	8.19	2.1	7.25	14.2	11.38	1.4
50-59	7.62	13.0	-	-	10.87	10.0
60-69	7.10	21.2	6.65	16.8	10.27	15.5
71-75	6.50	25.8	6.15	14.8	9.89	15.3
Untreated	6.33	30.9	5.79	16.5	9.03	20.3
St. Dev.	0.88	11.94	0.95	4.88	1.32	8.02

Yield is in t/ha. Diseases were measured as the percentage area affected on second youngest leaves. (yr = yellow rust; st = S. tritici; m = mildew)

At both Terrington and Rosemaund, where yellow rust and mildew were severe on the lower leaves by first node, most effective control and yield increases were recorded with spray programmes which started during this period. Study of progress curves showed that late season control was most effective when disease started to develop on upper leaves during the third node to flag leaf emerged stage.

Applications of single active ingredients appropriate for controlling the diseases present in this period between emergence of second node and flag leaf have always given yields equivalent to those of the best spray programme.

These data suggest that satisfactory and effective control of foliar diseases can usually be achieved from single sprays of effective fungicides applied during mid-May and that there is a yield penalty if these are delayed.

For eyespot, the situation is slightly different. Traditionally, fungicides have been applied during early stem extension, but more recently it has become clear that effective control can still be achieved from treatments applied later than this, at about two nodes detectable or in early May.

Experimental evidence for winter barley shows that the crop responds very differently to fungicides compared with wheat in that the largest yield response to a single spray usually comes from one applied at around the first node stage. Oilseed rape, peas and beans are different again; here the petals and pollen produced during flowering and then shed onto the leaves have a stimulating effect on such diseases as sclerotinia, grey mould and chocolate spot (Harrison, 1988). Linseed, despite the number of diseases that affect the crop has proved remarkably unresponsive to treatment (Hardwick & Mercer, 1989, Mercer & Hardwick 1990). Pea and bean crops tend to be erratic in their responses (Brokenshire & Oxley, 1990).

These are important principles. Careful study of disease life cycles in relation to crop physiology has defined those periods in crop development when diseases may be present but have relatively little influence on yield. Clearly, there is no point in applying fungicides during certain development stages - they may reduce the disease in the short term but they are unlikely to be economic.

Fungicide usage

For some years fungicides have been classified as protectant and eradicant or curative (Anon, 1973). Recently there has been a tendency to separate the terms curative and eradicant, so that eradicant is only used for control effected by applications made after symptoms have become apparent. This split in the terms is confusing and from a biological view-point invalid. It is possible to eradicate a pathogen, but not cure the disease, which is the symptom caused by the pathogen.

The different properties of fungicides have been appreciated by users and the industry at large for many years but we doubt that they have been exploited to their full potential. Recent work with septoria diseases in the UK (eg; Jordan *et al.*, 1986; Cook & Thomas, 1989) has demonstrated the protectant properties of chlorothalonil and the eradicant properties of the triazole fungicide group. Improved understanding of the properties of fungicides can be used with the knowledge of disease biology to enhance disease control.

In the UK over 90 per cent of winter cereal crops are currently treated with fungicides. However, evidence from ADAS surveys (Cook *et al.*, 1990) indicate that on winter wheat some of these programmes are not being applied at the optimum time to maximise control of their intended targets during the critical periods of crop development.

On oilseed rape fungicide use is less, at 56 per cent of the total crop area (Hardwick *et al.*, 1989), and timing is generally closer to the optimum. There has been a change from the majority of fungicide sprays being applied at the end of flowering to most being applied during stem extension as the disease of most concern has changed from *Alternaria*

(A. brassicae and A. brassicicola) to light leaf spot (Pyrenopeziza brassicae). It is also possible to define areas of the country which are at lower risk from disease and will, therefore, require less fungicide input. The further north in England crops are grown the less disease is found and the less responsive is the crop (Hardwick & Evans, 1988). It may, therefore, be possible to grow rape without fungicide treatment in these areas (Hardwick, 1990) and consideration might be given to growing specific crops in prescribed areas.

The fungicide dilemma

There is a problem. In order to achieve maximum returns from a smaller but more intensively cropped area fungicide use is necessary. In contrast, consumer and environmental pressures dictate a need to reduce pesticide inputs.

