SESSION 5

LAND USE STRATEGIES AND AGROCHEMICALS IN THE 1990s: CONFLICT OR CO-EXISTENCE?

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INVITED PAPERS 5-1 to 5-4

CHANGING LAND USE STRATEGIES AND IMPLICATIONS FOR CONSERVATION

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ABSTRACT

Embarrassingly large supplies of many agricultural commodities, with production well ahead of effective demand, led policy makers to seek ways to control production. Although a number of factors have greatly reduced stored surpluses the potential to increase production remains. Measures have been introduced which are designed to take land out of arable production and to encourage farmers to have more concern for the effects of farming practices on the environment. The extent to which these changes will benefit the environment will depend on the way in which the land is managed. There will also be implications for adjoining land and for those fields which return to cropping after being set aside. European Community funded schemes to change land use are, at present, voluntary. The rate of take up by farmers will depend on how attractive they are judged to be in relation to individual farms. Nevertheless changes in attitudes towards land use and crop production regimes are inevitable in order to meet the public demand for quality food and an attractive countryside.

INTRODUCTION

Although I do not wish to spend time looking back it is necessary to cast a brief look backwards to see what forces have been at work and how these have influenced the present and may affect the future.

This does present problems. This paper is being written during the summer for presentation in November. The UK harvest has been completed over most of the country and the indications are that cereal yields, at around 23,300,000 tonnes will be some 2 million tonnes more than last year, despite the drought. The quality of produce, especially wheat, is generally very good and there will be a surplus for export. Drought has affected parts of the USA and Canada and large areas of Europe.

The world and UK food supply position and the future looks very different from a year or two ago and this could influence the European Community (EC) and UK policies towards land use. For the third year in succession world wheat production will not meet demand. According to the United Nations Food and Agriculture Organisation, world grain stocks are critically low and unlikely to recover for at least a year. Wheat stocks in cereal exporting countries are at their lowest since the early 1970s.

A further note of caution is also necessary, where agricultural markets are concerned - which of course influence land use - uncertainties make predicting the future a very high risk occupation. Had we been discussing this problem five years ago it would not have been possible to predict the present agricultural situation or the land use strategies which will be in operation during the 1990s.

During the 1970s agricultural production expanded strongly in response to a large increase in price levels. Poor crops in many exporting countries and a rising demand were the main factors influencing production and the adoption of new technology. This period of expansion was followed by depressed demand, the accumulation of surpluses and the emergence of a policy with the main objective of restraining production. Between 1970 and 1980 world grain trade doubled from 100 to 200 million tonnes. Since then the trade has dropped back and has not recovered to its previous peak.

Surpluses, which are seen by many to be based on too high a price structure and the over-use of chemical aids to production, have been greatly reduced and over a very short period. It is the relative fragility of the surplus/shortage equation which cannot be ignored and which, I suspect, is of great concern to politicians. Following the drought, US wheat production in mid-July 1988 of 43.3 million tonnes showed a carry over of 6.4 million tonnes or just over half their safe trading level strategic reserve. The European Comminity began the 1988/89 trading season with intervention stocks of 3.8 million tonnes of wheat compared with a peak of 10.3 in 1984/85. Natural catastrophies, such as droughts, floods, locusts and smaller harvests in Europe can recur and at unpredictable intervals. Few, if any, of the critics of the Common Agricultural Policy (CAP) and modern farming methods recognised that production might fall and embarrassing surpluses become strategic reserves, maybe even shortages, in such a short time.

CONTROL OF PRODUCTION

It was the embarrassingly large supplies of agricultural commodities, with production well ahead of effective demand, which led policy makers to seek ways to control production. Technological advances have helped to produce a situation where the European Community is well able to meet its needs for the main commodities. Indeed it has become an increasing exporter which has further depressed world markets. The cost of maintaining prices to EC producers has risen and Europe is also in conflict with other major exporters. European governments have introduced measures to contain the cost to tax payers of agricultural support and to bring production of the major crops more in line with demand.

The introduction of milk quotas in 1984 was the first major step which epitomised the change from expansion to a period of restraint on production. Other measures followed, the most comprehensive being stabilisers introduced in 1988. Budgetary discipline limits the rate of growth of CAP expenditure to 74% of the rate of growth of Community gross national product (GNP). This means a real annual growth of about 2% between 1988 and 1992 compared with a figure of 10% per annum over the previous four years. At present (summer 1989) expenditure is about 7% below estimates.

Milk quotas are, of course, a physical control over production and the UK Government's preference is for action on prices rather than a widespread use of quotas. A mixture of price and supply controls and incentives for farmers to diversify are seen as providing the necessary flexibility for the future. Within this framework it would not be too difficult to change in the future should market circumstances and other developments make this necessary.

There are also external pressures through the General Agreement on Tariffs and Trade (GATT) to effect a 'substantial', progessive reduction in support and protection for agriculture. The UK Government believes that nearly all economies would gain if support and protection for agriculture were to be reduced. As far as the CAP is concerned there is a feeling that substantial improvements have been made and that farmers should be given time to adjust. Farmers in Europe have come to accept that high levels of support cannot be sustained and they have to operate within the constraints of a real market.

The impact of 1992 on agriculture is likely to be less than on other parts of the economy because, within the Community, it is already subject to common organisation of the market and a common set of rules. What is intended is a true common price system with the abolition of the agro-monetary system. More liberal trends across frontiers and more market competition will require farmers to pay greater attention to the precise requirements of the purchaser.

All these changes and proposals have taken place against a background of growing concern for the environment. Public concern for the environment and about farming methods now exerts a major influence on agricultural policy. Competition between farmers and the general public - who have increasing leisure time - over the quality of the countryside is of increasing concern as also is the occupation of the countryside by those who have no direct connection with farming or countryside pursuits.

ENVIRONMENTALLY SENSITIVE AREAS

UK Agriculture Ministers are (since 1986) under a statutory requirement to maintain a reasonable balance between agricultural interests, the economic and social needs of rural areas, conservation and recreation. Policies have been introduced designed to encourage farmers to have more concern about the impact of farming practices on the natural flora and fauna. The Alternative Land Use in the Rural Economy (ALURE) package, introduced in 1987, included woodland planting grants and funds for diversifying out of food production. The measures may be available to all farmers as with Set Aside and the Farm Woodland Scheme, or they may be specific to defined areas as with the Environmentally Sensitive Areas Scheme (ESA). In the latter farmers in the designated areas are encouraged, by financial incentives, to farm in ways which are more friendly to the natural environment. The scheme is voluntary and has attracted a lot of interest. Over 2500 farmers have applied in the various areas involving about 100,000hectares. Measures are designed to maintain or re-introduce 'natural' features such as low input/low output species-rich grassland through restrictions on the use of fertilisers and herbicides. The Breckland ESA offers financial incentives to those farmers willing to adopt 'conservation headlands' based on the work of the Cereal and Gamebirds Research Project. The ESA proposals are clearly designed to encourage environmentally sensitive farming - that is the main objective of the scheme. Other schemes, designed to take land out of farming as the main objective also aim to help wildlife and the environment. It is here that confusion sometimes arises because of the different objectives and the conflicts in management which can arise.

The ESAs contribute to reducing agricultural production as lower inputs are an integral part of the scheme together with retaining land in extensive use, rather than converting to arable or heavily stocked grassland. The effects of these management changes on wildlife are being carefully monitored. Uptake under the scheme has been encouraging but the ESAs cover only a small proportion of the UK farmland, a number are very small and the larger ones are located in marginal farming areas.

The major thrust to removing land from farming use lies under the Set Aside Scheme and the Farm Woodland Scheme - both voluntary.

SET ASIDE

Set Aside is, in the words of the Minister of Agriculture,"an opportunity for farmers to reappraise the way they manage their land during the next few years. Voluntary Set Aside is just one of the number of options open to you".

The Scheme is designed to reduce surpluses of arable crops. For taking out of production at least 20% of land growing arable crops, based on the year 1987/88, annual compensation is payable up to £200 per hectare for 5 years. Uptake for 1989 is 1816 farms offering 57613 hectares for set aside. Another 1412 farmers have registered 58330 hectares for 1990. There are a number of options and it is important to note that there must be no agricultural production from the land.

Options include fallow - permanent, where the same land is taken out of production for the full five years,
- or rotational fallow where the area of land left fallow is moved round the farm as part of the arable rotation.
The fallow may be whole fields, parts of fields or strips at least 15 metres wide.
The fallow option attracts the highest level of payment, but there are restrictions. Cultivations are to be avoided if possible, although traditional fallowing involved moving the land regularly. Cultivations must be used to control weeds in preference to herbicides and then only when really necessary. Cultivations are limited to spring and autumn and plant cover is recommended for the winter to reduce nitrate leaching.

Other options include establishing plant cover, including game mixtures or green manure crops. Cover such as this must be cut at least once a year. The cuttings must be left to lie on the land, they cannot be burned. If removed they must not be fed to agricultural animals. Horses (not for horse meat) can use the forage.

The use of pesticides on set aside land is prohibited - certainly insecticides and fungicides. Authority to use herbicides may be granted 'in limited circumstances'. Cutting is likely to be preferred to the use of herbicides. Only foliar herbicides will be permitted and only those which have little or no persistance in soil or water. In other words 'non-residual'. Here we have an example of actual controls over the use of herbicides under specific farm conditions.

Spot treatments or with a wick applicator are strongly recommended and if an overall spray is authorised to control weeds (normally Cirsium vulgare, C.arvense, Rumex crispus, Elymus repens, Alopecurus myosuroides or Galium aparine) a selective herbicide must be used. A record of all herbicides used on set aside land must be maintained, including the reasons for use.

Fertilisers cannot be applied to set aside land, although at the end of a one year fallow preparations can be made for the next crop. If necessary lime is allowed. No slurry or farmyard manure can be applied.

Set aside land can be used for non-agricultural purposes such as tourist facilities, caravans, camping, riding schools or nature reserves. This attracts a lower rate of grant.

There are also woodland options although these are bound to be of limited interest if the farmer wishes to bring the land back into cropping after the five year period.

The siting and subsequent management of set aside areas can be very significant for wildlife. Land set aside alongside existing wildlife habitats will extend their value and provide a 'buffer zone' against farming operations. Set aside can also link existing features. Managing set aside land requires a different approach from that of managing existing farm land, including conservation areas. Plants normally regarded as weeds - apart from those listed above, will be tolerated. Herbicide use will be drastically reduced both in volume and in type. Other methods of control such as cutting will be in favour. At present Set Aside is not all that attractive, although there will be farms - usually the larger ones, where marginal cereal growing land may 'pay' better in Set Aside than growing a moderate crop. On better land the return from crops should be greater than from Set Aside payments. Removing 20% of the arable area from cropping will raise overheads on the remainder as machinery will be used on a smaller area. Some farmers have set aside the whole farm which allows the dispersal of all but the minimum of equipment and, sadly laying off labour. In five years time they hope to be able to return to cropping with a rested and refreshed farm.

Just how attractive Set Aside will be depends on the prices received for farm produce, especially cereals. At present land set aside is about 2% of the total arable area. If cereals are in short supply, depending on the world situation, then the Set Aside option will be less attractive. It will mainly be of interest to those with marginal areas of arable land - even whole farms in some cases.

Set Aside can benefit wildlife particularly through providing wildlife corridors and acting as a buffer between habitats and cropped land. Some areas will develop a diverse flora or be sown to wildflower mixtures. Game crops will be atrractive to those with shooting interests and these will also help other wildlife. To be of greatest value to wildlife, management must be planned with this in mind. The Countryside Commission offers a 'Countryside Premiuim' providing an incentive to farmers for positive management of land entered in the Set Aside Scheme. At present this is available in only 7 counties (Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Norfolk, Suffolk and Northamptonshire). It only applies to permanent fallow and covers such items as hedgerow management, encouragement of wildflowers and groundnesting birds, creating new meadowlands and creating winter grazing areas for Brent Geese (Branta bernicla).

Set Aside land may make a very small contribution to reducing total cereal production but it can create serious problems for the farmer and his neighbours. At present the problem is small and confined to a few areas but if Set Aside becomes a more popular option then the scale of the problem will increase. There is no compensation for neighbours who, while not having set aside their land, may have to cope with problems from neighbouring land.

Land left to green over after harvest - a Set Aside option - will provide sites for overwintering pests and diseases and provide a 'green bridge' enabling diseases like yellow rust (Puccinia striiformis) and Barley Yellow Dwarf Virus to transfer from one years crop to the next. Winter cereals adjoining such fields may need a routine autumn aphicide.

Frequent cutting of set aside land will help by controlling volunteers which may carry disease and by preventing weeds from seeding. Each additional cutting adds to the costs of maintaining set aside land which only needs to be cut once under the terms of the Set Aside agreement. From a conservation point of view set aside land should not be cut between April and July when ground nesting birds are sitting - ideally seed bearing plants should be left as long into the autumn as possible for the birds. Weed seeds could blow into adjoining fields and create problems and extra costs. Thistles (Cirsium spp), docks (Rumex) and ragwort (Senecio jacobaea) are, of course, covered by the 1959 Injurious Weeds Act which states that these weeds must be controlled and not allowed to set seed. Getting this Act enforced may prove difficult in some counties. Rabbits (Coryctolagus cuniculus) are clearly a problem in some arable areas and their resistance to myxamatosis is increasing. Set Aside may be ideal for rabbits but they will not find favour with neighbours.

There are a number of options for the management of set aside land and most conflict with the ideals of weed control. Permanent set aside land, managed as cheaply as possible, without establishing plant cover and cutting once a year, is bound to encourage grass weeds. If the priority is to encourage game birds or wildflowers then there will be no cutting during nesting and flowering - April to July at the extreme and certainly not in May or June. Game crops such as buckwheat or amenity wildflower mixtures will also allow grass weeds to develop as no foliar applied herbicides are avialable for grass weed control and others are not allowed.

One option under the Scheme is to establish 15 metre wide strips, either as headlands or across large fields. These provide access and can be attractive for gamebirds. Here it is essential to create permanent cover and cut frequently to prevent seeding. Bromus sterilis and Poa trivialis can spread into fields from the boundary and A. myosuroides is frequently found on headlands. A regularly cut boundary strip will help to control the spread of these weeds into the field.

Without herbicides it will be difficult to prevent seed return from weeds, even with regular mowing. Some weed plants will be semi-prostrate and seed heads will escape the mower. When following the permanent fallow option farmers will be well advised to;

- start with a clean crop with as effective a control of grass weeds as possible,
- have a good burn and leave the field undisturbed in the autumn (straw burning is not popular and the ash must be cultivated or ploughed in within 24 to 36 hours),
- cultivate in spring and establish plant cover,
- cut frequently from mid-May onwards.

Good husbandry, but not good for wildlife.

Fewer problems arise if the rotational fallow option is taken. Annual cultivations will reduce the seedbank and there will be competition from the following crop. The rotational fallow will not prove attractive to wildlife.

Extensification - reducing the levels of use of fertilisers and pesticides - is another course which receives much favourable attention in some quarters. Less inputs would reduce costs, and the amount of fertiliser and pesticide going into the environment , and reduce output. The formula ignores the fact that not all such inputs are used to increase output. Many are used in order to maintain the quality of the produce, to protect it from pests and diseases and to control weeds which may contaminate the crop so reducing its value, or even making it unsaleable.

Reducing nitrogen levels may not increase Avena fatua problems in winter cereals or spring barley but may do so in spring wheat. Delayed drilling may be one way of controlling A.fatua while saving the cost of herbicide.

To reduce herbicide use some form of threshold level is needed, but there are many problems in putting these into practice. Thresholds need population assessments which are expensive to carry out, some levels calculated on the basis of economics are well above what would be visually acceptable. The new style of farming may well require a different set of standards among farmers and those who advise them.

FARM WOODLAND SCHEME

The Farm Woodland Scheme is confined to arable land and improved grassland (there is an allocation for planting unimproved land in Less Favoured Areas). Payments will be made for up to 40 years to farmers who convert agricultural land to woodland. Planting the whole holding is not acceptable - the lower limit is 3 hectares, the maximum 40 hectares. Grants are paid each year for 40 years where broadleaved trees are planted, with shorter periods for mixed plantings. This Scheme converts agricultural land to woodland - the trees must be managed to a satisfactory standard and this includes the necessary use of herbicides for weed control.

Large scale afforestation can have dramatic effects on landscape and wildlife habitat but small, farm woodland will be different. Many farm woods are established for shelter and can have profound effects in creating a better field environment for crops and stock and in protecting buildings. Old estate woods were often established for shooting and fox hunting and modern game management combines well with farm and woodland management. Mixed woods provide cover and warmth and in this respect are better than pure broadleaved stands. Increase in cover will benefit deer, particularly Capreolus capreolus and Muntiacus reevesi and a range of birds including game species. It may be necessary to control these if numbers become too large, and also other species such as Sciurus carolinensis.

There are a number of other grant schemes administered by the Ministry of Agriculture, Fisheries and Food, the Forestry Commission and the Nature Conservancy Council or through Local Authorities. These are aimed at encouraging wildlife and landsape works, usually on a modest scale; they are often discretionary.

CONCLUSIONS

Judging the situation on present circumstances it is clear that it is the intention of the CAP and the UK Government to control production through a number of measures. The price of the end product will clearly influence cropping policy and such schemes as Set Aside and Farm Woodland will become part of the equation. It is significant that these schemes are voluntary - the decisions are left with the individual land manager. The objective is to retain flexibility; set aside land could, if necessary be released into cropping. Set aside has happened before but without government assistance. Marginal, and not so marginal land went out of production on a vast scale during the agricultural depression between 1870 and 1940. The Daily Telegraph of September 4th 1939 was able to report that 1,500,000 acres (606,000 hectares) was to be ploughed out of neglected grassland and arable by next spring.

The other objective is to have controlled and managed wildlife habitats which will attract the interest and support of the general public. Farmers will not be paid to 'do nothing' but will receive their income from farming and managing the countryside for the benefit of a wide range of interests. The Country Landowners Association has suggested that, just as farmers use their land to produce cereals, potatoes and milk for sale, so they should also be able to sell environmental products. These would include landscapes, habitats for flora and fauna, recreational areas and leisure sites. An interesting thought which would keep land use and management firmly in the market place, putting responsibility for the environment on those who manage the land with payment by the public showing what is wanted.

There is much talk of land being surplus to requirements and going out of production. Some will, it will be developed where planning permission is given - some will go to farm woodland or forest. There will also be other, limited new uses, recreation of one sort or another, but the majority use will still be agricultural as the country needs food. But it seems very likely that agricultural use will concentrate on the land most suitable for particular crops or grass so that some land, now growing cereals, will revert to grassland. There will be both concentration and diversification.

There is another important factor involving the way land is used and managed and that is the influence of public opinion. The public is taking a greater interest in food, both the way it is produced and the materials used in production. They may not always be accurately informed but it is their perception of what is being done that matters.

An arable crop is a rather sterile environment for wildlife and it is not realistic to seek to enhance conservation in the midfield. There are many ways in which cropping practices interact with field boundaries and other wildlife rich areas of the farm. Sensitive management can do much to enhance this interaction.

Much of the appeal of the countryside depends on the mosaic created by hedgerows, trees and walls. It is not difficult to maximise the diversity of habitats and the amount of cover and shelter for wildlife and game, combined with good crop husbandry. Hedges have an historical interest and they provide corridors for the movement of butterflies and other fauna across the farmed landsape. In winter they attract birds and other wildlife to feed on fruits and nuts.