Much of the area of combinable arable crops is winter sown (Table 2). Their success is heavily dependent on pesticide applications in autumn and spring (eg Hardwick et al., 1989). Restrictions on foliar treatments, such as an autumn moratorium, would lead to major alterations in crop husbandry including later sowing in the autumn to reduce the risk from BYDV. This would, however, conflict with desires to increase cover by crops in the autumn to decrease leaching of nitrates. Later sowing in the autumn would lead to more sowing in the spring. This would tend to reduce the requirement for pesticides but give smaller yields. However, there would not necessarily be concomitant reductions in gross margins compared to those from winter sown crops with enforced reductions in pesticide inputs (Table 1).

One way of maintaining high yields while meeting demands to reduce foliar sprays may be to develop more effective seed treatments to reduce the amount of active ingredient applied. Indeed there is some urgency to do this as mercury is withdrawn from use on cereals. There is, however, a potential risk in this change. Many of the currently available chemicals which will be used as mercury replacements in the short-term belong to the widely-used triazole group of fungicides and will, therefore, increase the already considerable selection pressure on pathogens to develop resistance.

Reducing fungicide inputs would mean that greater emphasis would have to be placed on crop rotation and the use of resistant cultivars. However, disease resistant cultivars may have less yield potential, or, as in the case of the winter wheat cultivar Rendezvous, be deficient in key aspects of quality so, as always, compromises will have to be sought.

DISEASE CONTROL DECISIONS

British arable crop production is intensive with many large farms, which contrasts with the situation in much of mainland Europe. This has tended to stimulate the development of a large support industry with professional crop consultants acting either independently or on behalf of agrochemical and merchanting companies. As a consequence many crop protection decisions are made relatively remote from the farmer. This trend is likely to continue, but we envisage these relationships evolving during the next decade. For example, the recruitment of crop monitors to undertake observations during critical periods in crop development during the season would provide the farmer and their consultants with more detailed information on which to base treatment decisions.

Disease diagnosis

Advances in serology and related sciences offer exciting prospects for development of pathogen specific diagnosis systems. Identifying the cause of a crop problem is crucial for its solution but is often difficult for the farmer, as demonstrated by Smith and Webster (1986). Systems currently at, or near, the market place can improve the precision of disease diagnosis and in the future this technology will have a wider role in crop protection (Plumb, these Proceedings).

Nevertheless, we suspect that the potential value of these tools in practice has often been exaggerated. They will, at least for the foreseeable future, be relatively costly and they may not be as quantitatively accurate as often claimed. Their use will mostly be restricted to confirming the identity of pathogens as they will not necessarily help to establish the cause of a disease or problem. In practice their main role is likely to be to as an aid in research.

Information delivery

The revolution in information technology has so far not been widely adopted by the arable sector. Systems to improve information flow and to help individuals make better, more cost-effective decisions are already on offer. However, the demise of Prestel Farmlink and the ICI Agviser systems show that sheer volume of information and supplier enthusiasm is not enough. There rightly remains an inherent suspicion of electronic information and the need to get "mud on boots" will remain for a long time. We see information technology increasingly providing the back-up necessary for consultants and others with a specialist role. It also provides the potential for exchange of information in electronic form.

CONCLUSIONS

Two, increasingly powerful, forces for change will come together:

1. Demands for smaller areas of production to reduce total output.
2. Demands for chemical-free produce.

The two are not easily reconciled as more land will usually be required to produce food using fewer chemicals because yields tend to be considerably lower under "extensive systems" compared with current intensive systems. This move would, however, be compatible with the perceived requirement of the general public for land to be farmed in a "traditional" manner with lower agrochemical inputs. There is the advantage that the land could be immediately returned to a high input/output system should it prove necessary.

We consider that our future, as our past, lies with the plant breeders, producing plants which are not dependent on high inputs of chemicals to produce their maximum yield. This will involve not only incorporating new genes for disease resistance but modifying the structures of the plant, eg determinate bean cultivars and petal-less pea and oilseed rape cultivars.

Fungicides may be increasingly restricted to seed treatments with minimum use of chemicals applied to foliage. Those diseases for which fungicide sprays are the only option may need to be more carefully circumscribed. The "Pesticides code of practice" (Anon, 1990) provides the potential framework for the establishment of a requirement to obtain a licence to make individual applications. Permission may depend upon the risk, the development stage of the crop and the level of attack. A licence might only be given by a restricted number of certificated consultants. The greater precision needed to give prescriptive advice would require more confidence in disease forecasting and would imply a need for increased expenditure on R&D.