Plants in field boundaries are often perceived as weeds which threaten adjacent crops. If the boundary is well managed it can support a wide range of inoffensive and attractive wildflowers such as Silene dioica, Stellaria holostea and Viola spp which do not disperse into the crop. The ideal boundary vegetation contains perennial herbs and shrubs which eliminate or keep in check the few weed species which are capable of spreading. It is as well to avoid cultivating too close to the boundary - a one metre strip of vegetation should be left between the hedge and the cultivated ground. Grasses and wildflowers on this strip, cut on a two or three year cycle at the same time as the hedge, will provide shelter for wildlife and game. Close cutting should be avoided and also accidental burning and deliberate or accidental spraying with broad spectrum herbicides. Such practices create bare ground which encourages the germination of pernicious annual weeds such as G.aparine and B. sterilis. Fertiliser thrown into the hedge bottom also encourages agressive weed species and reduces the variety of wildflowers.

Insecticides are the most environmentally damaging and blanket spraying must be discouraged. There are ways of detecting pests before they cause damage and spraying only if thresholds are exceeded. Pest monitoring services are needed and further research; this is regarded as 'near market' and must be picked up by the agrochemical companies and the users. Without good advice there is a danger that unnecessary insecticide use may increase as the cost to the grower is small compared with the potential losses if the pest is not controlled. With even closer links between growers and processors the latter exercise a considerable influence on pest control measures. Supermarket chains are taking an increasing interest in production methods and some test for pesticide residues in produce. Potatoes treated with sprout suppressant may be refused, so forcing growers to use refrigerated storage. What is not clear is whether similar restrictions will be applied to imported potatoes and other produce where the buyers are not in such close contact with the growers. Similar restrictions on the use of certain materials, or requirements to use only specified products,can apply in the production of crops grown under contract.

A major source of concern is the leakage of nutrients and pesticides into the environment and possible residues in the produce.

Herbicide inputs could be reduced without cost to the farmer,especially where A.myosuroides is not a problem. The typical broadleaved weed flora has very little effect on yield in winter wheat, spring barley and oil seed rape. There is a strong antipathy towards all weeds but there are many farmers who halve their herbicide inputs, make more profit but lose their reputation for a weed free farm. Some growers must maintain weed free standards in seed crops and field scale horticultural crops but a move towards conservation headlands, where appropriate, with less complete weed control elsewhere would produce satisfactory crops and do much to appease the public.

Conservation headlands, as developed by the Cereals and Gamebirds Research project, are about 6 metres wide or the minimum width over which the spray boom can be switched off; they usually cover about 6% of the cereal area. They are best sited near field boundaries with a hedge and grass bank or a grass bank at least one metre wide. Crops with heavy infestations of G.aparine or B. sterilis should bot be chosen but A.fatua and A.myosuroides can be controlled with selective weed killers. E.repens can be removed by pre-harvest use of glyphosate. Insecticides can be used on conservation headlands up to March 15th but not afterwards; most fungicides can be used as they are usually harmless to insects. Loss of crop through managing conservation headlands is about 6% of the headland yield and 0.5% of the total cereal area. Even with full treatment headlands often yield 20% less than the rest of the field, so no great loss is incurred.

The advantage of the conservation headland is that it controls key weeds while leaving important host plants such as Polygonum aviculare, Sinapis arvensis, Polygonum convolvulus and Matricaria perforata. These host harmless insects which provide food for the first few weeks of life of game bird chicks. Other groups of farmland wildlife also benefit, many species of rare arable flowers have been recorded from conservation headlands which also attract pollinating insects.

Changes in the way in which land is used will depend upon decisions taken by individual farmers who will take into account the potential of their land and their own personal and financial circumstances. Besides official schemes designed to encourage farmers to reduce inputs, take land out of cultivation and farm in an environmentally sensitive way, there are other ways in which farming practices can be modified to favour wildlife. On each farm there must be a balance between production and conservation and there is mounting evidence that this can be achieved.

Co-existence is essential, conflict is negative. But to achieve satisfactory coexistence requires understanding and knowledge among all concerned. Producing food of acceptable quality in a well maintained and attractive countryside demands new skills and a high level of management. There are clear signs that these skills are being learned and practised. It is in the interest of all to ensure that the farming industry retains the flexibility which is necessary for it to react quickly to changed demands for different land use, increasing quality standards and above all to maintaining public confidence through a highly professional approach.

LAND UTILISATION - THE CHALLENGE CREATED BY SURPLUSES

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ABSTRACT

Surplus agricultural output has created a high support cost to western agriculture. Quality requirements are being imposed which conflict with the organic myth. These two facts will lead to surplus land in at least the medium term. I believe that this surplus land will be looked after as long as the Treasury is prepared to meet the cost.

The opportunity that is being presented to the community as a whole to re-assess the environment in which we all live, work and play has never happened before.

This challenge is, at the moment, being responded to by ill-informed, unscientific, pressure groups. We have allowed these groups to exercise a dominant role in a time of surplus. Agriculture and its dependant industries must not continue to fail in communicating the scientific truth. The opportunity of surplus must be grasped and turned to the world's advantage.

INTRODUCTION

Why, when in 1980 the world was projecting starvation and famine, by 1990 are we even discussing this subject?

Because of surpluses created by the agricultures of the industrial nations and a world price that is not based on the cost of production; indeed a world price that, until the 1988 drought in the United States of America, was below the cost of production of countries such as Australia and Canada.

These are the surpluses that well-fed politicians are no longer prepared to fund - or are they? I have my doubts that, in the United States of America, the mid-west American farmer is going to be abandoned by a President requiring re-election, even if the General Agreement on Tariff and Trade (G.A.T.T.) is persuaded that that is what has happened.

However, the reality is that within the European Economic Community (E.E.C.) we are self-sufficient, even if you start making adjustments for cereal substitutes, imports and other unfair trade distortions created on the back of historical patterns of trade or a requirement to export manufactured goods in an over-competitive world to countries with no ready cash.

Let us get rid of the myth that we farmers have produced more because of the vast profits and easy money created within a high priced E.E.C. farm policy. The reality is that without increased output farm bankruptcy would have been commonplace ten years ago and the world would have no surpluses. So, it is my contention tnat there is no fat in the E.E.C. farm system and continued price pressure must result in significant change. It cannot continue that many farmers earn less than their employees.

Hence this debate.

Unlike many changing industries the fundamental resource of agriculture, the land, will not go away and does not stay in some inert fashion, such as a coal mine.

Overlying this situation are, however, another two schools of thought; one loosely called the Organic Solution, now unfortunately adopted by the "Greens", and the other often confused with the first, being an increasing clamour for quality, contaminant free food. These two areas are in many ways exclusive, but it is not my purpose here to destroy some middle class comfortable myths about the cleanliness of free range, organic re-cycling, or any of the other illogicalities that we are being presented with in our daily diet of Government codes and proposals.

So, I start with certain assumptions included above. Firstly that we will continue to be farming in a world surplus market place, secondly that the E.E.C. will continue to apply price pressure and thirdly that the food lobby will ultimately see some sense and want a product of the highest possible standard, from a sustainable system of farming and from a background that can be trusted.

As you can see I believe that the majority of food production will require a balanced approach to input (agrochemical, varietal, technological or whatever.) Only then can a competitively priced, high quality product be available at the farm gate.

SURPLUS LAND

Despite all this, the result of the exportable surplus in E.E.C. production and Governments' short memories with regard to food availability and a lack of understanding of the economics of exporting, you can subsidise a power station to China but not barley to Poland in the future, is going to be a reduction in the acres farmed. Land use policies in the United Kingdom have always revolved around the tenet of most important uses and of those Agriculture has been the prime consideration - NO MORE.

Here I digress. For those who support the views of the Heir to the Throne, surely this change in land use emphasis is the greatest opportunity to improve the environment for the majority of the population, if, of course, the economy can afford park keepers, dog wardens and a return to wide open spaces seen in many areas before the advent of planning control. It must be time for planning to no longer be concerned solely about land use but about the quality of the total environment, with the highest regard being paid, not to those who overlook it or pass through it, but to those who live, work and play in it. To de-tune agriculture on the outskirts of towns and cities must make sense. To construct new infrastructure with regard to its needs rather than a supposed shortage of land must be a challenge that can be taken up. Let us hear no more of NO but much more about HOW and QUALITY.

Unfortunately, however much this challenge is taken up its impact on the land availability situation is still going to be minimal.

Of the eight million acres of arable production in Great Britain the sad truth is that unless there is a sustained reduction in world output we do not need 20% of it. That, in turn, means that we have a land surplus in excess of this amount given the need for quality production. At least 1.6 million acres, or over half a million hectares.

It is the fate (because I do believe that is the appropriate word) of that land that is of concern to all. We have a safety net to catch those who are not prepared to sacrifice their lives on the altar of world price - it is called Set-Aside. We are assured that the E.E.C. has learnt from the mistakes made in the U.S.A. and that the voluntary system introduced by the Brussels Agreement will do some good by removing 1.5% - 2% of the cereal production. Varietal increases are believed still to be contributing 1.5% yield increase per year, but at least the surplus should not be getting larger.

SET-ASIDE

Set-Aside - with an emphasis on non-rotational fallow for five years in exchange for £80 per annum, not inflation linked.

It is a voluntary scheme, I am told in place as a safety net - or is it there for the Government to salve its conscience for having encouraged you for forty years to increase output, with a five year payment with no guarantee of its renewal? At the end of this time, with no equipment worth having (the Government has not banished rust and decay), no staff and little resource, the land may still be yours, or the banks. You may be wondering what will happen next and if you are not, your non-Set-Aside neighbour certainly will be if the first year's reports are anything to go by. There appears, after year one, to be a need for a non-toxic growth regulator for environmentally unfriendly weeds to prevent them growing more than twelve inches and seeding - a whole new area of pesticide research awaits you!

Let us not be too dismissive of the only real safety net that is currently being proposed. Problems are already appearing and they will need solutions if we are not to be faced with major pressures to discontinue this only real opportunity to prevent the only other alternative - total bankruptcy and derelict land. This has always been the solution in the past and we are only talking of the 1930's - not very long ago. Set-Aside, the American solution to Treasury pressure on commodity support, will undergo changes and may keep land in a better condition for the time it is needed again than the free market alternative of dereliction.

This will only be the case if the Government is prepared to pay sufficient to those involved to enable them to have a reasonable standard of living and leave enough over to look after these non-cropped areas. Nevertheless this scheme is the major support that the Government is proposing.

There are other restraints to output as well as the "free market", nitrate protection zones, a new river policy on nitrates, as well as tighter controls on straw burning, spray drift and so forth.

It is for others to put the economic arguments, but as far as I can see the pressures on arable farms are not going to be where many of the experts would have said a few years ago. The small arable farmer is as much at risk now as ever, unless only as a part-time occupation. The large arable farm, on poor quality land with too high a labour cost, is at risk now. Those not producing in excess of £300 per acre of arable sales must face reality, or slowly slide out of business. That reality can, of course, be assisted by family labour, low inputs on good quality land, the neighbour's slurry or other individual situations that create a lower cost structure after what has traditionally been termed the variable inputs have been taken into account.

Economic reality is fast approaching many businesses. The structure that is most likely to be producing food in the future will be based either on the family unit, with no full-time labour, or a carefully costed large operation that is pitched to take full account of the economies of scale, but which does not over extend them.

So, given this situation, where is Set-Aside likely to fit?

Firstly must be the landowner having farms in hand, but who is not making anything like £60 an acre, and has no large investment in staff, machinery or specialised buildings.

Secondly must be the smaller farmer, nearing retirement, who wishes to slow down.

Thirdly must be those who wish to solve problems using rotational fallows, or whose unit size does not easily fit into the right current economic categories and where a 20% reduction, or slightly more, could make a significant impact on the costs as well as allowing first year crops at less risk than some of the current break-crops.

What impact is the first category going to have? A further change to the way in which land is owned and farmed in the United Kingdom. Changes in the ownership of the capital resources of agriculture are not new, or bad, but they do need to be noted. Whereas forty years ago the majority of land in the United Kingdom was rented, this is now no longer so. The traditional landowner is a rare animal, they too have been driven by economics, taxes and succession into many changes. The end result is that many of the "new" farms are, in market terms, undercapitalised.

With current interest rates and the real rate of inflation, there are pressures here for those in trouble to take one of two paths. Set-Aside must be on of these, if the borrowing levels are not significant and if returning to active farming at the end of a period does not present too many problems. The other must be to sell the holding, particularly if it has a value in the country house or estate market - a market that in some parts of the country is still rather more buoyant than the house market in the South-East.

So, I see here a trend for the non-dedicated landlord who can meet the one year farming rule to create a greater return than he, or she, has probably seen for a very long time - even more so if there is shooting or 'horseyculture' potential on the estate.

The second category I have identified as being the smaller arable unit, now only capable of supporting a part time owner. In the United Kingdom we do not have a tradition of large numbers of small part-time farmers as, for example, in parts of Germany. In the main our industry is not located so that this could, in the short term, become an alternative which, in view of the sharp reduction in the number of children leaving school, is perhaps a great pity. Neither is the level of payment for Set-Aside for, say, a one hundred acre unit going to be particularly attractive - but if of retirement age or with some other income this could still be rather more than the holding might make in any other way. The other consequence of price pressure must be to continue the process of farm amalgamation, a process that the Government no longer actively supports.

What of the sector of farming that can perhaps use partial Set-Aside as a tool of production (one that the family business with which I have been associated for eighteen years is a part of)?

Reading the advice, this is not a role for Set-Aside the Government favours but, nevertheless, a role that I imagine is more environmentally friendly than that of whole farm non-rotational Set-Aside. I will return to this aspect later when looking at some of the Countryside Commission's proposals for premiums on Set-Aside land.

There can be nothing more traditional than a fallow. I must, however, question some of the restrictions, particularly of timing, that appear to have been placed in the Set-Aside proposals, in particular the 1st August date for fertiliser applications, as well as cultivations.

Where profitable cereal crops cannot be grown other than as a first crop, there must be a role for the rotational fallow, so long as a reasonable level of payment is maintained. It is ironical that the most useful system, costing most to implement from the farmers' point of view and also perhaps the most environmentally supportive option in the long run, attracts the lower level of support. Many birds do not thrive in overgrown areas cut once a year and certainly the level of inputs that the current payments will permit is not going to allow much more than mowing once or twice a year. I see that the Countryside Commission have started to understand this.

So, I see at least three groups of farmers to whom Set-Aside is already going to be a not-unattractive option, given current price pressure. But, is this concept of Set-Aside going to continue beyond the current programme date? Any area where politicians are involved is impossible to predict, especially where so many countries are involved, as in the E.E.C.

At the end of the day I have no doubt it will depend on others; the Treasury, who pay a part of the bill directly, if the option becomes too popular, as I fear it might, SAY NO MORE, the public who will believe that "rich" farmers are getting something for nothing and the countryside lobby who will not actuqlly like what they see, even if they did mistakenly think that grass or regeneration has to be green and environmentally friendly.

The question of costs if for others to deal with, but at the end of the day it will depend on the farm structure that is felt to be desirable and whether this is politically important. I am sure that there is no consensus of view, either in or out of Government, as to what this structure should be, but, as ever, what we can see in history must be better than the unknown. I wonder?

COUNTRYSIDE PREMIUMS

The countryside lobby, if I can call it that, perhaps best said here to be led by the Countryside Commission and the Nature Conservancy Council, has come up with some interesting, if at times controversial, proposals for a premium scheme to be trialled in the Eastern part of the United Kingdom.

The largest problems here will not relate to payments for Brent Geese grazing areas or the encouragement of areas for ground nesting birds, but to the proposals for meadowland that include provisions for public access.

Many farmers will not want to encourage the public unless they can establish a better dialogue than at present exists with some of the so called environmentally friendly organisations, albeit that most of these problems are not at a local level.

It will be interesting to see the uptake of these proposals, but it is concerning that top-up payments are appearing to be linked to public rights without any overall review of the real demand for access, or an attempt to create an access to the countryside that is suitable for today's users. After all the majority of public paths and bridleways were not for leisure use and were created when a different scale of agriculture was the norm. Very few farmers object to public rights but with a land surplus facing United Kingdom agriculture, surely this is a unique opportunity to review access, make it more suitable for those who wish to arrive by car and then walk and create a better network of modern paths which the community must then be preapred to pay to have maintained.

I would hope that future Countryside Commission proposals can take this area on board within some of the Set-Aside premiums.

FORESTRY

The change in Government emphasis with regard to forestry is also going to have an influence on land use. Few would argue that the environmental impact of large areas of forestry in the Highlands has not been wholly beneficial. Scotland seems to be an area that has historically attracted large scale changes. However, the possibility of farm woodland with an annual payment for twenty to forty years is a welcome departure but, with inflation at 6% to 10%, perhaps a little too much of a shot in the dark for most of us, unless planning to plant trees anyway.

At one time there appeared to be a shortage of nursery stock, but a major change in tax relief for woodland owners changed that position overnight.

This simply highlights the problem once a Government starts to interfere with the normal commercial processes. How much better to have a sustainable level of production, whether arable or arboriculture. Unfortuantely, that would require some accurate planning as to this country's and now the E.E.C.'s needs, an area we seem to be woefully short in.

ALTERNATIVES

Current proposals from Government are voluntary. It is not my position here to propound a National Farmers' Union view, however it has been that organisation's argument that the surplus problem will not be solved by a voluntary Set-Aside. Indeed it had, earlier than the E.E.C., suggested a policy of compulsory Set-Aside, fearing some of the distortions that are already apparent being present in a voluntary scheme.

There is a view that restriction of inputs, in particular fertiliser, would solve our problems. I fail to understand how any reduction in income on the farm is going to solve the problem of farm income pressure. A policy of output reduction will not be matched by a policy of price increases unless the world price moves significantly upwards. It could do so, but is more dependant on the American climate than anything else and predicting movements in that is even more difficult than trying to understand politicians.

In the area of fertiliser we must not ignore the impact of E.E.C. legislation with regard to water quality. It is unfortunate for areas with underground water supplies that so many of them are in high input farming areas. A return to low intensity grazing, or even woodland, is going to be a great personal cost to many farms, but it will be a part of the overall changing pattern of land use. I imagine that a hungry Europe would not be passing so many laws that impinge on farm output with very little scientific basis for the environmental concerns being expressed. Commercial pressures are still the best moulder of policies. We currently seem to believe that we have relatively few strong points to make. How wrong can we be?

Planners and politicians have created many monstrosities - very little of what has been erected in the past few years will ever be served with Protection Notices and very few trees planted by authorities are served with Tree Preservation Orders.

The real influence in the landscape will still be the farmer, hopefully supported by a society that begins to genuinely understand some of the inevitable conflicts between competing uses.

THE FUTURE

The current position that we find ourselves in is far from clear and yet we are, in many cases, faced with some interesting opportunities.

Farms whose values have always been more than the earning capacity of the land are still in that position. If we look carefully, however, we see that Roll-Over Relief, a newly emergent professional class with a desire for a return to the family roots, accompanied by the cash resource to do so, have created a new basis of value for the assets we, the farmer, have been using.

The barns we nearly knocked down were, with planning permission of course, last year worth more than the farm.

Faced with a value from a non-farming sector of the public, should we sell and allow them the privilige of understanding at first hand the economies of food production?

I am sure that in the next decade we will see a growing number of such owners and it is up to all of us, but in particular the industries dependant on the farmer, to support an education process for this new generation of country people.

I have discussed at length Set-Aside and I envisage that in ten years time it will have been changed significantly. Landlords will find it more difficult to enter, whole farms will not be acceptable. Techniques for the modern management of fallow will have evolved resulting, I am afraid, in the need for lower inputs in the succeeding crop.

Will it have solved the surplus - NO it will not. Weather and price pressure, or a growth in the world's population may have done so.

The changes and possibilities outlined will, however, have created a new land owning class. It will tend to be on a more fragmented scale than we have been used to and will require a different approach to the way land should be farmed. In no other business do you have a life time right to the control of someone else's assets. Whilst some security is needed, particularly where a fixed investment is called for, new concepts of business partnership are going to evolve to meet the needs of the new owners. Contracting will become an even more important part of the farming scene. Some of these new owners will require advice and the Ministry of Agriculture, Fisheries & Food (M.A.F.F.) will no longer be there.

The increasingly high standards demanded by the food processors and retailers will give rise to a growth in the demand for independent advisers, specialising in an area of production but free of the commercial necessity to sell a product. I see a time when agrochemicals will only be used on "prescription" thus ensuring public confidence in the final farm product. The agrochemical industry will have to move to meet the challenge that we are all facing.

Surplus will mean a lower level of demand. Quality will, however, mean that optimum inputs are demanded on at least 80% of the acreage. The challenge that surplus brings should not be seen as a conflict but as an opportunity to prove that your testing procedures are the best in the world; that your marketing is not regardless of the ultimate consumer demands.

If you fail to meet these challenges you will contribute to a general downfall in public support for our domestic agriculture. As an industry, of which you are all a part, we have been appalling at communicating with our consumers and have allowed a little, often wrong, knowledge to create all sorts of difficulties.

Surplus gives us the opportunity to look again at where we are. Food and Farming Year has also created a climate where we know that we do not have to be guilty about our success in supplying the country's food needs.

Agricultural organisations have not always responded in a way which can lead a hard pressed industry down new paths to the changing and challenging world in which we find ourselves.

Surplus land is not a guilty secret, but the very evidence of success. The loss of United Kingdom Government support for the future of our industry, with their policy on research, a policy based on Party principle rather than logic, shows that as an industry we need to work closer with all those involved than we have before. This is a challenge we should look forward to and meet, not fear.

The challenge that we face is how can we, the farmers and our support industries, best utilise our resources, including land, in the 1990's? Individuals are facing and will face serious financial problems. What is being done to create structures out of the private enterprise economy to tackle these problems? It is time we stopped talking about easy solutions to the pressure - there are none.

I have not mentioned the position of Environmentally Sensitive Areas (E.S.A.'s), Areas of Outstanding Natural Beauty, Green Belt and the whole area of Upland payments, E.S.A.'s designed to retain systems of farming that even the Ministry realised were at risk and worth preserving; perhaps they should be re-named Economically Sensitive Areas and available to all who meet that criteria, wherever they might be.

The restrictions that, by public pressure, are increasingly being placed on those who have the misfortune to farm in areas of Britain's most outstanding countryside, unfortunately do not receive any financial consideration for the responsibility placed upon them. There are no longer profits available to subsidise uneconomic farming systems to maintain the countryside in a manner that the "Hedge Viewer" believes is right.

We are, therefore, faced with a challenge which at the moment I do not believe is even being recognised.

The release of land from quality food production is being responded to in different ways. The popular, simplistic view, that a return to an historical "organic" system will solve all the problems simply shows how poor we have all been at communicating and why those systems were largely left behind in the first place. There is a place for them as a part of the overall agricultural scene. The inevitable changes in farm structure must now be recognised, not fought against and the opportunities that will be created must be used to build a business structure in the countryside that reflects the structures and systems of modern businesses generally.

If you, the Agrochemical industry, wish to retain your role in the future jointly we are going to have to tell a much more accurate story of why, how and where. The consequences of not doing so will be the rapid decline of the United Kingdom's agriculture and an increasing dependence on world surpluses, with all the quality problems that we know are inherent with such imports.

We, in agriculture, in total will determine the way in which the land resource will develop.

Are we prepared to meet the challenge?

AGROCHEMICAL USE AND STRATEGIES FOR THE 1990s : A MANUFACTURER'S VIEWPOINT

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ABSTRACT

Land in the 1990s will be devoted to agriculture to grow food for an expanding world population, for conservation and a wide variety of other purposes. Agrochemicals will continue to provide essential crop protection in agriculture. Understanding, discipline and co-operation will be needed if agrochemical use in agriculture is to develop in harmony with conservation, other enterprises, consumer and countryside users. A list of action items in the 1990s for UK manufacturers, users, lobbyists, media contributors and conservationists is proposed and discussed.

INTRODUCTION

In these days of plenty and surpluses, it has been easy, even fashionable, to set aside the efforts needed to produce food and discount practical problems which farmers face. Contributors at Brighton have reviewed the present and future demand for food, along with the role which agrochemicals play (Orson, 1987; Griffiths, 1988). They highlighted:-

1. the growing world population and the number of mouths to feed.
2. the likely reduction in available and suitable land per capita on which to produce vegetable and animal products.
3. the inadequacies of traditional rotation systems to provide yield, quality and reliable production.
4. the response and great success in producing quality food since 1945 through new technologies such as improved crop varieties, mechanisation, synthetic fertiliser and agrochemicals.
5. the practical flexibility given to the farmer by agrochemicals and particularly by modern herbicides.
6. the benefits of modern agrochemicals and the need to keep in perspective claims made about the potential dangers of agrochemicals.
7. the politics of managing overall production and surpluses.

This paper examines likely land use in the 1990s for food production, the need for crop protection using agrochemicals, especially weed control and the measures required to manage agrochemicals within farming enterprises and at the margins with adjacent enterprises or activities.

LAND USE IN THE 1990s

Underlying the world demand for land are the contrasting issues of increases in global population, the need to grow more food, and the conservation and leisure requirements of modern society. Furthermore there is a marked difference between developed countries where there is over production, and developing countries which are faced with undernutrition (Spedding 1983).

The need to supply a growing world population

While the 'West' can demonstrably feed itself from its own resources, agricultural production in the developing world has failed to keep pace with population. In an FAO study, World Agriculture Towards 2000 (1988), it is anticipated that approximately 150 Mt of grain will be imported by the deficit regions in the year 2000, up from 100 Mt today. Demand for grain in the developing world is increasing by 3% annually which continually raises the tonnage targets to be achieved. The FAO study assumes that local production will rise, primarily by raising yields but not at the 3% required to match demand. The primary constraint is land availability, Table 1. The developing world will find it difficult to expand production to meet its needs. Land availability and efficiency of production is better in the 'West' and this will have to be used if the gap is to be filled. What part European agriculture plays in this market will depend on the politics and economics of international trade, the weather, and the ability to match production with other suppliers who have lower fixed costs.

TABLE 1. Land Availability in the 1990s (ref. World Resources, 1986.)

Region	Crop land (ha/head) 1971/5	2000
Industrial Market Economies	0.55	0.46
Comecon	0.80	0.65
China	0.16	0.11
Other Developing Countries	0.35	0.19

The need to supply Europe

Grain consumption in the European Community is steady at around 140 Mt. About 10-15 Mt is imported for various purposes, leaving 125-130 Mt to be produced internally. At current average cereal yields of 4.4 t/ha this is equivalent to an area of 29 Mha against 33 Mha or so currently planted. Similar over-supply applies to sugar, whilst with oilseeds and protein the Community is in deficit.

So on this analysis, there will continue to be in Europe a large, but not necessarily growing arable market of around 40 Mha based upon cereals, sugar, oil and protein crops. Exports may help expand this area, and 'set aside', quota schemes and the like will be more frequently used to balance production with total demand.

The land remaining in arable production will have to provide the necessary volume and quality of produce, and an adequate income for growers. To do this individual farmers will have to practise efficient, cost effective husbandry with certainly in Britain a decreasing labour force (Country Landowners' Association, 1989). Crop protection will continue to be an important part of this husbandry.

CROP PROTECTION NEEDS IN THE 1990s

Examples of pest and disease control can be found in previous papers - Ahrens et al (1983), Reed (1983) and Teng and Shane (1983), but here we shall only discuss the effects and advantages of practising good weed control. Problem weeds in agriculture are persistent, versatile, tough and difficult to control. That is why they are weeds! Weed flora have evolved over thousands of years, producing a wide range of unwanted effects. The greatest species diversity is found in cultivated landscapes (Eggers, 1987) and often weeds depend on cultivation for survival.

The benefits of weed control arise from the harmful effects and damage caused by weeds, not simply their elimination for the sake of it. The examples below illustrate the range of this subject in world agriculture. The subsequent discussion considers the principles and strategies of weed control in UK arable crops.

The problem of Urtica urens (annual nettle) weed control in 'pick-your-own' strawberries is an example that should be easily understood by the public. Such a weed problem makes a crop unattractive or unharvestable and on a large scale could break a business.

Water weed control within an irrigation system is much more fundamental and less parochial. Weeds can clog the flow so that the growers downstream do not get irrigation. (Kasasian, 1981). No water, no crop! Just to underline the benefits slow moving water may prove an ideal habitat for water snails and mosquitoes, which are vectors for the diseases bilharzia and malaria. When this is the case then improvements in weed control and water management really do improve the quality of life.

Senecio jacobea (ragwort) is an attractive but poisonous weed and must be removed from grass for fodder. Animals will not normally eat it, and so it flowers and seeds undisturbed and could soon take over a pasture. It is more palatable to stock when mown or dried, it contains alkaloids so that animals fed with S.jacobea will die from toxic cirrhosis of the liver (MAFF, 1981). Nature's toxins can be very potent indeed.

Pteridium aquilinum (bracken) is another example of a poisonous and invasive weed, currently spreading in the UK at 1-4% per annum. The consequence is lost grassland and moorland with reduced grouse and sheep productivity. In conservation terms P.aquilinum carries fewer birds, mammals and insects than the ground it replaces. (Hudson, 1987).

Weed control in UK arable crops has been the mainstay of this Conference for the last thirty years. Recent studies on crop competition, crop equivalents, and weed control thresholds illustrate the full range of weed control effects and benefits, and also point the way towards the weed control strategies of the future. (Wilson, 1986; Cussens et al, 1985; Wilson and Wright, 1989).

CROP PROTECTION METHODS IN THE 1990s

In the context of weed control, the choices appear to be between a reversion to traditional methods, or the use of agrochemicals, or the application of new technologies such as biological control. The final selection will depend on market forces; does the preferred choice give a positive benefit over cost for both the user and consumer?

Herbicide Use

Herbicide use compared with traditional methods, it will be argued, allows the grower more control over weeds on his land and gives him the ability to produce more marketable produce from his resources.

The benefit/cost analysis must include all implications of treatment. These range from the immediate, obvious effects on the weeds and crop, through the effects on harvesting, weed seed production and future cropping to an evaluation of the possible long-term effects on operators, consumers and the surrounding environment. The latter part of this analysis is predominantly the responsibility of industry and registration authorities, but with new UK regulations farm managers and operators are having to take an increasing part.

The principal factor determining herbicide usage in annual crops is weed/crop competition. Many factors affect this, eg competitiveness of the crop, time of sowing/emergence (crop and weed), seed rate, variety, fertility/fertilizer use, weather pattern, time of weed removal and soil type. The more competitive weeds produce greater dry weights/m^2 and rob the crop to a greater extent and this relationship has been quantified and published. Crop equivalent values rank the most common annual weeds (Wilson, 1986). Extrapolation allows prediction of thresholds which justify herbicide treatment taking into account the weed infestation, the cost of treatment and the value of the crop.

When deciding on weed control policies there are factors other than direct competition to be considered including the following: seed production, harvesting and drying costs, grain quality, stubble weeds, herbicide performance and spray timing (Samuel, 1986). Specific details will vary from product to product and according to environmental factors, notably soil, rainfall and temperature.

Data from Long Ashton shows that there is a very strong case for using herbicides to remove the most competitive and invasive weeds in cereals, particularly *Alopecurus myosuroides* (blackgrass), *Galium aparine*, (cleavers) and *Avena fatua* (wild-oats). Consequently they suggest 'optimum economic thresholds' for winter cereals, Table 2. For some weeds the thresholds suggest a rigorous approach to control, for others leaving weeds in crops may only hurt the farmer's pride. These results also confirm that these weeds should definitely not be left on conservation headlands.

Sugar beet and oilseed rape are also examples where competition from specific weeds and yield reductions mean that treatment can be advantageous and cost-effective. The same principles of weed/crop competition are thought to apply, but thresholds have yet to be developed to the same extent as they have in cereals.

In oilseed rape, removal of volunteer barley populations ranging from 100- 600/m^2 has resulted in yield increases over 3 sites from 0.9 - 1.4 t/ha (42-64%), (Ogilvy, 1987). The approximate cost of herbicide and treatment would be £35/ha, the yield benefit worth at least £180/ha. This also shows how volunteer crops have become a significant problem;

volunteer potatoes, oilseed rape and weed beet are also causing difficulties on many farms.

TABLE 2. Optimum economic threshold. (ref. Samuel, 1986, Wilson, 1986)

Weed	Crop equivalent threshold	Number/m^2
A. myosuroides (blackgrass)	1	2
A. fatua (wild-oats)	1	0.4 - 1.25
G. aparine (cleavers)	1	0.1 - 0.6
Stellaria media (chickweed)	3-5	6 - 10
Other broad-leaved weeds	3-5	varies with species

Recent results from Norfolk Agricultural Station compared weed control programmes on a heavily infested oilseed rape crop (Palmer, 1989). In this trial clearly some products and programmes were more effective than others. The margin over costs ranged from £60-200/ha for 11 of the treatments. Benefits of such programmes are obvious, provided the grower chooses treatments suitable for his own situation.

The Alternatives

Non-chemical weed control systems depend on crop rotation, cultivation, hand weeding and the prevention of seed dispersal (Roberts, 1982). Rotations were developed to conserve fertility, reduce cereal diseases and aid weed control. The traditional Norfolk 4-course rotation of roots - barley - seeds - wheat effectively brings together cleaning and 'fouling' crops in a system with high labour inputs for mixed animal and crop production. Throughout the last 100 years the work force has been leaving the land so that highly labour intensive systems are becoming less viable (Country Landowners' Assocation, 1989).

The arable rotations of the last 20 years have been dominated by a high proportion of winter cereal crops and the invention of "continuous winter cereals". Modern management, machinery and technology have all had a tremendous impact on cereal production. This would be impossible without herbicides, and 'it is for the very reason of the inflexibility of "organic" farming that herbicides were first used'. (Orson, 1987).

Cultivation techniques rely on burial, cutting and desiccation to remove weeds from the crop, or before the crop is planted. The plough, harrows and cultivators are all used for land preparation either with or without agrochemicals, whereas the hoe can be used selectively within row crops. Steerage hoeing and hand hoeing both work by cutting off the weeds just below ground level but neither is effective on a wet soil. Consequently cultivating and hoeing which may be effective in spring sown row crops are limited in their effectiveness in the autumn and are also labour intensive, inflexible and slow. Small seeded crops and winter sown crops are much less amenable to weed control by hoeing, yet they are Europe's major arable crops.

Hand weeding can be effective for removing small populations of tall weeds such as A.fatua and weed beet, but its return to modern farming is surely not a viable, economic proposition on a large scale.

Seed dispersal has greatly contributed to the spread of weeds in modern farming and with present mobility care must be taken not to move weeds from farm to farm on machinery and in fodder or straw.

All innovative techniques for weed control have a place - black plastic and other mulches can be effective on a small scale. Biological control, if perfected, could be appropriate in some situations such as P.aquilinum control. So far these systems have been difficult to maintain and their environmental impact must be very carefully evaluated so as not to introduce adverse effects.

Research into alternative methods of weed control must continue if for no other reason that they may provide additional or complementary management tools for the grower.

CONFLICT OR CO-EXISTENCE IN THE 1990s

From this analysis, there is little doubt that in the 1990s there will continue to be a core of countryside devoted to intensive agricultural production. At the same time there will be other areas of the same countryside 'set-aside' from arable production to control surpluses, or used for organic crops or nature conservation or the harvesting of water for domestic consumption.

For economic success the intensively managed agriculture will demand good crop protection, and there will be very few successful alternatives to agrochemicals which provide flexibility of management and cost-effective solutions. The other enterprises such as organic farming and set-aside will use minimal quantities of agrochemicals, depending on specific problems which arise. They will be financed either by public subsidy or from customers willing and able to pay a premium for agricultural produce. The financial viability of these enterprises and the ability of farmers to make a living from them have still to be proved.

But there will only be complete success if all these countryside enterprises exist and develop in harmony, and the public and consumer have all round confidence in the manner of intensive agricultural practice and the quality of its output.

Two issues will have to be addressed in the 1990s in order to gain this harmony and an adequate and consistent supply of food. These are an understanding by each and every party of all others' needs, wishes and problems, and the discipline to contain activities within defined boundaries regardless of whether that activity is the application of an agrochemical to a farm crop, or a Saturday afternoon ramble on established paths across farmland.

The interests interacting with agricultural production and agrochemical use are diverse. Some interact within the farm enterprise eg ramblers who desire access through farmland, or conservationists who wish to see certain features or biological communities preserved within a farming system. With others the interaction occurs at the interface between farming and adjacent enterprises or interests. The Game

Conservancy who wish to see hedgerows and field margins managed in such a way as to sustain game birds; visitors who wish to see those hedgerows managed to proliferate flora and fauna; the adjacent homeowner who wishes to avoid the noise, dust and smell that can be generated by farming and last but not least the consumer who has become much more interested in how food is actually produced and what does and does not go into its production.

ACTION REQUIRED IN THE 1990s

Agrochemical manufacturers, users, lobbyists and media contributors have in common a desire to see the public, including their own families, regularly fed, well fed, safely fed, and living in a pleasant, biologically healthy environment. To this end, they must unite in making sure agrochemicals are properly used when needed, and set out to inform the public on the benefits and risks of using both these valuable farm tools and their alternatives. This objective requires the following actions.

1. Manufacturers must continue to research and develop new products which are effective, economical and perceived to be environmentally 'friendly'. These are not new goals. Industry research is already targeted this way. In his 1988 Bawden Lecture, Finney reviewed world crop protection prospects and observed that "new products will be very active (with use rates per hectare measured in grams rather than kilograms), suitable for use in integrated pest management programmes and with increased margins of safety to the user, the environment and the consumer of treated crops". (Finney, 1988).

2. Manufacturers and Government have a responsibility to continue guiding users in proper, accurate agrochemical use, encouraging regular inspection of crops, the use of thresholds and forecasting systems wherever feasible and promoting accurate and exclusive application of products to target areas. This managed approach is supported by results from the Boxworth Project in the UK funded by the Ministry of Agriculture, where few ill effects on birds, small mammals, plants or insects were found when this approach to pesticide use was practised (MAFF 1989a).

3. Manufacturers must recognise the need for continuing research and development into new methods of packaging, handling, application and disposal of agrochemical products.

4. Research workers and advisers must continue to improve and expand existing prediction methods, particularly for broad leaved crops such as sugar beet and oilseed rape. Government as well as the agricultural industry has a responsibility to finance work of such national importance.

5. Farmers must apply agrochemicals accurately, according to approved directions and within the target area. Observing codes of practice to prevent drift and on disposal are essential. Contamination of field margins and adjacent property can be avoided.

6. Farmers and growers must locally and nationally promote the image that they apply agrochemicals responsibly, but above all in a professional manner. Displaying a National Proficiency Certificate is one practical

way of demonstrating that an operator has been trained, examined and is competent to apply agrochemicals. Operators should be proud of this and advertising on tractor and/or sprayer is one simple way of showing neighbours/bystanders that application is in the hands of a professional.

7. Research workers must continue to monitor the environmental impact of agricultural systems involving agrochemicals. The Boxworth Project has produced much useful, interesting data on the impact of agrochemicals on wildlife. Establishing relationships such as this is important if valuable farm tools are not to be lost by default. So often changes in flora and fauna have been associated almost exclusively with agrochemical use, but the effects of other factors are becoming more apparent. The rapid decline of three quarters of Britain's 59 resident butterfly species is being caused not apparently by chemical farming but by changes in woodland and downland management, according to a Nature Conservancy Council survey. Decline is now ascribed to the loss of sunny clearings following the dying out of traditional coppicing (Clover, 1989).

Small mammal data from Boxworth do not indicate any drastic effects but have alerted us to the potential interaction with molluscicide baits. Both bird and mammal data are consistent with results of the Wildlife Incidents Scheme (WIS), which suggests that there are no particular direct toxicity problems from pesticide use in the UK (Brown, 1988). This type of study should continue, and industry is happy to continue financial support of the WIS, and indeed is happy to see closer co-ordination of all four systems which currently monitor poisoning and wildlife incidents.