There is a postscript. Many researchers have long argued that we should use arable crops as chemical feedstocks or biofuels. These options were untenable during the period of low oil prices in the mid to late 1980s. However, increases in oil prices would make such uses more attractive. Such a scenario would increase demand for agricultural produce and lead to the intensification of production beyond that previously envisaged. It might even see evaporation of public concern for the environment.

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OPPORTUNITIES FOR CONTROL OF INSECTS IN ARABLE CROPS USING SEMIOCHEMICALS AND OTHER UNCONVENTIONAL METHODS

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ABSTRACT

The ways in which semiochemicals are employed in arable crop protection and the problems relating to their use are reviewed. Methods of increasing the effectiveness of pheromones, allomones and kairomones in unconventional strategies are described.

INTRODUCTION

At present, most insect control on crops is managed effectively by conventional chemicals, on which more than US $ 6000 million is spent each year (Jutsum *et al.*,1989). However, because of the development of resistant strains of insects and public pressure to reduce pesticide use, there is an increasing need to explore alternative methods. This paper reviews progress that has been made with semiochemicals alone or in combination with other agents, and examines the prospects of such methods for future use.

DEFINITIONS

Semiochemicals are "signal chemicals" which transfer information between organisms; they are also known as behaviour-controlling or behaviour-modifying chemicals. They are broadly divided (see Nordlund *et al.*, 1981) into *pheromones*, where communication is between members of the same species, and *allelochemics*, where interaction is between members of different species (Fig.1).

Semiochemicals
(Signal chemicals)

Pheromones
(act on same species)
1. Sex pheromones
2. Alarm pheromones
3. Epideictic pheromones

Allelochemics
(act on different species)
1. Allomones (favour emitter)
2. Kairomones (" receiver)
3. Synomones (" both)
4. Apneumones (from non-living source)

Figure 1. Classification of semiochemicals.

PHEROMONES

Sex pheromones influence mate finding and courtship behaviour, alarm pheromones warn neighbours of impending danger and epideictic pheromones influence the spacing of organisms e.g. aggregation pheromones and oviposition pheromones.

Pheromone use in insect management has been recently reviewed (Ridgway et al. 1990b). The greatest progress in the use of pheromones in insect control strategies has been in the development of monitoring systems (Wall, 1989). Many such systems have been successfully developed, based usually on the sex pheromones of Lepidoptera or the aggregation pheromones of Coleoptera. Sometimes food components are added to pheromone traps, for example to enhance their attractiveness to certain Diptera.

A successful example of the use of pheromones in British agriculture is the monitoring system for the pea moth Cydia nigricana. The basic kit for sale to growers consists of a pair of sticky traps baited with an analogue of the pea moth female sex pheromone. The farmer places the traps 100 m apart and 5 m into the crop on adjacent headlands on the side of the prevailing wind. The traps are examined every other day and if a "threshold" is reached (10 or more moths in either trap on two consecutive examinations), the farmer can telephone the ADAS/PGRO 'phone-in' service for advice on the most appropriate time to spray. The advice is based on computer models, using the date when threshold numbers of male moths were caught and the recorded and forecast daily temperatures from a series of local meteorological stations. The purpose is to predict when the larvae will hatch from the eggs laid by the females, so that they can be killed before they enter the pods. Because the pea moth is an erratic but very damaging pest, there is the temptation for growers to apply insecticide as an insurance policy and one of the greatest virtues of the monitoring system is that, when no threshold is reached, the farmer has a clear indication not to spray. Considerable research went into the system but, for the farmer, it is very simple to use.

There are no well-documented examples in the UK of the agricultural use of pheromones for direct control of insect numbers, although exciting work is in progress with aphid sex pheromones, to capture male aphids (Campbell et al.,1990), and alarm pheromones, to flush aphids out of their protected feeding sites and to make them easier targets for contact pesticides (Pickett, 1989; Bennett et al., 1989; Zhang, personal communication). Possibly the best-known example from overseas agriculture is the application of the female sex pheromone of the pink bollworm to cotton fields to confuse the males and to disrupt their normal mating (Campion, 1989; McVeigh et al., 1990, Baker et al., 1990). The other main method of controlling insect numbers with pheromones is by mass trapping. A good example from agriculture is the use of the aggregation pheromone of the cotton boll weevil to trap insects of both sexes and to decrease significantly their numbers where low density populations exist (Ridgway et al., 1990a).