8. Farmers must communicate effectively with local people and visitors explaining the advantages of agrochemical use.

9. Manufacturers and Government at all levels must guide and inform the public about the benefits and levels of risk associated with agrochemicals and their recommended use (British Agrochemicals Association, 1988). This will include established as well as new products and is probably the greatest challenge facing manufacturers and Government in the 1990s. Both bodies are involved, because each assesses and evaluates the various factors.

Countryside users and consumers should make effort to understand the problems and difficulties faced by farmers and growers in producing food.

Benefits of crop protection are easy to convey; evaluation of risks much more difficult. Testing to levels which provide clear and definite toxicology effects, often over a lifetime, yet basing use on the level that causes <u>no effect</u> plus an additional large margin for safety is a policy not clearly understood by the general public or opinion formers. Similarly the concept of Maximum Residue Levels to monitor the proper label use of a product is still poorly understood. Much more will have to be done before members of the general public can properly balance the large benefits of pesticide use against the low level of risk in their total environment.

Manufacturers and Government have recognised this issue and are stepping up their activities. Whether by a sufficient amount can be debated. Government has increased its News Releases to the Press on pesticide matters, expanded publicity on its monitoring of residues in food (MAFF, 1989b) and raised its profile at events such as Food & Farming.

Similarly the British Agrochemicals Association (BAA) has now increased its regular briefing of the Press, food processors, MPs, local authorities, retailers; it is widening teaching aids for schools and Universities, increasing wherever possible TV and radio appearances to discuss agrochemical issues (BAA, 1989). All these initiatives will have to expand if co-operation and understanding are to flourish.

10. Media contributors and lobbyists, manufacturers and Government should co-operate in promoting considered public discussion on the benefits as well as the risks of agrochemicals.

11. Manufacturers should co-operate with nature conservation projects either at a research level which may lead to new label recommendations or in the promotion of conservation.

Sponsorship of literature (Game Conservancy Council, 1989; British Crop Protection Council, 1989) or projects on conservation can help. The Course on 'Conservation Management on the Farm' developed by the Agricultural Training Board and the Farming & Wildlife Trust is one such project intended to improve the appearance of farmland and its value as a habitat for wildlife without significant cost to the farm business (Agricultural Training Board, 1989). This is crucial to the success of farming and conservation; the 'gardener' has to be paid, it is unreasonable to ask him to work for nothing. How the public will pay this bill is one further challenge.

Manufacturers can also aid conservation by making available compounds for testing in conservation projects. Some may show promise, eg selective graminicides in Gamebird projects (Boatman, 1987), others may not, but may still be valuable, useful products in the main area of the field.

CONCLUSIONS

To provide the food needed in the 1990s, agrochemicals will be needed to give essential and economic crop protection in a manner which secures public confidence and continues to conserve non target flora and fauna within treated fields and at the margins of treated fields. To achieve this, communication and co-operation will be required throughout the 1990s between manufacturers, farmers, lobbyists, the media and Government, and above all consumers.

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ECONOMIC IMPLICATIONS OF SUPPLY AND ENVIRONMENTAL CONTROLS ON UK/EC AGRICULTURE

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INTRODUCTION

Excess capacity in farming is now the main problem confronting policy makers and the agricultural supply industry in the EC. Many other industrial countries in the northern hemisphere share the same fate, in particular the United States. Guaranteed farm gate prices, often set at levels twice those prevailing on the world market, encouraged farmers over the last two decades, most noticeably those producing grain and dairy produce, to invest heavily in their farming systems so that they could increase and enhance productive capacity. New crop varieties and improvements in livestock technology led to annual increases in output of between two and four per cent a year in many EC countries. Against a background of a growth rate of less than half of one per cent in the consumption of food (now tending to stagnate) it is not surprising that there is now excess capacity which must be removed from farming sectors if farmers and the supply industry are to prosper in the future.

PRODUCTIVITY IN PERSPECTIVE

In the mid 1960s the UK and EC-6 were large importers of food and food raw materials. Policy makers sought to remedy this by introducing policies which would encourage farmers to expand the production of food in the EC. The twin objectives were import substitution of indigenous type food raw materials, and to support farm incomes in a more prosperous rural economy. High guaranteed farm gate prices signalled to farmers that they could increase profits by producing more output and to the supply industry that more inputs would be required to meet these objectives. A highly subsidised farming economy with guaranteed prices for open ended levels of production also stimulated research and development. Memories of war time shortages of food, though fading fast, still had a role to play, albeit a passive one, in agricultural policy a decade or two ago.

Early predictions of farmers' responses to price implied modest rates of growth in output, on the basis of the technology which was available twenty years ago. Indeed with hindsight it now appears that this was given far too little weight in early forecasting work. Not surprisingly, expansion in the output of cereals and livestock products (in particular) was accompanied by a rapid rise in public support for farmers. This support was given by taxpayers through their contributions to the CAP budget and by consumers who had no option but to pay high prices for food, often at levels well above those prevailing on the world market.

BURGEONING CAP EXPENDITURE ON EC FARMING

During the early days of the Community's existence (EC-6: the six founder countries) the burden of public support for farming was relatively modest. Income, such as it was in those early days, often matched annual expenditure. The original idea was that levies and customs duties on imports could be used to pay for higher farm gate prices and to underpin guidance measures for farming. When the UK became a member of the Community in 1972/73 (EC-9) the finances of the CAP were relatively healthy. The early and mid seventies were years of buoyant trade for agricultural commodities, accompanied by stable and often rising (nominal) prices for agricultural products. This buoyancy spilled over into EC markets; there was little pressure for intervention buying and any small surpluses such as there were over and above domestic needs were sold at good prices on world markets. Consequently the burden on taxpayers in the form of subvention for export restitutions was comparatively small. The grain and sugar crises of the early 1970s and later the drought in the UK and EC in 1975 and 1976 prevented surpluses from building up. Thereafter, spurred on by open ended levels of production and guaranteed prices, coupled with the availability of new technology, farmers in the UK and the EC-9, in a mood of unprecedented confidence, continued to boost output (Table 1). In real terms farm gate prices barely kept abreast of the unprecedented levels of inflation which raged throughout much of the 1970s. However the technological triumphs in farming, led by the advisory services (ADAS) and university and other research institutes, followed by the supply industry (weed and pest control, precision fertiliser application) and more importantly, by new cereal varieties bred at Cambridge and elsewhere, enhanced the productive potential of farming systems throughout the EC-9. Very quickly, however, gathering momentum in output growth edged past even the most optimistic forecasts made by economists working mainly with supply response equations using farm gate prices as the principal explanatory variables when predicting future output levels. For example in a paper widely quoted in 1975, "Food from our own resources" , predicted farm output for most of the major indigenous type food raw materials in the UK for the early 1980s fell short of those levels actually achieved between 1982 and 1984.

At the time this was regarded as a great achievement for UK farming and the view taken then was that surely surplus farm production over and above domestic needs could be readily exported on world markets, so why attempt to restrain farmers from producing goods for export, or withhold recognition from them for the success achieved in import restitution, thereby saving foreign exchange. Unfortunately as the burden of expenditure falling on the CAP grew, first as the Community expanded to include nine countries, and later twelve, so did the extent of the financial burden on taxpayers. Worse still, this burden fell disproportionately on member states and grew at an even faster rate as domestic farm production levels exceeded domestic requirements. This is understandable as markets approach saturation: taking surplus farm products off the market at fixed guaranteed prices, together with underwriting the cost of storage and transport is an expensive exercise. However it is the subvention of the disposal of surpluses to make up for the difference (often as much as £50 to £60 a tonne for cereals) between the price paid to UK/EC farmers and the much lower prices obtained on fiercely competitive world markets that bites hardest on public funds. It was the cost of this exercise that began to alarm taxpayers, particularly in those states which were net contributors as opposed to those who are net recipients, and alerted the Commission in Brussels that limits ought to be placed on CAP expenditure on farming. Plainly this could be most appropriately done by placing physical limits on the quantities of dairy produce, cereals, oilseeds and so on, which might be produced by farmers. Indeed from the mid 1980s onwards a greater proportion of expenditure under the guarantee section of the European Agricultural Guarantee and Guidance Fund (EAGGF) was incurred to purchase, store and export surplus farm production, in particular dairy products, cereals and beef (Table 2). In addition there were also losses in store due to deterioration; yet another loss to taxpayers.

SUPPLY CONTROLS ON FARM OUTPUT

THE DAIRY SECTOR

Although this paper will concentrate on cereals - the mainstay of arable farmers' incomes - there are useful lessons to be learned from supply control measures in the dairy sector. In the decade 1966 to 1976 (EC-6) and later under the EC-10, dairy production almost doubled from 46 to over 83 million tonnes. As early as 1977 milk deliveries from farms to dairies were about five million tonnes per annum more than consumption, which tended to stagnate, somewhat erratically so, at around 80 million tonnes a year. Despite much opposition from some member states the Commission introduced a co-responsibility levy on farmers in an attempt to stem the tide of growing surplus production. Unfortunately this levy was not penal enough and production grew at an even faster rate between 1976 and 1984, when it reached 100 million tonnes (1983/84).

The Road to Milk Quotas

Despite the drastic measures taken in March 1984 to introduce quotas, coupled with a swingeing super levy designed to harshly penalise those who produced over quota, deliveries to dairies are still 15 to 16 per cent above stagnating consumption (98 million tonnes a year in 1987). The good news is that intervention stocks have been drastically reduced but ironically only because they have been given away at knock down prices. If present consumption trends and dietary preferences continue then dairy quotas may have to be revised yet again downwards. When dairy quotas were first introduced in March 1984 dairy farmers feared the worst. Now five years later, though production is still well above consumption needs in the EC, quotas have induced an air of buoyancy in dairy farming. The capital value of dairy quotas has more than compensated dairy farmers for any loss of value in farmland.

Financial aspects of supply controls: quotas on milk production

CAP expenditure on the milk sector rose rapidly after 1976 and stockpiles grew, consuming over one third of the annual budget. Between 1979/80 and 1985/86 this burden increased by over 50 per cent and the Commission was faced with no other alternative against the background of trends in consumption and the need to heavily subsidise exports but to introduce what popular commentators thought at the time would never happen: quotas coupled with a swingeing super levy. The meaning of the word quotas has of course been much misconstrued since it is in essence an exemption from tax on any milk produced on a particular holding. Quotas have now introduced an air of certainty into the dairy sector and to a lesser extent an air of confidence into taxpayers' perception of what the commissioners in Brussels have now undertaken to control runaway CAP expenditure. Indeed since the introduction of quotas expenditure on the milk sector has declined from 6.61 billion ECUs to 4.7 billion ECUs in 1989. The irony is that in nominal terms this expenditure is not much different from what it was in 1980, but in real terms plainly it is now much reduced.

The introduction of milk quotas has resulted in the removal of resources from the dairy sector and the shock waves have reverberated into the supply sector. The expectation is that after 1992 milk quotas may have to be revised downwards and this will inevitably lead to the further removal of resources from this sector. This in turn will lead yet again to further rationalisation of milk processing plants, a reduction in the amount of concentrate feed used and a smaller market for dairy stores and supplies. The objective for the future is to ensure that supply matches consumption trends more closely (allowing for a sensible level of exports from the EC-12) so that markets are not glutted with surplus produce. Price improvement should follow and this should be reflected in a recovery in real income for those profit maximising producers who remain in production. For the foreseeable future farmers with good business commonsense and entrepreneurs in the supply industry will be wiser to plan their future roles in a smaller, leaner, more dietary and environmentally conscious dairy industry. In the short run there will be more losers than gainers.

THE UK/EC CEREAL SECTOR

Against the background of high guaranteed prices for cereals it is not surprising that scientists, farmers and those involved in the advisory services have collectively promoted the development of new varieties and technology in cereal growing throughout the Community. This has led to a spectacular and sustained growth in output. In less than two decades the EC, once one of the largest importers of cereals, is now a large exporter of wheat. In the 1950s and 1960s this would have been regarded as well nigh impossible. However this triumph was not without its attendant financial burdens and problems. Indeed it is doubtful if this agricultural revolution could have taken place were it not subvented by generous taxpayer funds, upon which the CAP depends. Indeed it is now widely recognised that most of the taxpayer support for EC farming, initially generously donated to fend off any remaining threat of food insecurity, has not gone into farmers' pockets but has been subsumed into costs of factor inputs used in farming, including land. High farm gate product prices bid up the cost of inputs and land. The 'Ricardian' principle of land prices following farm gate prices and not the other way round is plainly evident. Cereal production in the EC-10 has increased by about 40 million tonnes since the early 1970s (Table 1) due almost entirely to a 50 per cent increase in yields. Indeed the area grown between 1973 and 1985 declined by almost one million hectares in the EC-10.

Production in the EC-12 between 1985 and 1989 increased to in excess of 160 million tonnes (1984 was an exceptional year; production was almost 174 million tonnes). Against a background of at best a static domestic consumption of about 132 to 135 million tonnes per annum (EC-12), net of imports of about 11 million tonnes (1986/89), production plainly was still over 20 per cent in excess of requirements. The decline in intervention and other stocks held throughout the Community in recent years is ironically not attributable to any deliberate policy to control the supply of cereals but to weather conditions. Consequently the potential for EC grain growers to produce 40 or 50 million tonnes in excess of domestic demand still exists. Were they to do so the burden of support which would fall on taxpayers' shoulders might become intolerable. Cereal farmers will argue quite reasonably in their circumstances that export markets should be found for surplus production and that the Community should build on its success by further expanding export markets. This would be extremely difficult to achieve since it would have to be done largely at the expense of US world trade in grain and to a lesser extent Canada and Australia. It is unlikely that these countries would stand idly by. Although the stance to produce goods for export should not be discouraged, it is plainly naive to produce for markets that do not exist, and to persist in producing high cost products which might not otherwise be produced if taxpayer support were to be removed for that particular industry. World trade in wheat and coarse grain which grew considerably from the mid 1960s to the mid and late 1980s is now showing signs of stagnation. Indeed world trade in the EC-12 main cereal export, wheat, is now sluggish, though world prices have increased recently because of the shortfall in production in parts of the drought stricken United States. The EC crops in 1988 and 1989 were somewhat smaller than past trends would indicate but only because of unfavourable weather conditions. Consequently the present limit on EC production of 160 million tonnes may have to be revised downward if EC consumption cannot be increased and growth in world exports remains sluggish. Ironically all the major cereal exporting countries, including the US, Australia and Canada, are looking to a resurgence in export growth, all having expanded production with varying degrees of enthusiasm at different times since the mid 1960s. Indeed it may have escaped the notice of many that while the EC was expanding cereal production so were many other major cereal exporting countries throughout the world.

Despite a spate of natural disasters across the globe in recent years there is still no genuine shortage of grain though stockpiles have declined sharply from their historically very high levels of over 350 million tonnes in 1986/87 to around 200 million tonnes in 1988/89 or about 16 to 17 per cent of annual consumption. While prices have risen quite considerably over the last year as stocks have been run down, in the US more land is now being released for cereal production, and other major exporting countries are also looking forward to an expansion in production. If the cycle commences all over again and world stocks build up rapidly, then this will put renewed pressure on farm gate prices and inevitably on farmers' incomes. However world wide the short term prospects for grain production and trading are much better and now is the time to ensure that policy makers, bureaucrats and farmers learn from the experiences of the past.

A prospect on cereal growing in the EC-12 in the 1990s

Looking to the future it is likely that the EC-12 area of cereals will decline to 30 million hectares or less as yields continue to increase and consumption continues to stagnate. It is expected that consumption of grain in the livestock sector is now set to decline faster than consumption in the human and domestic sector because of dietary trends. Indeed if these are taken seriously there could be a small rise in human consumption of grain. However the central issue in EC grain growing is not so much divergent trends between production and consumption but the cost of support. Indeed it could be argued that EC farmers could be allowed to produce as much grain as they wished, provided they were capable of doing so without government support and preferably at or below world prices. Indeed many would be willing to do so provided they could obtain inputs at or below world prices, including land. There is a school of thought that believes expansion in EC output could also have been achieved by reducing the cost of inputs, a matter of common sense, rather than by boosting farm gate prices to levels so high above world prices that as a result much farm production in the EC cannot now compete on world markets without subvention from taxpayers.

CAP expenditure on the cereals sector has risen very sharply in the last decade, from 1.67 billion ECUs (1980) to over 4.0 billion ECUs (1988/89). Since the greater proportion of this sum is spent on intervention buying, storage, interest costs and export subvention, it could be argued that this money is being unwisely spent since it has not maintained real farm incomes. Indeed market support costs for all major arable crops have increased steadily throughout the decade with in many cases a noticeable acceleration after 1984, ironically the year when the Community first launched its current round of CAP reform initiatives. For the two most expensive régimes, cereals and oilseeds, budgetary allocations have increased by over 100 per cent in both cases since 1984, with over a threefold increase in expenditure on oils and fats. Recently the rate of increase in the budgetary costs for these commodities has decreased noticeably, largely as a result of external factors such as the US drought in 1988 and fluctuations in world currencies. The impact which the new budgetary stabiliser mechanisms on cereals and oilseeds is likely to have in the 1990s is eagerly awaited by all. It is the Commission's stance on burgeoning public expenditure on EC-12 farming that will prompt and implement further restrictions on supply controls in the 1990s. Environmental and Green issues will add a new dimension, all of which will make life much more uncomfortable for farmers, financiers and the supply industry.

Cereals supply control measures, set-aside and stabilisers

Cereals production in the UK and throughout much of the EC-12 is now considered comparatively unresponsive to price changes. In economic jargon the supply elasticity in respect of price may be as low as .3. That is to say if a ten per cent reduction in supply were required a cut in price of as much as 30 per cent might be required. This would almost certainly bankrupt many cereal farmers and create much hardship in the farming sector. It is not surprising that a more compassionate method of controlling grain production was sought: taking land out of production by renting it from cereal growers (now dubbed set-aside). It would be naive to assume that farmers would rush in to such a scheme or expect handsome rewards for adopting such an option. From a policy standpoint it would be unfortunate if such compensation fuelled land prices and rental levels yet again which would spill over into the farming sector as a whole, thereby damaging its competitive stance. Indeed it could be argued that one of the main obstacles in seeking to expand the export market for UK/EC-12 grain is not so much taxpayers' or the Commission in Brussels' unwillingness to subsidise exports, but the high cost of production per tonne. Despite the triumph of productivity and the doubling of yields per hectare, particularly in the Eastern counties of England, since 1970/71, the real cost of production per tonne, though understandably erratic from year to year in line with changes in yield due to weather, has altered but little, remaining in the range of £85 to £90 a tonne (Table 3). The observed trends in the real cost of production of spring barley, winter barley and spring wheat are similar. Worse still, the real gross and net margins per hectare and per tonne are also remorselessly declining. Similar trends are also evident from international comparisons with EC member states. Oilseed and protein crops behaved in a similar manner; the real gross margins per hectare and per tonne are trending downwards while the real cost of production per hectare and per tonne are rising. This is the great dilemma facing arable farming at the present time.

Public support for the sector is still very high, yet real incomes earned by farmers are relentlessly declining. Farmers and those in the supply industry will understandably ask how long can these trends continue, and argue perhaps that unless more public support is available for farming, it is difficult to see how individual farmers can continue in business. However it is not unreasonable to respond that given there is excess capacity in the industry (the arable sector) then until such time as this is brought into line with future consumer requirements economic adversity will rage throughout the sector.

Detailed studies on individual farm enterprises give reasonable guides on where resource withdrawal ought to take place. The question now uppermost for researchers, farmers and advisers in the supply industry alike is whether maximum economic efficiency in the use of the inputs shown in Table 4 have been achieved. For farmers the economically efficient or more precisely, the profit maximising level of use, is that at which the increment in cost resulting from the last unit applied is just covered by the effect on revenue. In economists' jargon the marginal factor cost and the marginal revenue productivity must be equal. The estimates of marginal productivity for each input are shown in Table 4. At the average farm gate price prevailing in 1987/88 - 1988/89 and yield performance averaged over the last five years, wheat producers in the Eastern counties could have still increased further inputs of fertiliser and spray chemicals without exceeding the optimum input level. However all other inputs, machinery, labour and sundry service costs were all over allocated at £105 a tonne and at the yield levels mentioned. Since the ratios of marginal factor cost to marginal revenue productivity were all less than unity this analysis implies that profits could have been higher had wheat growers on average used less labour and machinery and specialist services. Wheat producers are using too much machinery, too much labour (both manual and professional) and not surprisingly too much land.

To move to a situation in which marginal increments of land used were no longer adding more to the cost (in terms of rent paid or rent foregone) than to revenue, the individual farmer on the basis of this analysis should reduce the amount of land devoted to wheat growing and rent it to other farmers, who presumably could use it for purposes other than wheat growing. Perhaps the idea of set-aside is not such a bad option after all for wheat growers who find themselves in this category. The limitations of this approach are that it takes no account of either fiscal considerations or institutional inflexibilities in the land market. There is needless to say also the general aggregation problem of such analysis.

Predicted effects on fertiliser and spray chemical use resulting from lower cereal (wheat) prices

A question of interest not only to farmers but to those concerned with the costs of agricultural support and the protection of the rural environment from excessive pollution is what the effect on the use of agrochemicals would be of much lower prices for cereals. From the production functions estimated it appears that if price restraint were to be used as the sole instrument of control on cereal production and if ever the price per tonne were to fall to £85 the optimum level of fertiliser use would not be below present levels of application. The same argument would apply on average to the application of spray chemicals, since the ratio of marginal cost to marginal return would still be just slightly greater than 1 (Table 4). This is a rather surprising result given that in recent years, up to the harvest year of 1989, the yield of cereals per hectare in the Eastern counties has been running below trend, largely because of unfavourable weather conditions at harvest time. If and when yields come back to or move above the underlying trend then of course the marginal price and marginal cost ratios will increase, enforcing the findings of this research. Of course a discussion on the efficiency of fertiliser and spray chemical usage based on average performance masks the difficulties facing those achieving less than average performance. Consequently cereal growers with below average performance would have to withdraw these inputs; equally those with above average performance could increase yet further their inputs before reaching maximum economic efficiency. To induce a reduction in the use of fertiliser and spray chemicals under existing technology a cut in the price of cereals (wheat) would have to be very drastic indeed.

The lesson to be learned is that looking forward to the 1990s the use of price control will be a very blunt instrument with which to persuade farmers to reduce the output of cereals or to entice them to adopt measures which would restrict to within tolerable limits pollution in the environment.

Withdrawal of factor inputs other than agrochemicals

Although a sharp reduction in the price of cereals is unlikely to affect much the use of fertiliser and spray chemicals there would have to be adjustments in the use of what are conventionally called fixed resources (factor inputs). Since the ratio of marginal cost to marginal return is less than unity for all these items (Table 4) they are all over allocated at their present unit cost. Consequently if the price per tonne were ever to fall to £85 annual labour and machinery inputs at present prices would have to decline by well over 40 per cent. Considerable reductions would also have to take place in the cost of using land, annual rents or rental charges.

CONCLUSIONS

Given the problems associated with attempting to control the supply of cereals through price reduction, it is not surprising that policy makers, following the examples available from the United States, opted for set-aside as a means of enticing farmers to take land out of cereals production. Its critics have been many but it is a much more humane approach than using the price weapon. More importantly, however, it fits in well with the notion of a more environmentally acceptable countryside where pollution control will grow in popularity and urgency in future years. A new method of farming will slowly evolve in response to changing consumer tastes and there will be renewed pressure on scientists to develop new techniques in biotechnology to slake the thirst of a more health-conscious society.

TABLE 1
EC PRODUCTION OF CEREALS AND DAIRY PRODUCTS 1973-1989.

Year	1973/74	1983/84	1984/85	1989/90
Million tonnes				
Cereals	108.0	138.0	173.0	160.0
Oil Seeds/Fats	1.1	3.5	3.8	4.9
Milk	92.0	109.0	107.0	101.0
Beef/Veal	5.6	7.5	7.4	7.3

TABLE 2
EC ANNUAL SUPPORT FOR FARMING 1973-1992 (Billion ECU)

Year	1973	1978	1980	1984	1988	1989	1992
Cereals	1.04	1.12	1.67	1.94	4.23	4.00	3.8
Oils/Fat	0.37	0.65	0.75	1.97	4.61	5.42	5.0
Sub.tot Arable	1.78	3.31	4.40	9.20	14.76	15.94	14.8
Milk	1.50	4.01	4.75	5.44	5.91	4.72	4.6
Sub.tot L.stock	1.64	4.74	6.37	8.69	10.09	9.22	8.8
Total	3.42	8.05	10.77	17.87	24.85	25.16	23.57
EAGGF*	3.82	8.67	11.86	19.11	27.50	27.70	29.60
EC Tot.cost	-	-	18.21	27.27	45.30	45.30	50.10

* European Agriculture Guarantee and Guidance Fund.

TABLE 3* (Real terms 1987 prices)
Winter Wheat Cost of production 1971-1989(UK,East Counties)

Year	.1971	1981	1984	1987	1989
Yield t/ha	4.66	6.29	8.36	5.85	7.40
Output£/ha	698	854	963	608	762
Gross Margin	579	632	737	404	534
Net Margin	259	209	317	26	132
(per tonne)	(55.8)	(33.2)	(37.9)	(4.4)	(17.8)
Cost £/tn	94.1	102.5	77.3	99.6	85.1

*Adapted from table 3.1a,Report on Farming in the Eastern Counties of England University of Cambridge 1987/88.

TABLE 4
The Marginal Priductivity of Inputs/Wheat Growing(1985/89)

Wheat price per tonne		£105	£85	
Input	AVP	MVP	MP/MC	MP/MC*
Fertiliser	8.5	2.81	2.25	1.83
Sprays	8.4	2.51	2.01	1.81
Machinery	4.7	0.62	0.90	0.71
Labour	9.7	0.20	0.18	0.13
Rent	6.3	0.95	0.82	o.66
Overheads	12.4	0	0	0

* MVP=Marginal Value Product,MP/MC=Marginalprod/marginal cost ratio.

SESSION 6A

SET-ASIDE AND CROPPING WITH REDUCED INPUTS: IMPLICATIONS FOR WEED CONTROL

CHAIRMAN	MR H. M. LAWSON	
SESSION ORGANISER	DR R. E. L. NAYLOR	
INVITED PAPER		6A-1
RESEARCH REPORTS		6A-2 to 6A-7

EXPERIENCES WITH REDUCED HERBICIDE DOSES IN DENMARK AND THE DEVELOPMENT OF THE CONCEPT OF FACTOR-ADJUSTED DOSES.

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ABSTRACT

Field experiments in cereals have shown that the herbicide dose often can be reduced to 1/3 to 2/3 of the recommended dose without any significant loss of efficacy and yield. In the experiments three key factors have been identified to affect the activity of a herbicide in the field: the weed spectrum, the growth stage of the weeds and the environmental conditions. Until now, the decision to reduce the herbicide dose has been based mainly on the farmer's own experiences, as the traditional way of analyzing results from herbicide experiments has not allowed for any quantification of the influence of the key factors. However, we have found that the activity of a herbicide on different weed species, at different growth stages or under variable environmental conditions can be regarded as a parallel displacement of one and the same dose-response curve and, consequently, the influence of these factors on herbicide activity can be described and quantified by applying a parallel-line assay technique. This has led to the development of the concept of factor-adjusted doses, i.e., the dose is adjusted according to the susceptibility of the weed species occuring, their growth stage and the environmental conditions at the time around application. The hypothesis of parallel dose-response curves and the derived factor-adjusted doses is the basic principle underlying the computer based advisory system which is currently being developed in Denmark. A widespread use of factor-adjusted doses could contribute substantially to meet the political demand for a reduction in the use of pesticides.

INTRODUCTION

Currently there is in many European countries an increasing concern towards the use of pesticides and restrictions have already been introduced in some countries.

In Denmark the total use of pesticides has to be reduced by 25% before 1 January 1990 and another 25% before 1 January 1997 compared to the average use from 1981 to 85. Besides regulating the use of pesticides in terms of tons active ingredient a new concept, the treatment intensity index, has been introduced. The treatment intensity is calculated every year on the basis of the total sales and expresses how many times in average the arable land could have been treated with a recommended dose of a pesticide. The reduction in the use of pesticides must be reflected both in the tonnage of pesticides used and in the treatment intensity. This implies that a shift from, for example, the phenoxy acids, recommended at doses of 1 to 2 kg/ha, to the sulfonylurea herbicides, recommended at doses of 4 to 6 g/ha, will only partly meet the demand for a reduced pesticide use, because the treatment intensity index will be unaffected.

A reduction in the treatment intensity can be obtain either by reducing the number of times the crops are treated with pesticides or by applying reduced doses, as the recommended doses are the basis for the calculation of the treatment intensity index. A reduction in the number of herbicide treatments can be achieved, for example, by introducing economic thresholds and non-chemical methods of weed control. Research is currently being conducted in these fields at our institute, however, the results are still preliminary and reduced herbicide doses therefore seem, in the short term, to be the most feasible way to meet the political demand for a reduction in the pesticide use.

EXPERIENCES WITH REDUCED HERBICIDE DOSES

The first field experiments with reduced herbicide doses were carried out in spring barley from 1973 to 1977. It was found that the yield increase was not correlated with the herbicide dose even though the effect of the reduced herbicide doses on the number of weeds was significantly lower than of the recommended dose (Table 1).

TABLE 1. Effect and yield increase of reduced doses of two herbicides in spring barley. Average of 93 experiments in 1973 to 77 (After Thonke, 1978).

	% reduction in number of weeds			% yield increase		
Dose	Full	3/4	1/2	Full	3/4	1/2
Herbicides						
MCPA+dichlorprop (n=405+1620 g/ha)	89.1	85.4	77.2	2.6	2.8	2.5
MCPA+dichlorprop+ ioxynil (n=330+990+165 g/ha)	92.3	88.6	81.7	1.9	2.2	2.6
	LSD_{95}=4.8			LSD_{95}=2.1		

These and similar results in the recent years have promoted the use of reduced herbicide doses, particularly in spring barley, and have resulted in the treatment intensity index for herbicides in cereals remaining approximately 1 during the last 4 to 5 years although winter cereals often are treated more than once. However, to meet the demand for a 50% reduction in pesticide use before 1 January 1997 it is required that more farmers exploit reduced doses and also that reduced doses become a common practice in crops other than spring barley, particularly in winter cereals which constitute an increasing area.

In order to further develop the use of reduced herbicide doses it was essential to identify the key factors affecting the field performance of the herbicides. The research work during the recent years has shown that:

- weed spectrum
- growth stage of the weeds
- environmental conditions

are the most important factors considering the effect of reduced herbicide doses, as illustrated in the following Tables.

The effect of reduced doses of chlorsulfuron on various weeds in spring barley is shown in Table 2. Whereas *Matricaria spp.* and *Stellaria media* were controlled with 1/8 of the recommended dose, a reduction in herbicide dose resulted in a pronounced reduction in the effect on fresh weight of *Viola arvensis* and *Veronica spp*. Similar differences in the susceptibility of the weeds were found with ioxynil+bromoxynil (data not shown).

TABLE 2. Percent effect on four weed species of reduced doses of chlorsulfuron[a] in spring barley. Average of 2 experiments in 1987 (after Petersen & Jensen, 1987).

	% reduction in fresh weight of weeds			
Dose g/ha	Matricaria spp.	Stellaria media	Viola arvensis	Veronica spp.
0.25	70	80	60	41
0.5	89	90	69	70
1.0	95	92	78	68
2.0	95	95	78	75
4.0	97	93	90	82
LSD_{95}	9	6	16	24

[a]Recommended rate is 4 g/ha, dilutions were applied in mixture with 0.05% (v/v) of the nonionic surfactant Extravon.

In 1987 the effectiveness of herbicides in spring barley was generally good, and it should therefore not be concluded that Matricaria spp. and Stellaria media can always be controlled by 0.5 g/ha chlorsulfuron. This was not the situation, for example, in 1988. However, what should be noted is that major differences occur in the susceptibility of the weeds to the herbicides and, consequently, if application of reduced herbicide doses is to be succesful a knowledge of the weed spectrum in the field is essential.

The effect of bentazone+dichlorprop applied to weeds at four growth stages in spring barley is shown in Table 3. It is obvious that early application resulted in considerably greater reduction in fresh weight than did late application. Thus a reduction in herbicide dose was only feasible when the herbicide was applied at the early growth stages. Similar results have been found in winter cereals when comparing the activity of herbicides applied in the autumn and spring, respectively (Table 4). Although the full dose, which is the recommended dose, was increased by one third in the spring, it can be seen that on all weed species, except Viola arvensis, a reduction in the dose without loss of efficacy was only possible at the autumn application. Against Viola arvensis it was not possible to reduce the dose of the herbicide without a significant loss of efficacy at any of the two application dates. In this, as well as in the spring barley experiment, in addition to differences in growth stage, the environmental conditions were also different. However, similar trends were found in all four winter wheat experiments and it is therefore most likely that the differences in growth stage account for the observed differences in herbicide activity. The results in Tables 3 & 4 emphasise the importance of correct timing when applying reduced herbicide doses.

TABLE 3. Influence of growth stage on the effect of bentazone+ dichlorprop on two weed species in spring barley.

	% reduction in fresh weight of weeds							
	Stellaria media				Chenopodium album			
Number of leaves	0-2	2-4	4-6	>6	0-2	2-4	4-6	>6
Bentazone+ dichlorprop g/ha								
32.5+42.5	91	64	-[a]	-	91	74	-	-
65+85	97	75	75	50	98	77	58	66
130+170	99	88	82	94	98	99	79	73
260+340[b]	-	-	83	91	-	-	91	83
	LSD_{95}=32.3				LSD_{95}=11.7			

[a]Not included in the experiment.
[b]Recommended rate.

TABLE 4. Effect of autumn and spring application of ioxynil+mecoprop on four weed species in winter wheat. Average of four experiments in 1987 and 1988 (after Petersen & Jensen, 1987 and Petersen, Jensen & Jørgensen, 1988).

Ioxynil+mecoprop g/ha	Matricaria spp.	Viola arvensis	Stellaria media	Lamium spp.
	% reduction in fresh weight of weeds			
	Autumn application[a]			
60+180	93	68	86	97
120+360	93	77	98	98
240+720[c]	99	95	98	96
	Spring application[b]			
80+240	75	53	62	68
160+480	80	77	74	77
320+960[c]	94	87	93	94

[a]Application October/November
[b]Application late April
[c]Recommneded rate

It can be seen in Table 4 that some of the most common weed species in winter cereals in Denmark like Matricaria spp., Stellaria media and Lamium spp. were controlled satisfactorily with 25% of the recommended dose and, actually, field experiments carried out in the recent years have shown that a low dose applied in the autumn often is sufficient to give effective control in many winter cereal fields. This indicates that there also seems to be a potential for reducing herbicide doses in winter cereals.

The third key factor, environmental conditions, has not been studied intensively under field conditions, however, studies under controlled conditions have demonstrated that the variable environmental factors can significantly influence herbicide activity (Gerber et al., 1983). While a range of environmental variables like temperature, humidity, rain and soil moisture can affect the activity of foliar-applied herbicides, the main factor to consider when applying soil-active herbicides is soil-moisture. The general recommendation in cereals has been to apply the herbicides in the morning, as conditions normally are more optimum than later in the day.

The many experiences in Denmark with reduced doses have clearly shown that there are potentials for reducing the herbicide use, particularly in cereals, if the farmers are aware of which weed species occur in the fields, their size at the time of application and the environmental conditions in the days around the application. However, a main question is still unanswered: How much can the dose be reduced?.

THE CONCEPT OF FACTOR-ADJUSTED DOSES

Most of the experiments designed to study the effect of herbicides on different weed species or growth stages have been conducted with only a few doses and have normally been analysed by ordinary analyses of variance. Such experiments can only provide a qualitative answer as to whether significant differences are observed or not. From a pratical point of view such experiments can be used to define the optimum conditions for application but not to give any indication of how much the dose can be reduced when the herbicide is applied at optimum conditions.

In order to overcome this problem a computer based advisory system using the concept of factor-adjusted doses is being developed in Denmark. The concept of factor-adjusted doses is based on the hypothesis that the dose-response curves of a herbicide applied, for example, at different growth stages of a weed are parallel and, consequently, the results can be analysed by applying a parallel-line assay technique. As pointed out elsewhere (Kudsk, 1988), the experience obtained so far has indicated that the hypothesis of parallel dose-response curves seems reasonable, so long as the variable factors in question can be assumed not to affect the mode of action of the herbicides. Based on the knowledge available in literature, it seems reasonable to assume that the mode of action of the herbicides are identical on different weed species, on different growth stages of a weed and under different climatic conditions. Although differences in the primary mode of action between susceptible and very tolerant plant species can not be ruled out, we have found that the hypothesis constitutes a reasonable basis for assessing the influence of the three key factors on herbicide activity.

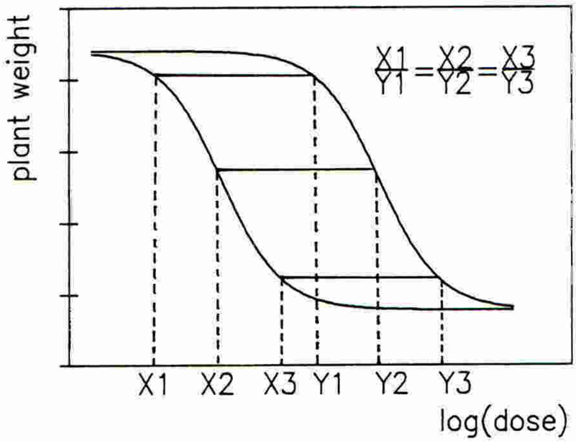

FIGURE 1. Schematic illustration of parallel dose-response curves showing that the ratio of the doses giving similar effect is constant.

As the dose-response curves are assumed to be parallel the horizontal distance is the same all along the dose-response curve. Furthermore, as the dose axis is logarithmic a constant horizontal distance implies that the ratio of the herbicide doses giving similar effect, for example, on two weed species is constant at all response levels, as shown in Figure 1. This means that application of the parallel-line assay makes it possible not only to test whether significant differences occur but also to quantify these differences and, consequently, to factor-adjust the doses according to weed species, growth stage and environment. In Figure 2 are shown examples of how the influence of the key factors on herbicide activity can be assessed by applying a parallel-line assay.

Mathematically, the parallel-line assay assumes that the dose-response curves are identical in all parameters except the one determing the horizontal location along the dose axis. In the computer system the logistic model, suggested by Finney (1979) and Streibig (1989) is used:

$$\underline{U}_i=(\underline{D}_i+\underline{C}_i)/[1+\exp(-2(\underline{a}_i+\underline{b}_i\log(\underline{z})))]+\underline{C}_i \qquad (1)$$

$\underline{U}_i$ is the fresh or dry weight of the weed, $\underline{D}_i$ and $\underline{C}_i$ denote the upper and lower limit at zero and large doses, respectively, $\underline{a}_i$ is the parameter describing the horizontal location, $\underline{b}_i$ is proportional to the slope around ED_{50} and $\underline{z}$ is the dose. As $\underline{D}_i$ and $\underline{C}_i$ are 100 and 0, respectively, and $\underline{b}_i$ has been estimated for each herbicide on basis of all available results from field and pot experiments, the only parameter varying is $\underline{a}_i$, which results in the following equation:

$$\underline{U}_i=100/[1+\exp(-2(\underline{a}_i+\underline{b}\log(\underline{z})))] \qquad (2)$$

For each herbicide the parameter $\underline{a}_i$ will have a specific value for each combination of weed species, growth stage and environment. In the computer system, however, for each herbicide an $\underline{a}_i$ value has only been given for each weed species and the resulting dose is then adjusted according to growth stage and environment. The $\underline{a}_i$ value in the computer system has been calculated on basis of the average effect of the recommended dose of the herbicide in the official experiments, as well as in the experiments carried by the company marketing the herbicide.