Why are there so few examples of established agricultural uses of pheromones for insect control? Silverstein (1990) lists some major causes of failure, which include inadequate knowledge of insect behaviour, inadequate definition of chemical communication systems, high population density, too small an effort (inadequate resources), inadequate pheromone formulations, improper distribution of traps or release sources, invasion from outside the test area, and poor timing. However, these difficulties have been overcome in the case of many forestry and fruit pests,and there is no reason to believe that, given well-directed research, the same cannot be done for a greater range of agricultural pests.

ALLELOCHEMICS

The two main classes of allelochemics that have been most studied from the point of view of insect control are kairomones (which are of benefit to the receiving organism) and allomones (which are of benefit to the emitting organism).

Kairomones, for example, include chemicals produced by host insects which aid their location by parasites or predators. There is considerable research interest in these compounds for increasing the effectiveness of natural enemies (Powell *et al.*,1990). However, the inter-relationships are often complex and the very compounds that act as pheromones for one species may act also as kairomones towards a different species. Thus, the aphid alarm pheromone, in addition to disturbing aphids, is thought to attract syrphids (Bennett *et al*, 1989), so the chemical ecology of such substances requires to be understood fully before they can be put to practical use.

Volatile kairomones and allomones

Volatile substances from plants (both kairomones and allomones) represent an area of pest control research that deserves much greater attention than it has received in the past, and for which powerful research methods are now available. Insects are attracted to host plants or repelled from 'unsuitable' plants by general plant volatiles which can now be studied by entraining air over the plants and collecting the volatiles in a trap (Blight, 1990). The resulting sample can be investigated by a technique which, in its most sophisticated form, combines gas chromatography (GC) with single cell recording (SCR) from the insect antenna (Wadhams, 1990). Samples from the entrainment are injected onto a GC column to separate the complex mixture of substances into individual components. The output from the column is split into two, one part going to the GC detector (which is sensitive to all the components) and the other part being directed simultaneously to the insect antenna. A micro-electrode, inserted into a sense cell on the insect's antenna, records the activity of the individual olfactory cells, which are "tuned in" to receive specific chemical signals. Thus, when the right compound arrives, the cell "fires", so the single cell preparation pinpoints exactly which compounds stimulate the insect's receptors. This technique has been used to great effect with aphids and other insects , but much detailed study is still required to determine the behavioural role of the electrophysiologically active compounds. Again, a material that acts as an allomone for one species may behave as a kairomone for another species. For example, the isothiocyanates, which make *Brassica* plants distasteful to many species are attractive to Brassica specialists such as cabbage white caterpillars and the mealy cabbage aphid .

Involatile substances

The involatile allomones of plants include the antifeedants and oviposition deterrents. There is a long history of work with antifeedants (Chapman, 1974) and some active materials have been found , particularly from the families Meliaceae, Labiatae, Solanaceae, Simaroubaceae, Polygonaceae and Piperaceae . Some progress has been made with marketing them, for example, azadirachtin from seeds of the neem tree Azadirachta indica is marketed in the US for insect control, quassinoids from plants belonging to the Simaroubaceae are marketed for vertebrate control, and seaweed preparations sold as fertilizers are said to affect pests also. However, no antifeedant is marketed as a pure compound for insect control, despite scientific evidence of considerable activity for some antifeedants. For example, azadirachtin stimulates the gustatory sensillae of larvae of Spodoptera exempta at levels of 2.36 x 10^{-8} M (Simmonds & Blaney, 1983).

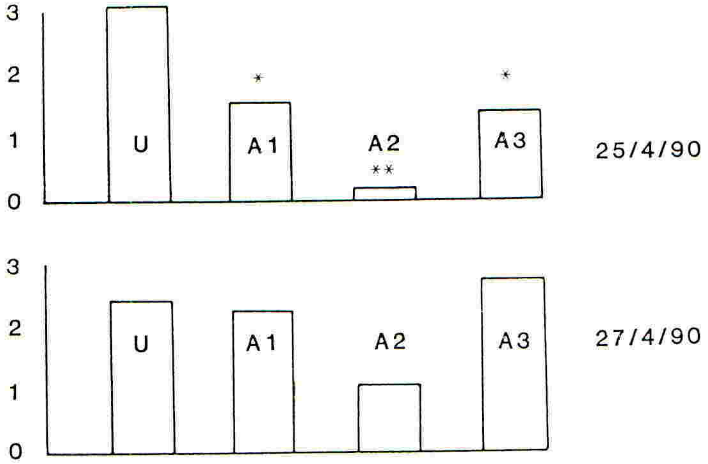

Figure 2. Mean number of pollen beetles per raceme. Sprays applied on 25.4.90. U = untreated, A1,2,3 = different formulations of antifeedants. **,* = significantly different from control at P = 0.01, 0.05.