One of the advantages of knowing the dose-response relationship is that the dose to achieve a particular weed reduction can be estimated. For example, if the weed density is very low or the particular weed species is not very competitive then a relatively small effect on weed survival or growth might be sufficient to ensure maximum yield. When the parameter $\underline{a}_i$ and the desired effect $\underline{U}_i$ are known then the required dose $\underline{z}$ can easily be estimated using equation 2.

In the field the crop itself will also affect the growth of the weed plants. The hypothesis of parallel sigmoid dose-response curves is based on the assumption that only the herbicide affect the growth of the weed plants and under field

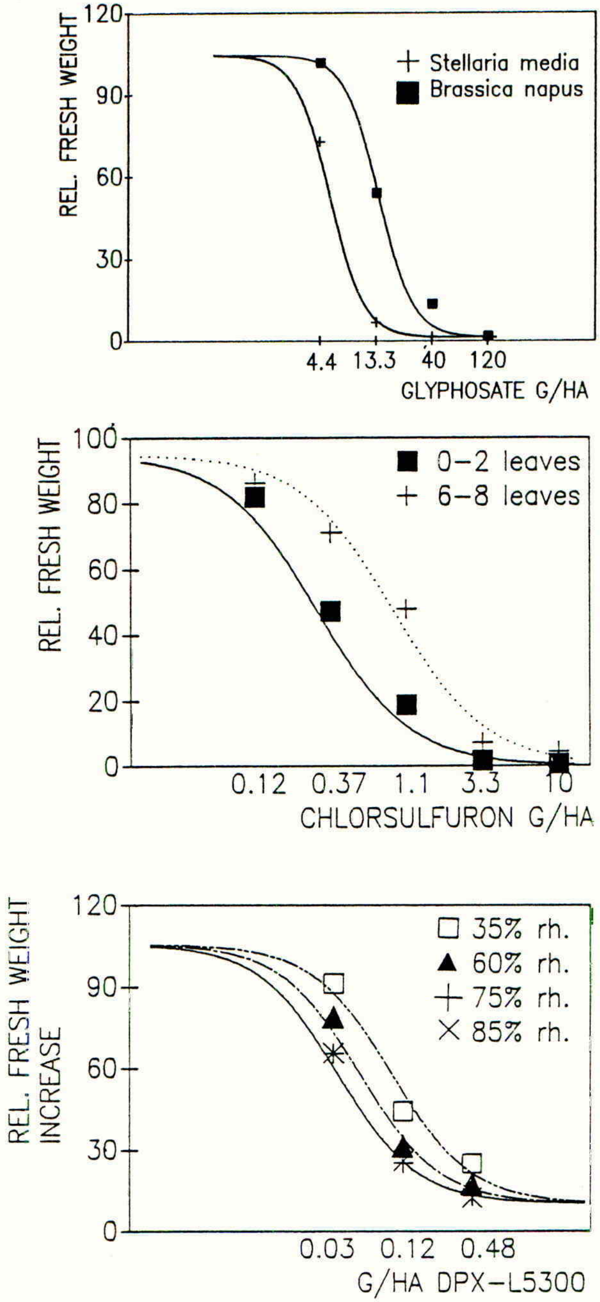

FIGURE 2. Examples showing how the parallel-line assay has been applied to assess herbicidal activity of glyphosate on two weed species (a), of chlorsulfuron on two growth stages of <u>Stellaria media</u> (b) and of DPX-L5300 on white mustard at a constant temperature of 22.2°C and different relative humidities (c).

conditions the parallel-line assay technique will therefore only be an approximate approach. However, at the high effect levels required in the field, corresponding to the lower part of the dose-response curve in Figure 1, the herbicide is the single dominant factor and we have found that also under field conditions do the hypothesis of parallel dose-response curves form a reasonable basis for assessing differences in the effect on various weed species and growth stages of a weed.

Many herbicide products consist of two or more active ingredients with different mode of actions. One can therefore not always expect the dose-response curves on different weed species to be parallel, as one weed species might be controlled primarily by one of the active ingredients while another will be controlled mainly by some of the other active ingredients in the product. As sufficient data are not available on the activity of all active ingredients on all 60 weed species in the expert system, it was necessary to consider each herbicide product as one "active ingredient". However, as the results obtained during the last three years of tests show, even when applying this simplified approach it has been possible with herbicides containing more than one active ingredient to factor-adjust the dose according to weed species. (Baandrup & Ballegaard, 1989).

At present, environmental factors are not included in the calculations of the factor-adjusted doses but after the construction of new climatic simulators, which can simulate natural climatic conditions, work on the influence of environmental factors is also in progress at our institute.

Factor-adjusted doses have been developed for spring and winter cereals and have been implemented in the computer based advisory system. The spring cereal part of the system has now been tested for three years and these results are presented elsewhere in this volume (Baandrup & Ballegaard, 1989). The winter cereal part has just been released for testing and in the next years factor-adjusted doses will be developed and implemented in the computer system for other major crops like oilseed rape, peas and sugar beet.

Little is known about the long-term effects of repeated applications of reduced doses, particularly in terms of the seed return to the soil and the effect thereof on the future weed problems, but work is also in progress in this field. The widespread use of factor-adjusted doses, however, will could lead to a substantial reduction in the use of herbicides, particularly in cereals, and contribute to meeting the political demand for a reduction in the use of pesticides in Denmark.

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THREE YEARS FIELD EXPERIENCE WITH AN ADVISORY COMPUTER SYSTEM APPLYING FACTOR-ADJUSTED DOSES.

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ABSTRACT

The development of information and advisory systems progresses as modern computer technology gets better, cheaper and more efficient.
In Denmark an advisory computer system, which uses the concept of factor-adjusted doses, is being developed for weed control in spring barley and winter wheat. The system can help farmers by selecting a herbicide and adjusting the dose according to the susceptibility of the weed species present in the field and their growth stages. In the future the system will also be able to adjust the dose according to the prevailing climatic conditions. The system uses information on about forty active ingredients (representing about eighty trade names) stored in a database.
During the last three years the advisory system has been tested in field trials in spring barley in order to ensure that the advice is practical. The results confirm that it is possible to adjust the herbicide dose according to weed species and growth stage.

INTRODUCTION

The decision-making process of herbicide management can often be a difficult task for the farmer. New herbicides are being developed every year with varying efficacy towards the weed species and there may be many formulations available. Much information has to be considered in order to achieve the best weed control. The farmer is also faced with legislative demands for a reduction in the amount of herbicide used. At the same time a substantial fall in crop-prices makes it very important for the farmer to get a satisfactory weed control using no more herbicide than necessary.

Many Danish farmers use reduced doses of herbicides, but to a large extent these farmers must rely on their own experience and intuition regarding the extent of this dose reduction. The need for a more sophisticated system for advidesired level of control for that species is reached. In mixed weed populations the most difficult species to control sets the limit to the dose reduction. The recommended dose (i.e. the normal-dose) of a herbicide is also the maximum dose the system can suggest.

At present, climatic conditions are not included in the advisory system, but they will be added when research data become available.

FIELD EXPERIENCES WITH THE ADVISORY SYSTEM

The advisory system has been developed for weed control in spring barley and winter wheat. In order to test whether the system will support the farmer with a good and proper recommendation, field trials have been carried out for three years (1987-89) taking the advice the system provides. The herbicide selected by the system has been tested:

1. at the normal-dose (1987-89)
2. at a factor-adjusted dose, where the desired weed control level on average has been ninety percent (1987-89)
3. at a dose, where the desired weed control level has been lowered to seventy percent on average (1988-89), and
4. at a dose, where the weed control level has been lowered further to fifty percent (1989).

These computer-selected treatments have been compared with an untreated control and with a standard treatment: a commonly used mixture of MCPA and dichlorprop at the recommended dose (399 + 1602 g a.i./ha) (1987-89). Weed control assessments were made by counting the weeds (numbers of each species per m^2).

RESULTS AND DISCUSSION

Through all three years the herbicides selected by the advisory system have been more efficient at weed control than the standard MCPA + dichlorprop mixture (table 1). In 1987 and 1988 all herbicide treatments gave significantly higher yield than the untreated control. However, reduced doses gave slightly lower yields compared to the standard treatment. In 1989 there was the same trend in the yields, but without a statistical significance.

The herbicides were selected to fit the perceived problems and the doses adjusted to weed species and growth stages, whereas the standard hormone mixture was chosen in advance without any knowledge of the weed flora and without any adjustment of the dose. The lowering of the desired level of weed control (ninety -> seventy -> fifty percent) led to a corresponding reduction of the average herbicide dose. Reductions in the dose of herbicide to about 75% and 50% only

TABLE 1. Relative reduction in herbicide dose, effect on weed control and yield of spring barley using the advisory system of weed control.

treatment	Relative dose (1987-89)	Weed control (%) 1987	1988	1989	Yield (t/ha) 1987	1988	1989*
untreated	-	0	0	0	4,730[b]	4,719[c]	5,903
MCPA+dichlorprop	100	73	74	68	5,058[a]	4,976[a]	6,020
selected herbicide, normal-dosage	100	94	80	79	5,123[a]	4,986[a]	5,965
selected herbicide, adjusted to 90%-control	74	90	76	78	5,056[a]	4,922[ab]	5,978
selected herbicide, adjusted to 70%-control	49	-	74	73	-	4,859[b]	5,973
selected herbicide, adjusted to 50%-control	33	-	-	69	-	-	5,908

1987: 10 field trials
1988: 27 field trials
1989: 15 field trials

In each column figures followed by the same letter do not differ at the 5% level according to Duncan's multiple range test.

* 1989 yields were not significantly different at the 5% level.

reduced yield by 1,1% and 2,4% respectively compared to the standard treatment in 1988. In 1989 there was no significant difference in the yields even when the herbicide dose was reduced to about 33%.

The individual field trials (fifty-two trials in three years) confirmed that there was a positive correlation between accurate identification of the weed seedlings and the subsequent weed control achieved.

The climatic conditions of the three years of field trials in spring barley varied greatly. In 1987 precipitation was high in May and June, whereas the same period in 1988 and 1989 was characterized by drought. In 1988 there was also much windy weather during the application period, which together with the drought offered very unfavourable conditions for the herbicides.

A period of drought in advance of a herbicide application seems, especially, to reduce the susceptibility of the weeds (Kristensen, 1989). At present the climatic conditions on the days around the application are not included in the dose adjustment of the advisory system, but work on this subject is in progress at our institute and, when included, it will refine the advice that the system can give the farmer.

CONCLUSION

This advisory system can help the farmer to achieve a satisfactory weed control in order to maintain yields. By using factor-adjusted doses it also contributes to the legislative demand for a reduction in the use of herbicides.

A major practical problem is that the farmer must be able to identify the weeds at early growth stages in order to get the full benefit from the system. If the system can offer better advice than the one based on the farmers own belief and experience, then the motivation to learn to identify the weeds will increase.

The advisory system has been developed for weed control in spring barley and winter wheat, but it will be expanded to oilseed rape, peas and sugar beet, where a split application of herbicides will be a possibility in order to achieve a satisfactory weed control. The use of expert system technology in the advisory system will also be considered, because this technology can enhance the useability of models and data bases (Jones et al., 1987).

Information and advisory systems of weed control can become useful tools for the farmer in the decision-making process concerning herbicides. This current system will be integrated with advisory systems for plant protection and in this way become part of an overall advisory system of diseases, pests and weed control.

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A COMPUTERISED DECISION SUPPORT SYSTEM FOR SUGAR BEET HERBICIDE SELECTION

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ABSTRACT

A computer program has been developed to provide information and assist in giving recommendations to sugar beet advisers on appropriate herbicides, mixtures and sequences for the range of sugar beet weed problems in the United Kingdom.

Herbicide selection in beet is a complex and important management decision, and it is desirable to have a central, consistent source of information and advice on approved herbicide applications to back up local field advisers. The computer is ideally suited to this purpose, and can improve weed control by providing correct and timely information.

The program provides a summary of label information for all herbicides approved for use on sugar beet, along with approved tank mixes and sequences. Information is available by chemical and trade names. Advice is given on products which will control problems selected from a menu of specific weeds. There is also an expert system component of the program that analyses weed control problems on the basis of crop and weed growth stage, soil and weather conditions, cropping history, etc, and gives appropriate herbicide recommendations.

The program has been developed through consultations between weed control experts, computing specialists and pest management systems analysts. It has been written using the KnowledgePro expert system shell and works on IBM compatible desktop personal computers. The program is now being evaluated as a backup resource for weed control advisers in the field.

INTRODUCTION

Sugar beet is grown on approximately 200 000 ha in the United Kingdom. Weeds are a major problem, since beet is also a clean-up crop for weeds in cereals. The majority of beet crops receive between two and three herbicide applications for broad-leaved weed control. Some fields receive more sprays than this, where weeds germinate over a long period of time (eg peaty soils) or where *Cirsium arvense* or grass weeds are present. Currently, there are over 50 herbicides approved for use on sugar beet, each product having individual recommendations for the susceptible weed spectrum, the time of use, and permissible mixtures, sequences and dose rates. The number of sprays used and the number of recommendations available are mainly due to growers adopting the low pressure, low dose technique (Smith, 1983). With an increasing necessity for farmers to improve gross margins through greater efficiency, together with demands from environmental interests to reduce pesticide inputs, there is an even greater need to improve herbicide practice.

Advice on all aspects of crop production, from drilling through to harvesting, is provided centrally by British Sugar plc, although farmers can also call on other private and public sector advisers. A large advisory organisation like British Sugar needs a consistent and reliable way for all its staff to be able to recommend control strategies for a problem as complex as sugar beet weed control. This advice also needs to be based on detailed product knowledge and on sound rules for choosing products and mixes of products. Such a situation, where the problem is complex, diagnostic in nature, important to solve correctly and where there are relatively few human experts is exactly where expert, or knowledge-based, systems can play a significant role in aiding decision-making (Forsyth, 1984).

Expert systems are computer programs which mimic the decision making process of a human expert. By asking simple questions of the user, and then employing rules and additional technical information derived from advisers and field trials, an expert system is able to reach the same solution to a problem as would a human expert. Early applications of these systems were in medical diagnosis and mining; more recently expert systems have been developed for use in agriculture and pest control (Stone *et al.*, 1986; Peart *et al.*, 1986; Coulson and Saunders, 1987; Mumford and Norton, 1989; Saunders *et al.*, 1989; Bouchard *et al.*, 1989). Decision support systems can be considered as a more general class of knowledge-based systems that provide additional, non-expert, functions, such as providing background information and performing calculations to help support a decision made by the user. The first knowledge-based system used in crop protection in Britain was Counsellor, which advised users about the control of cereal diseases (Jones *et al.*, 1984). Another program, HESTA, has been developed by the Scottish Agricultural Colleges to give general recommendations on herbicides for a range of crops in Britain (Dr D H K Davies, pers. comm.).

The steps involved in building a knowledge-based system are described below, followed by an outline of the specifications of the program and a discussion of the advantages such a system offers for improving herbicide use on sugar beet.

STEPS IN DEVELOPING A DECISION SUPPORT SYSTEM

Building a decision support system involves four steps: problem structuring, knowledge acquisition, knowledge engineering and program encoding.

Problem structuring

To specify what is required of a decision support system, it is important to fully describe the problem to be addressed: the nature of the problem, the options available, and the users and their objectives. The more time spent in the early stages defining the problem area and how solutions need to be presented, the easier designing the system will be.

In this case, the pest status of weeds and the options for their control are well known. The major decision in the planning stage was the form and scope of the system. The requirement was for a decision support system for use by Factory Agronomists to help Crop Advisers with telephone enquiries, and to use in training programmes. Because the system could be used by advisers while talking to farmers on the telephone, it was essential to keep menu paths and response times as short as possible.

Complex label advice makes the task of recommending tank mixes in the field particularly difficult. In the future regulations arising from the Food and Environment Protection Act (FEPA) may add to these difficulties. Tank mix recommendations were identified as a key area to be covered by the system, along with sequence recommendations and the choice of herbicide(s).

Before designing the system it was important to determine the needs and background of the user (person operating the system and giving advice) and the end-user (the grower acting on the advice given). A good program is tailored to specific users and end-users and their needs. Questions that needed to be answered include: "How much knowledge about the subject will the users have?"; "How familiar are users with computers?"; "Under what conditions will the system be used, in the office, over the phone, in the field?"; and "What computer facilities are available? (machine type, processor speed, peripherals, etc)".

The users in this case, at least initially, are British Sugar Factory Agronomists. They have good subject knowledge, are becoming familiar with computers, would use the system in an office as a reference source and to answer telephone queries and have access to IBM compatible PC's with standard peripherals.

Knowledge acquisition

The quality of the advice given by a knowledge-based system will depend on the quality of rules and information provided by the human expert(s) who contribute to its development. A good expert is fully conversant with the technology to be employed, who understands the benefits of developing a knowledge-based system and who can communicate his ideas and thought processes well. It is probably unwise to consult too many experts while building a system. However, forcing an expert to justify his decision-making process to another expert often provides valuable insight into their thought processes. It also provides a checking mechanism on the validity of any decision reached.

During the development of this system members of the British Sugar agricultural staff and the Norfolk Agricultural Station were the human experts. In addition to these experts, industry-produced product manuals and herbicide labels provided valuable information. Information was extracted from the experts in small, structured workshop sessions.

Knowledge engineering and encoding

The rules and information that form a knowledge-based system must be organised within a computer program. This can be done either by directly programming in a computer language, such as PROLOG, C, PASCAL, etc, or they can be entered using a "shell" program. Shells are programs that organise information and compile it into computer language. By using a shell developers can concentrate attention on the structure of the user's problem, rather than the computing problem, which then becomes secondary. There are over 30 shells currently on the market (Barron, 1989). Most of them vary in their structure, philosophy, output and ease of use. If a shell is to be used to develop an expert system it is essential to recognise this variation and to chose an appropriate shell for the requirements.

The sugar beet herbicide system was developed in KnowledgePro, a shell sold by Knowledge Garden Inc., Nassau, New York. KnowledgePro stores information and rules in natural units called topics. The shell is written in PASCAL and its structure and syntax are very similar to its parent language. It is possible to link separate knowledge-bases and external programs from within KnowledgePro, and this feature provides potential for modular development and expansion of the system.

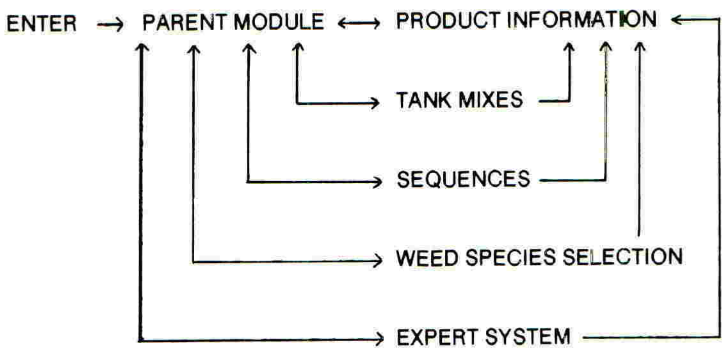
STRUCTURE OF THE SYSTEM

The program was built and runs on a modular basis. The various modules are initially called from the main program, and subsequently call each other as required (Figure 1). The system is entirely menu driven. KnowledgePro provides a hypertext facility separate from menus. Hypertext allows any words or phrases on the screen to be highlighted, and selection of this highlighted text then reveals further screens of information. The advantage of incorporating hypertext into a knowledge-based system is that unfamiliar or technical terms may be entered as hypertext. New users may access this data if necessary, whereas experienced users do not have their screens cluttered up with information they do not need.

Parent module

This is the point of entry into the system. It contains the title screens and help screens. Its main function as parent knowledge-base is to hold and execute the rules for accessing the other knowledge-bases.

Figure 1. The structure of the decision support system for herbicide selection.



Product information module

This module contains label information for all registered sugar beet herbicides. It includes data on susceptible weeds, FEPA regulations, dose rates, sequences, tank mixes and general notes. As recommendations may be made by product name or by active ingredient this module also contains a cross-referencing capability that lists all the active ingredients in currently marketed herbicides. Selection of an item from the active ingredient menu gives a list of products containing that chemical and accesses relevant label information on request. Label information can also be obtained directly from a menu of product names.

Tank mix module

This module provides a list of products which are approved for use mixed together. At present, most recommendations are for two-way tank mixes. The majority of three-way tank mixes include clopyralid, and three-way tank-mixes are recommended if one of the products included contains this chemical. The system initially asks what crop stage is being considered, and then provides a list of all products used at that stage. On selection of a product from this menu, a list of recommended tank-mixes which include the selected item is provided. Label information and the identity of the company recommending each mix is then available from another menu.

Sequence module

This module presents a list of products which may be included in a sequential spray programme following a specified product, based on positive recommendations on product labels. It operates in a similar way to the tank-mix module, the user is first asked the current crop stage, and then at what stage the crop was last treated. The user then specifies the product(s) already applied to the crop and the system lists products which may be included in a sequence with those already applied. Although originally designed to make real-time recommendations, this module can also be used at the beginning of the season to help plan control programmes.

Weed species selection module

This module, based on rules and information from labels and field trials, allows the user to specify the crop stage and to input the weed problem(s) from a list of thirty common species. The system then recommends appropriate herbicides, determined by weed susceptibility. As in the other two modules, label information on the recommended chemicals is immediately available on request.

Expert system module

This module incorporates the decision process of weed control experts, and is more subjective than the weed species selection module. By asking a series of simple questions, the system provides detailed weed control recommendations. The module is written in plain language, with technical terms explained in hypertext, allowing inexperienced users to reach the same decision as recognised specialists.

DISCUSSION

All advisory organisations in the United Kingdom face serious problems in recommending herbicide practices to farmers. In particular, new legal requirements mean that it is now even more important that advice must be correct and consistent. The number of herbicide products, mixes and sequences available to control weeds at various weed and crop growth stages, under a range of environmental conditions, creates a problem of enormous complexity. Economic and environmental forces make it especially important to limit excessive herbicide use. As the difficulty of making recommendations increases, economic pressure is also preventing competent experts can spend giving adequate attention to specific farmers' problems.

This prototype computerised decision support system helps to reduce these problems:

* The recommendations are consistent, since the computer always gives the same advice for a given set of inputs.
* The modular construction allows rules and information to be checked and edited relatively easily to ensure that advice meets legal requirements and label instructions.
* Central updating and distribution of computer disks to regional advisers is a more efficient way of making sure that advisers are always up to date, compared with individuals being left to keep up with the latest situation themselves.
* All the product information is contained within a single system, and can be cross-referenced, allowing advisers rapid access. By contrast, combinations of information scattered in dozens of product manuals, labels, reference books and papers are not readily accessible and cannot be easily sorted to provide only that information appropriate to the immediate problem. The computer is ideal for sifting and processing such large volumes of information.
* Although most of this data is already available to advisers, it is widely dispersed. Thus decisions may be made on the basis of the first information that comes to hand, rather than through a systematic examination of all relevant information.
* The collation of the data into one system makes it easier to compare options, and should allow more rigorous, economically sound recommendations to be made.
* The expert system module allows less experienced users to reach a quality of recommendation similar to that of recognised experts, leaving experienced weed control experts time to concentrate on unusual and changing problems, the more routine work being handled by the computer program. On the other hand, experienced advisers should find the label information and sorting routines particularly useful as memory-joggers.

Knowledge-based systems can also be used in training new "experts". They allow less experienced users to examine the reasoning process of experts, to improve their understanding of how recommendations are made and to learn how to approach different situations.

Some problems have been encountered in building this program. Recommendations for products from different manufacturers are not always consistent, manufacturers do not always supply product information in a standard form, some manufacturers have difficulty supplying any information at all, and there is a lack of agreement about what to do in some less common weed control situations. This emphasises the continuing need to maintain a high level of weed control expertise to provide the human input that will still be essential, despite the increasing use of programs such as this in routine cases.

Additional modules could be added to this herbicide selection program in the future to provide a more complete package of information and advice for sugar beet growers. Potential areas of interest include insecticides, fungicides, fertilisers, machinery selection, budgeting and conservation practices.

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FORECASTING WEED INFESTATIONS - THE DESIRABLE AND THE POSSIBLE

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Abstract

Current research into weed forecasts has emphasised forecasts over the short term. They attempt to predict crop yield losses by using some measure of weed density or biomass, and use population models to forecast likely levels of the weed infestation into the future. In order to be of practical use under changing conditions, such models need to be accurate, yet the degree of variation - between years, between fields, between parts of the same field - makes such accuracy difficult to achieve (except possibly for forecasts about yield losses in the current season only). Simulation analysis suggests that weed populations are unpredictable and can easily generate misleading data.

It may prove more useful to produce general yet robust long term forecasts than to use population models which claim spurious accuracy. One initial approach might be simply to identify those weeds which would increase under a given set of conditions - questions of the detailed numbers involved would not arise.

INTRODUCTION

Farmers will be subjected to many changes in the near future - changes of management and inputs, changes of agricultural policy, even changes of climate - and accurate forecasts of pest, disease and weed infestations will prove highly desirable, both in economic and environmental terms. Whereas substantial progress has been made in forecasting some insect pests and some diseases, weed forecasting in practice has progressed little beyond simple rule-of-thumb thresholds. Some of the reasons are clear; for example, weed infestations are highly localised, so there is no value in the generalised predictions which work well for larger scale aphid and disease outbreaks. Yet, given the amount of work that has been done on weed - crop systems, the lack of practical progress may appear disappointing. It is the aim of this paper to explore why this is the case, and to suggest approaches which may prove to be more fruitful.

CURRENT APPROACHES

Current research into weed forecasts has emphasised forecasts over the short term. They attempt to model crop yield losses by using some measure of weed density (e.g. Cousens 1985) or biomass (e.g. Kropff 1988), and use population models to forecast likely levels of the weed infestation into the future (e.g. Firbank *et al.* 1985). Not unreasonably, the models emphasise mean responses, yet in practice the degree of expected variation is most important. There are several levels of variation which become subsumed within such approaches;

1) Variation within fields

This is present even within carefully conducted field trials, and can be due to changing microclimate, soil properties, and levels of herbivores and diseases. The resulting patchy growth of the weeds presumably becomes reflected in the seed bank, and the resulting variation may be increased further by patchy herbicide performance and application. Field trials on small plots suggest that typical deviations are around 20 % of the mean crop yield. These may average out in larger, field scale, experiments, but even so experience elsewhere in ecology suggests that local spatial variation can significantly affect the abundances of species through time.

2) Variation between sites
Soil type and weather differences between sites can have a marked effect on the mean response of crop yield to weed density (Cousens *et al.* 1988).

3) Variation between years
Differences in weather conditions can also affect crop yield - weed density relationships. Emphasis has been placed on the importance of conditions at the start of the growing season (e.g. Firbank *et al.* 1985, Spitters & Aerts 1984), but extremes of waterlogging, drought, cold or lack of frost can all influence the growth of weeds during the season. Models of global warming suggest that such extremes of weather may become more common in the future.

4) Variation in management
The choice of management clearly affects the dynamics of weeds, and also the effectiveness of a chosen management strategy may be very variable, especially the effectiveness of herbicide application.

The results of any forecasting programme are very suspect unless these sources of variation are either very small (as, for instance, Gill, Poole & Holmes (1987) have claimed for *Bromus diandrus* infestations in Australia) or can be easily accounted for. Kropff (1988) suggests that much of the variation manifests itself as differences in relative emergence and growth of the weeds and crops (but see Firbank *et al.* in press). If this is so, then by looking at weed growth early in the season, it should be possible to predict likely crop yields and weed biomass at the end of the season (Kropff 1988). The spatial scale at which such a system could be expected to work is unknown, as is the sensitivity of the model to extremes of weather. Nevertheless, such a forecasting system does show promise and would be useful for decision making about post-emergence control.

The situation becomes much less tractable if the forecast is extended to future seasons. Here, the seed return expected from the weeds is used to predict the number of weeds present in future years, and the relationships between crop yield and weed density are used to forecast likely yield losses into the future. For such forecasts to work, the efficiency of control practices must be predictable, as must the competitive relationships between weeds and crops. Even then, the forecast would not be expected to be accurate more than two or three years ahead. In addition, it becomes desirable to look at potential problem weeds as well as the species of current concern, since management which controls some weeds may promote others.

A SIMULATION ANALYSIS OF WEED POPULATIONS

It would take many years to evaluate experimentally how feasible it really is to predict crop yields and weed densities several years into the future. However, useful work can be done by constructing simulation models. Some results of such an analysis of the behaviour of three weed species are presented in this section.
The number of seedlings of each weed species in each year depends upon the amount of competition from the crop and from the weed community during the previous season and upon the level of control;

$$N_{t+1,i} = p_i \cdot N_{t,i} \cdot h_i \,/\, (1 + a_i(c_i + \sum_j (B_{ij} N_j)))$$

where $N_{t,i}$ is the density of seedlings of species **i** at time **t**, p_i is the proportion of seeds produced which survive between seasons according to the effectiveness of control, h_i is the number of seeds produced by isolated plants of species **i**, a_i is a scaling constant, c_i represents competition from the crop and B_{ij} represents the competitive effect per plant of species **j** on species **i**. The term $B_{ii} N_i$ in the summation is included to describe the effects of intraspecific competition. Thus increasing the density of any weed species present results in a reduction in the seed return of all of them, as long as the competitive effect terms are greater than zero. Variation can be built in to the values of p to simulate changes in the effectiveness of control and h to simulate year to year variations in weed fecundity. Also a simple seed bank algorithm is built into the model where a fixed proportion of seeds produced enter the seed bank and a fixed proportion of those already present germinate each year. This model, a multispecies modification of that used by Firbank *et al.* (1985) is simple, especially as spatial variation is not addressed, but hopefully is not unrealistic. In these runs, the three species have identical parameters except where stated.

Simulation results

Rather than deal with all outcomes of the model, I will focus on several simulation runs with different implications for forecasting efforts.

1. Non-linear behaviour

If there is no element of random variation, and there are no seed banks, in many cases the weed populations approach an equilibrium monotonically from their starting densities. If the parameters of all weeds are the same, then of course these equilibrium densities are the same for all species. However, it is quite easy to generate fluctuations and even cycles of weed abundance by altering the starting densities, fecundities and competitive relationships between the weeds while still having no random fluctuation (e.g. Fig. 1, where starting densities and competition terms differ between species). These fluctuations and cycles may have such long wavelengths that they would probably not be detected - indeed studies of the typical three year time span would generate very different results depending when they happen to fall within the cycles. People interpreting these results would also tend to underestimate the importance of those species which are currently rare.

2. The butterfly effect

It is common in non-linear systems that slight differences in starting conditions can become magnified into much larger differences - the so-called butterfly effect. The capacity to produce worthwhile predictions therefore depends upon the ability to measure the starting conditions with sufficient accuracy. For example, in the model, when all parameters are constant and equal for all species they quickly approach the same equilibrium densities. However, if the scaling parameters a are altered slightly to 0.19, 0.2 and 0.21 - differences too small to be detectable by most experiments - marked divergence of the weed densities results (Fig. 2). Slight inaccuracies of parameter estimation can cause substantial errors in predicted weed levels.

3. Variation in the control efficiency

The model suggests that both variation in weed fecundity and variation in the efficiency of control from year to year can cause large fluctuations in weed density, making the system very difficult to understand, never mind predict. Even when the species are identical in all parameters, and are subject to an equal degree of random variation in control, one species may dominate for many years and then it may be replaced by another one (Fig. 3A). Not surprisingly, species without seed banks can be easily eliminated by the occasional year of very effective control. The presence of seed banks appears to buffer the populations so that less extreme fluctuations are seen (Fig. 3B). Again, because the changes can take many years, short term experiments would give a misleading impression of the overall system. The farmer's own experiences may also be disconcerting, in that a weed which appears to have been under control for many years can suddenly become a major problem, with no changes in management and no apparent cause.

FIG. 1 SIMULATED WEED CYCLES

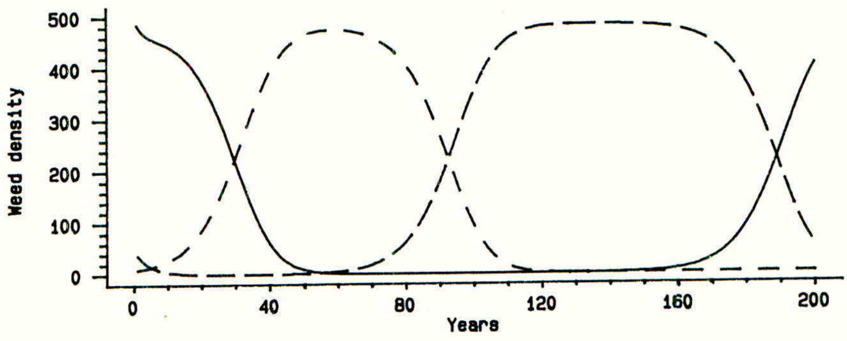


FIG. 2 VARIATION IN INITIAL CONDITIONS

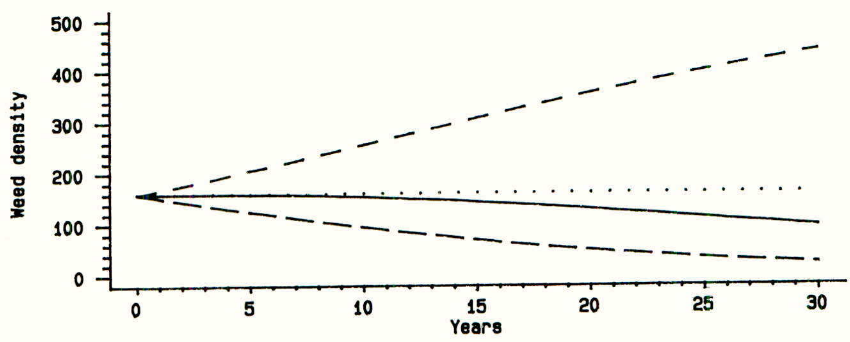
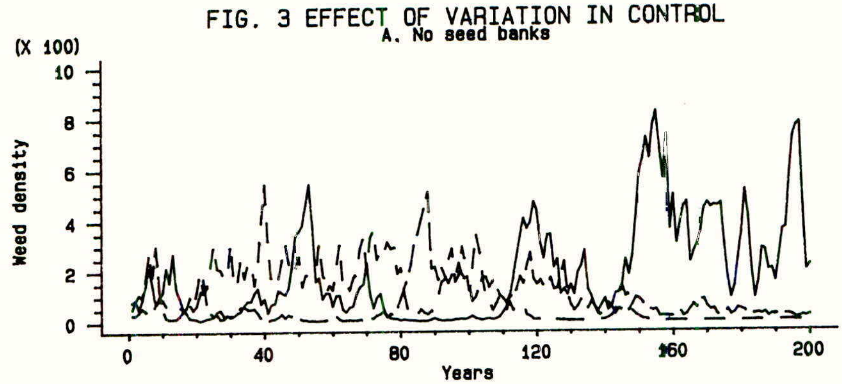


FIG. 3 EFFECT OF VARIATION IN CONTROL



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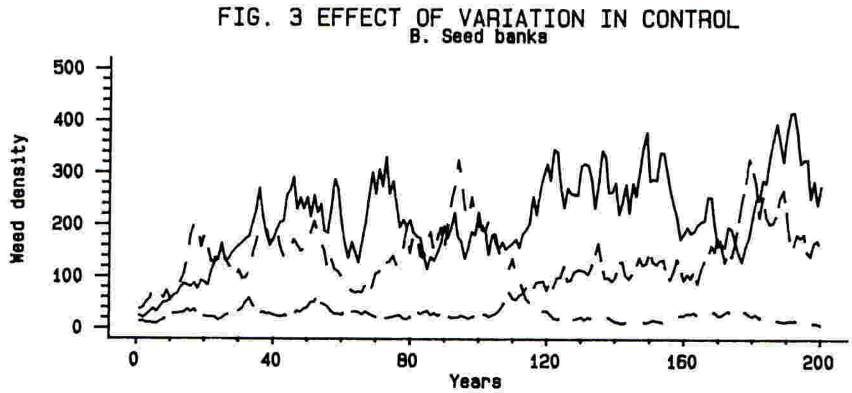

FIGURES 1 - 3: Simulations of the changing densities of three weed population growing in a continuous crop. Model runs are as described in the text. Parameters are hypothetical and so weed density scale is arbitrary. Mean control level ***p*** *is 70 % per year;* ***h*** *= 400;* ***a*** *= 0.2,* ***c*** *= 450,* ***B*** *= 1 except for* ***Fig. 1*** *where* $B_{1,2}$, $B_{2,3}$ *and* $B_{3,1} = 2$; $B_{1,3}$, $B_{2,1}$, *and* $B_{3,2} = 0.5$, *and for* ***Fig. 2*** *where* ***a*** *= 2, 1.9 and 2.1. The dotted line in Fig. 2 is the trajectory of the three weeds when all values of* ***a*** *are 2. Note that Figs 1 & 2 show deterministic models, but* ***Fig. 3*** *model includes random variation in control level, and shows example runs (A) without and (B) with a persistent seed bank for all species.*

OTHER POSSIBLE APPROACHES

There is much work to be done before the simulations can be shown to be reflect the field situation: the model may be inherently inaccurate or the combinations of parameters used here may not be typical. If these results are realistic, however, they suggest that the levels of variation which may reasonably be expected are too great to allow accurate predictions from deterministic population models. There are, however, other approaches which may be more robust.

One alternative would be to use stochastic population models. Data from the field would be input into a simulation model which includes a realistic level of variation. The model would then be run a large number of times to establish the probability of weed extinction or outbreak.

Another alternative is to use a less mathematical approach. For example, a simple mental model suggests that those weed species without persistent seed banks which require light for germination can be controlled by ploughing. This recognises the farmer's ability to manage the habitat to make it less suitable for species with particular ecological characteristics. It should prove possible to establish expert systems models which incorporate such principles; they would use general rules to relate the ecological consequences of each management option to each weed species in turn. Such models would not offer the spurious accuracy of the more 'traditional' population models, and might often be inaccurate in the short term, but could nevertherless give reasonably cheap yet reliable indications of which species might be promoted, and which controlled, over a period of years by a particular management system.

CONCLUSION

The main thrust of research into weed forecasts has resulted from attempts to understand the principles of weed-crop competition and weed population dynamics. However, the practice of weed control requires a much greater awareness of the variability around the average expected behaviour, so that risks can be safely assessed. It may well be possible to use determinisitc population models only in certain circumstances. If so, then other, less ambitious approaches may be of more practical benefit by offering general advice about how to manage the weed community in the long term rather than by offering spurious, unobtainable accuracy in the medium term. Such general forecasts would still be highly desirable; after all, if farmers are to meet the changes ahead with success, they will need all the help they can get.