Antifeedants have a rapid action and can interfere with virus transmission by aphids in the laboratory (Gibson et al., 1982) and in the field, where they have given significant increases in yield (Dawson et al., 1986), although in this case repeated sprays were necessary. However, whereas conventional insecticides usually have a broad range of toxicity, some antifeedants are not equally effective against a wide range of insects. Also, in many cases antifeedants have given disappointing results in the field (Bernays, 1983). A possible reason is transience of the antifeedants. For example, in trials at Rothamsted, three antifeedant formulations gave considerably decreased numbers of pollen beetles on oilseed rape when counts were made within a few hours of application (Fig. 2) but the effects had disappeared two days later. It may be possible to improve performance of antifeedants by employing slow release formulations, although this may be counter-productive if it leads to decreased initial activity.

Another explanation of the short-lived effects of antifeedants in the field is habituation of the insect's nervous system to the compounds. For example, Raffa & Frazier (1988) showed that larvae of *Spodoptera frugiperda*, given a choice between untreated foliage and foliage treated with aristolochic acid, did not eat the treated foliage at first, but when the untreated had all been consumed, the insects ate the treated foliage as voraciously as if it was not treated at all.

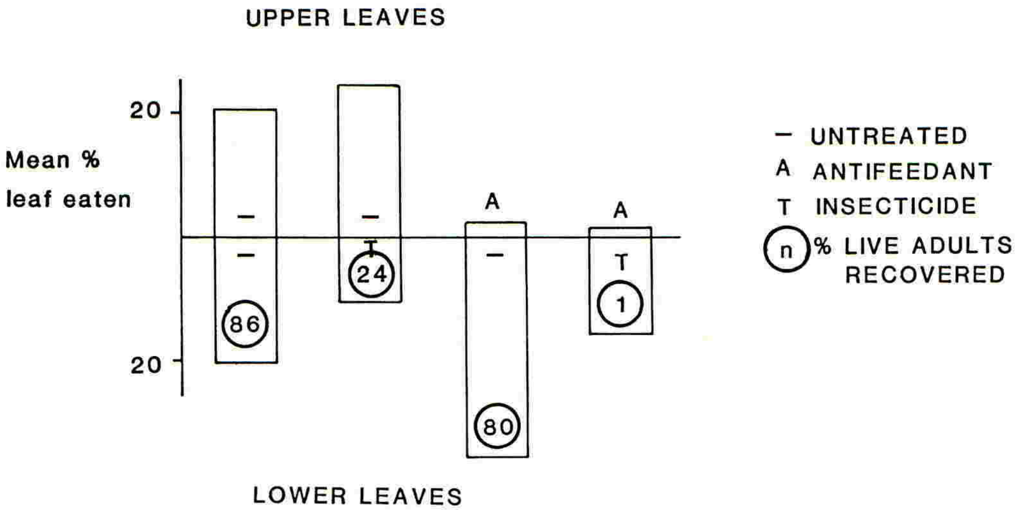

Figure 3. A push-pull strategy on a laboratory scale. Mustard plants attacked by mustard beetle larvae. Upper leaves treated or not with antifeedant, lower leaves treated or not with insect growth regulator insecticide. (Griffiths *et al*., 1990).

The consumption of antifeedant-treated food in conditions of no choice can be explained by classical ethology in terms of an increase in reaction specific energy associated with the physiological need to feed (Thorpe, 1948). Alternatively, it may be the result of desensitization of the peripheral or central nervous system brought about by increased contact with antifeedant. Whatever the explanation, the effect is real and would apply equally to built-in allomones brought about by genetic manipulation of crop plants. It follows that the main effects of antifeedants are likely to be during the first few hours, or at most the first few days.

This may be sufficient when interference with the early acquisition or transmission of viruses is the aim, but it implies that, for longer term protection, antifeedants should not be used in the same way as conventional pesticides in the field. The best way to employ these biologically active compounds , therefore, is to make maximum use of their immediate effect and to integrate them with other methods in novel pest control strategies. It is the development of such strategies that will be the key to their use.

Novel pest control strategies

The potential for using antifeedants in new ways has been demonstrated on a laboratory scale by applying antifeedant to the tops of mustard plants (Fig. 3) to drive mustard beetle larvae down to the lower, less vulnerable leaves.

When the lower leaves received a slow-acting insect growth regulator, the larvae fed readily and were killed. This combination of treatments achieved long-lasting protection of the vulnerable parts of the plant, with no opportunity for habituation by the insects, coupled with control of the insect population using only minimal amounts of a selective pesticide. Such a method is called a push-pull strategy or stimulo-deterrent diversionary strategy (SDDS) (Miller & Cowles, 1990).

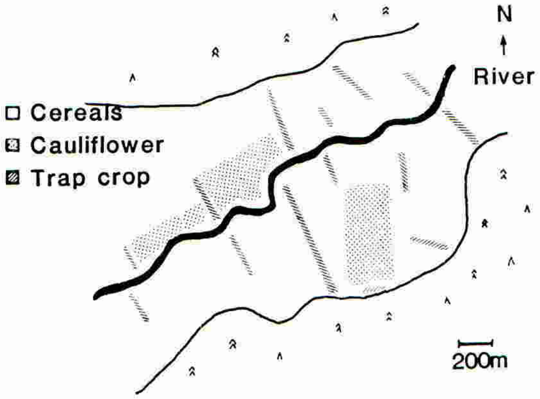

Figure 4. A trap crop system . Trap crops = 4 ha total, main crop (cauliflower) = 40 ha. For clarity the trap crop strips are shown disproportionately wide. (After Hokkanen et al., 1986).

A similar approach is being examined in the field, at Rothamsted and elsewhere. In an ideal example of this method, pests entering a crop would be deflected to an area of trap crop by visual cues and by attractant kairomones, and held there by involatile kairomones (feeding stimulants). A selective pesticide would be applied to the trap crop; the long term aim is to use an improved microbial pathogen applied to the undersurface of leaves to kill insects *in situ* and to infect and spread infection to others if they escape. The crop plants would not be treated with pesticides but may be treated with allomones, and with plant kairomone inhibitors, to switch off pest attraction to the crop.

The question that arises is whether it is technically feasible to develop such systems in agriculture. To answer this, let us look at the individual components. First, there is evidence that trap cropping does work. Thus, Hokkanen et al. (1986) used trap areas of Chinese cabbage, calabrese and oilseed rape 3- 5 ha in extent to protect 40-45 ha areas of cauliflower (Fig. 4) from pollen beetle, and so decreased damage by this insect from 20-40% to 3-15%. Progress has been made in identifying antifeedants active against different orders of insects, e.g. clerodanes against Coleoptera (Griffiths et al., 1988), drimanes against aphids (Asakawe et al., 1988). Air-entrainment of insects and plants followed by investigation by GC-SCR methods make it possible to identify plant-derived kairomones and insect- derived aggregation pheromones which could be used to enhance the attractiveness of the trap crop. Spray application systems exist (Arnold & Pye, 1980) for the accurate placement of biological pest agents on the undersides of leaves, where they are protected from desiccation and UV radiation. Effective strains of entomophagous microbes are being found, at least for some pests (Eilenberg & Philipsen, 1988). Separation of closely related plant components is now possible with HPLC Plasmaspray/thermospray techniques (Mudd, 1990), thus facilitating the identification of both allomonal and kairomonal plant constituents. Finally, kairomone inhibitors do occur in nature, and have recently been identified in aphids (Wadhams, personal communication). Such compounds form the scientific basis of "companion plant strategies" where susceptible crops such as carrots are interplanted with smelly neighbours such as onions to deter carrot fly attack (Matthews et al., 1983).

Thus, the ability to develop the individual components does exist, and such studies form part of existing research projects on onion fly control in the US (Miller & Cowles, 1990), cotton pests in Australia (Pyke et al., 1987) and the multidisciplinary project on pests and diseases of oilseed rape that is being supported by the MAFF in the UK.

Will growers accept the use of unconventional pest control strategies if they can be developed? At the moment, these methods look complicated because of the nature of the research and development that is involved. However, increased knowledge should supply leads for plant breeding and genetic manipulation. The long term aim is to develop plants with their own built-in protectants expressed in the appropriate part of the plant, as has been done already for toxic agents (Boulter et al., 1989; Van Mellaert et al., 1989). In its final form, the novel method would be just as simple to operate as a monitoring system, and would consist merely of an attractive trap crop sprayed with a biological pesticide, sown next to a harvestable crop containing its own allomonal compounds.

To work out the chemical ecology for each crop/pest situation and to put the components together as a coherent system is a considerable challenge to the researcher, but one that is full of scientific interest and whose long-term influence will be of great benefit to the consumer and to the environment.

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