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CROP COMPETITIVENESS AS AN AID TO WEED CONTROL

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ABSTRACT

Growth habit and earliness of ground cover varies between crops and between cultivars of each crop. Trials on winter wheat and spring barley have shown that higher crop ground cover results in lower ground cover of weeds. The results are variable and more work is required to define the factors that affect crop competitiveness. More competitive crops have potential for the organic grower in order to supress weeds, and for the conventional grower to achieve reduction in herbicide input.

INTRODUCTION

The current desire, for environmental and economic reasons, to reduce the quantity of herbicide applied to crops has led to refinements in the way herbicides are used. One approach is to use weed thresholds to define the point at which a herbicide application is required depending on weed numbers and species present (Wilson, 1986). Another approach is to use carefully-timed applications of reduced rates of herbicides to control weeds when they are small (Davies, 1987).

An area that has received less attention is that of optimising crop competitiveness with weeds to give less reliance on control by herbicides. It is a difficult area because crop competitiveness depends on a number of factors: timing of crop emergence in relation to weeds, availability of moisture and nutrients, crop vigour and health, spatial pattern of crop and weeds, crop physiological factors, crop morphology in relation to weeds, soil structure, allelopathic effects (Cousens, 1985; Fisher & Miles, 1973; Wilson, 1986, Vaughan & Ord, 1989).

Some of these factors can be exploited to improve the competitive ability of crops, for instance timing the sowing of wheat to avoid an autumn weed flush, using close row spacing or cross drilling to improve the smothering effect of the crop on weeds. Differences in crop morphology could be exploited to improve crop competitiveness with weeds.

A number of morphological characters, for instance tallness and leafiness (Donald, 1981), root growth habit (Hurd, 1968), crop ground cover and growth habit (Amos, 1988) have been shown to affect the way a crop competes. The effect of some of these characters have been investigated at Edinburgh over the last three years; data have been gleaned from three current trial series: cereal variety trials, untreated strips in cereal variety herbicide screens, and untreated plots in cereal herbicide trials.

MATERIALS AND METHODS

Cereal variety trials were undertaken as part of the UK National List testing system and the Scottish Recommended List system. Plots, 2m x 20m were drilled by an Oyjord drill and replicated twice with and without a fungicide program. Herbicides were routinely applied to control weeds. Visual assessments were made of crop ground cover of each of the cultivars in winter wheat and spring barley trials, but data presented here are limited to eight of the cultivars. Where a cultivar was not in every trial an adjustment was made using the Fitcon technique to make allowances for the effects of differences between trials (Patterson & Silvey, 1980).

Cereal variety herbicide screens were sown with cultivars drilled by Oyjord drill in single 2m strips, herbicide treatments were applied at right angles across cultivars. At intervals there were unsprayed strips and these were used to record crop ground cover and weed growth by visual assessment.

Untreated plots in eight winter wheat weed control trials in 1989 were used to demonstrate the effect of crop ground cover on weed growth. Weed density was assessed in 15 x 0.1 m^2 quadrats per plot; ground cover of crop and chickweed (Stellaria media) was assessed in 10 x 10 point quadrats per plot. Cultivar and sowing date differed between sites, they were as follows: Fortress (F1) sown mid-Oct.; Fortress (F2), sown mid-Oct; Fortress (F3), sown mid-Oct; Riband (R1), sown late Sept; Riband (R2), sown mid-Oct; Apollo (A), sown early Nov; Slejpner (S1), sown late Sept; Slejpner (S2), sown early Nov.

RESULTS

In each cereal variety trial differences between cultivars were obvious, the best cultivar having significantly higher ground cover than the worst. However, the ranking varied between trials. Crop growth stage at the time of assessment had an effect on this, the ranking of cultivars being different depending on the the growth stage at which they were recorded (tables 1 & 2).

TABLE 1. Mean ground cover % and straw length of winter wheat in trials 1987-1989. Assessments at Zadoks growth stages (GS) 14-24 and 30-32.

Year	1987-1989		1987	1988	1989	Mean straw length cm
Growth stage	GS.14-24	GS.30-32		GS.30-32		
Number of trials	4	6	3	4	2	
Apollo	36	65	64	76	54	92
Fortress	48	69	75	78	56	89
Galahad	42	72	79	77	59	86
Mercia	35	72	80	75	62	90
Parade	21	43	51	-	-	79
Rendezvous	49	65	78	63	-	90
Riband	41	69	76	72	59	88
Slejpner	36	58	68	59	48	83
Mean	44	64	71	71	56	87

TABLE 2. Mean ground cover (%) and mean straw length of spring barley in trials 1987-1989. Assessments at Zadoks growth stages (GS) 23-24 and 30-32.

Year	1987-1989		1987	1988	Mean straw
Growth stage	GS.23-24	GS.30-32	GS.30-32		length cm
Number of trials	2	4	4	2	
Blenheim	38	67	57	78	74
Camargue	53	66	56	76	72
Golden Promise	57	61	53	69	73
Hart	-	74	-	84	84
Prisma	46	70	56	84	77
Sherpa	59	64	53	74	75
Triumph	69	75	69	81	76
Tyne	54	60	49	72	73
Mean	54	68	56	78	76

There were some cultivars, however, that either had consistently high or consistently low ground cover; for example Parade and Slejpner winter wheats had consistently low ground cover (table 1), Triumph spring barley with a prostrate growth habit had consistently high ground cover (table 2). In the 1988 cereal variety herbicide screens those cultivars that had high ground cover had low weed ground cover (figures 1 & 2). In the winter cereal screen Riband and Parade had lowest crop ground cover and highest weed ground cover. In the spring cereal screen, spring wheat cultivars had lowest crop ground cover and highest weed ground cover, spring oat cvs. Adamo and Keeper had highest crop ground cover and lowest weed ground cover. Of the spring barleys Hart and Tyne had highest ground cover with lowest weed ground cover (figure 2).

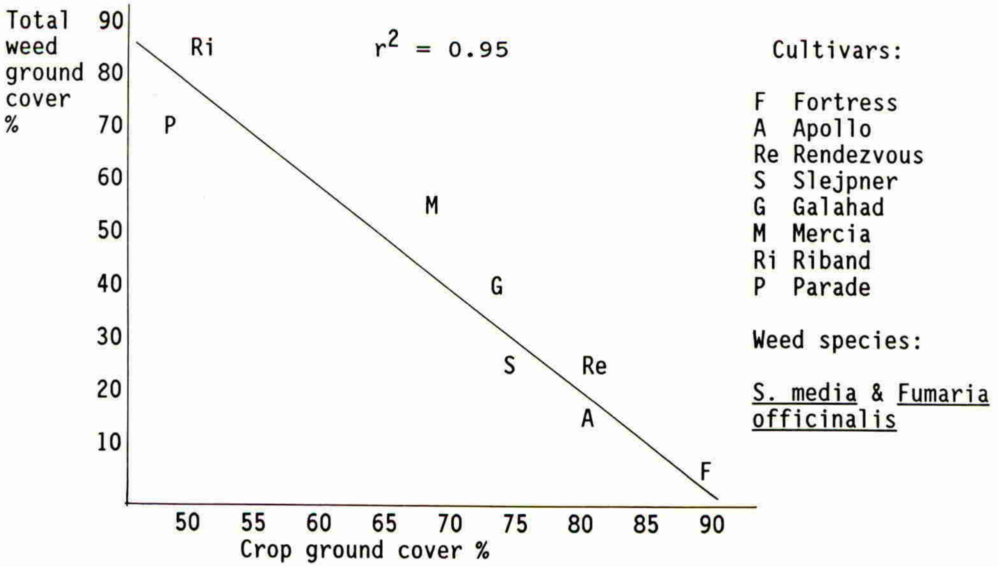

FIGURE 1. Mean total weed ground cover compared with crop ground cover for eight winter wheat cultivars 1988, assessed at Zadoks GS.69.

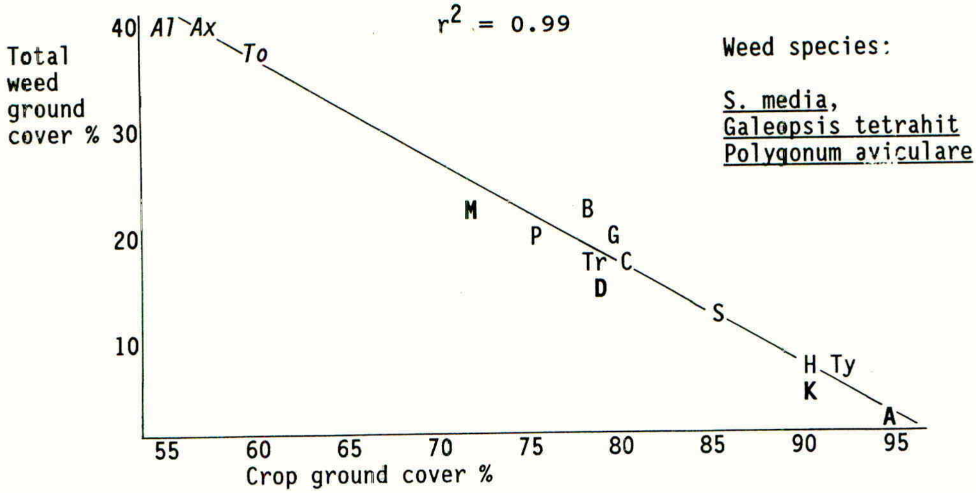

FIGURE 2. Mean total weed ground cover compared with crop ground cover for spring cereal cultivars 1989, recorded at Zadoks GS.65. (Cvs. Barley: Tr Triumph, G Golden Promise, Ty Tyne, B Blenheim, S Sherpa, H Hart, P Prisma, C Camargue; Wheat: *Ax* Axona, *Al* Alexandria, *To* Tonic; Oats: **D** Dula, **M** Matra, **K** Keeper, **A** Adamo).

In untreated plots in eight herbicide trials the beneficial effect of high crop ground cover can be seen in the reduced ground cover achieved by individual overwintered S. media when recorded in the spring (figure 3).

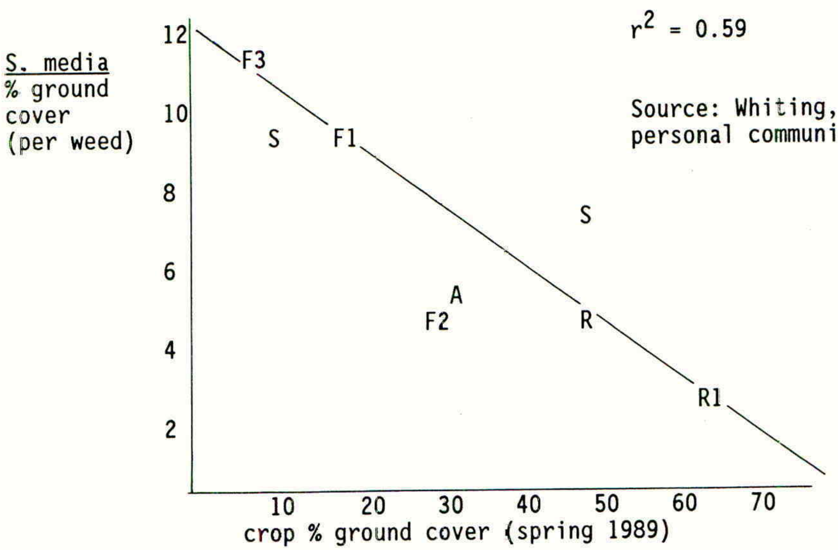

FIGURE 3. Effect of winter wheat ground cover, recorded in the spring, on ground cover of overwintered S. media plants 1989.

DISCUSSION

This data demonstrates that differences exist between cereal crops and cultivars in their competitive abilities with weeds. Ground cover scores from cereal variety trials identified cultivars such as Parade and Slejpner that were slow to achieve ground cover. There was some consistency between the trial series, eg. Parade had low ground cover in the variety trials and also competed poorly with weeds in the herbicide screen, but there were large variations in the ranking of most cultivars. This may be because the herbicide screens were recorded at a later growth stage than the variety trials by which time crop height was having an effect, and because cvs. were growing in the presence of weeds. More data from a larger number of trials is needed to get a clearer understanding of the relative competitiveness of crops and cultivars in different conditions and in the presence of different weed species. There are a number of potential uses for such data.

Recommendations for herbicides tend to be kept as simple as possible, to make them easy to use and to reduce opportunities for error. For example metsulfuron methyl, sold as 'Ally', is applied at 30 g/ha in wheat, barley, oats, triticale and rye at a wide range of growth stages. Weeds are controlled up to 20 cm across across or high (Du Pont 1989). The same dose rate is used in very dense or very thin crops. There could be potential for reducing herbicide rates in more competitive crops and cultivars.

In organic cereal systems weeds are controlled by cultivation and rotation. Timing of operations is critical but good results are possible (Wookey, 1985). Tall crops were traditionally used to smother weeds (Moore, 1943). Work in Germany on winter wheat has shown that tall cultivars tend to yield better than shorter ones in organic systems (Stoeppler, 1987 personal communication) but it is not clear whether this is because of more effective weed supression or because tall cultivars take up more nutrients from the soil. In organic spring oat trials at Edinburgh the cv. Matra, which is shorter strawed and has been slower than average to achieve ground cover, has been lower yielding than taller cultivars that have given comparable yields to Matra in conventional trials (Richards, 1988).

The only parameter currently recorded in the UK variety testing system that gives some indication of the competitiveness is straw length. In some countries other characters are recorded. For instance; the Rassenlijst of the Netherlands provides information for winter wheat on: earliness of covering the soil, leafiness and length of straw (Commissie voor de Samenstelling van de Rassenlijst, 1989). Recording of these characters in the UK would provide information on likely competitiveness with weeds. This could be used by advisers for herbicide recommendations, for instance by avoiding very low rates where least competitive cultivars are being grown. In the longer term it might provide information on environmental factors that influence varietal competitiveness. In addition to this, much improved information could be obtained from properly designed trials with cultivars of varying competitiveness and from herbicide applied at reduced rates.

ACKNOWLEDGEMENT

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THE MANAGEMENT OF SET-ASIDE AND ITS IMPLICATIONS ON WEEDS.

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ABSTRACT

A series of trials was commenced in autumn 1987 to examine the effect of a one year rotational fallow on subsequent arable cropping. A further 5 sites were established in autumn 1988 after small changes to the treatments had been made following the announcement of the UK set-aside scheme. Lowest weed numbers were found on chemical and bare cultivated fallow treatments. Where there was green cover, frequent cutting was required to prevent seeding of annual grasses. Cutting frequency varied between sites and was highest on heavy land. The weed species encountered reflected the cropping history and soil type of the sites. Despite some fairly high levels of weed these have not so far been a significant problem in subsequent cereal crops. Some rare plants have been found.

INTRODUCTION

The EC set-aside scheme came into operation in the UK in July 1988. The 5 year scheme is voluntary and designed to reduce surpluses of arable crops (Anon 1988). In return for taking at least 20% of eligible arable land out of production on a holding, annual compensation payments of up to £200/ha are available. The majority of land set aside was expected to be "fallowed" either on an annual rotation (rotational) or permanently for 5 years (permanent). "Fallowed" land has to be managed within defined conditions which include a requirement to establish or allow natural regeneration of green plant cover. This plant cover must be maintained without the use of fertilisers or pesticides, although under certain conditions some herbicides can be used. Cultivations are allowed to control weeds (provided a plant cover is re-established) or to establish a plant cover and the land set aside must be cut at least once during the set aside year. Land set aside may be planted with trees or used for permitted non-agricultural purposes.

In the first year of the scheme, around 1750 farms have taken about 55,000 ha of land out of production. Of this, some 90% was for the "fallow" option (43,600 ha in permanent and 6,000 ha in rotational). Similar areas have been entered in 1989. The scheme is open for further applications annually for the foreseeable future.

With the prospect of a set-aside scheme being introduced ADAS started a rotational set-aside trial at 5 sites in autumn 1987. Once the scheme was announced some of the initial treatments were changed for autumn 1988 to fulfil the requirements laid down for the management of fallow land.

METHOD

In autumn 1987 and 1988 the experiment was established at 5 sites on a range of soil types (Table 1). Plot size was about 24 m x 24 m. A range of treatments, replicated 4 times, were laid down each treatment year (Table 2). Each treatment year was followed by 2 test years of winter wheat in the first of which 7 different nitrogen rates (0-280 kg/ha) were applied as sub plots. The plots were managed as appropriate with regard to fungicides, growth regulators, insecticides and herbicides during the test year.

TABLE 1. Sites and soil types (both years).

Site	Soil Type	Textural Classification
1. Boxworth, Cambs	Silty clay	Heavy
2. Bridgets, Hants	Silty clay loam	Medium (calcareous)
3. Drayton, Warwicks	Clay	Heavy
4. Gleadthorpe, Notts	Sandy loam/loamy sand	Light
5. High Mowthorpe, Yorks	Silty clay loam	Medium

TABLE 2. Treatments during set-aside treatment year.

Established Autumn 1987

1. Chemical fallow with no cultivation. Weed growth controlled by repeat low doses of paraquat or glyphosate. Aim to prevent weeds seeding.
2. Bare fallow established by autumn ploughing and maintained by mechanical cultivation if possible. Herbicides used if necessary to prevent weeds seeding.
3. Italian rye-grass (*Lolium perenne* ssp *multiflorum*) "green cover". Established as soon as possible after harvest, topped during the growing season to prevent seeding.
4. Continuous cereal, normally winter wheat.
5. Natural regeneration of stubble, no cultivation or spraying. Plant growth controlled by repeated mowing to prevent seeding (not at all sites).
6. Forage rape sown in stubble. Destroyed and buried in spring. Fallow subsequently maintained by cultivation. Herbicides used if necessary (not at all sites).

Established Autumn 1988

1. Bare fallow established as soon as possible after harvest by cultivation or glyphosate. Ploughed at least once.
2. Italian rye-grass established as soon as possible after harvest, topped during the growing season. Broken up after 1 August.
3. Continuous cereal, normally winter wheat.
4. Natural regeneration of stubble, no cultivation or spraying. Plant growth controlled by repeated mowing to prevent seeding.
5. Autumn fallow, spring legume established using a minimum of cultivation (not at all sites).

During the treatment year plots were monitored for weed germination in the autumn, summer and spring by counting species in random quadrats. In the subsequent test year those plots established in autumn 1987 were sprayed with post-emergence herbicides after early weed establishment had been monitored. There were also small unsprayed strips. Additionally nitrogen, disease and pest monitoring was undertaken.

RESULTS

1987/8 Treatment Year

At each site the number of cultivations and frequency of mowing to prevent weeds seeding varied (Table 3). More operations were required on the heavy land sites than the medium or light sites.

TABLE 3. Frequency of cultivation/mowing 1987/8.

Site	Italian rye-grass		Natural regeneration		Bare fallow
	Date of 1st cut	Number of cuts	Date of 1st cut	Number of cuts	Number of cultivations
Boxworth	1 June	3	23 May	4	6
Bridgets	26 May	2	n.a.	n.a.	3
Drayton	13 May	5	n.a.	n.a.	5
Gleadthorpe	14 June	2	14 June	2	3 + 2 glyphosate
High Mowthorpe	1 July	2	n.a.	n.a.	2

The most common weeds were grasses and of these volunteer cereals were present at all sites (Table 4). They were generally greatest on the natural regeneration and Italian rye-grass treatments. Numbers were also high on some of the chemical fallow treatments but this reflects the time of assessment relative to spraying. The weed present in highest numbers was *Poa* spp especially on the lighter sites of Gleadthorpe and High Mowthorpe. Again chemical fallow and natural regeneration treatments resulted in the greatest numbers. Black-grass and wild-oats were found only on one site each at moderately low numbers. Highest numbers of wild-oats were found in the continuous cereals.

A range of broad-leaved weed species were encountered at the different sites. Highest numbers were often found in the Italian rye-grass treatment. At 2 sites (Boxworth and High Mowthorpe) this treatment did not establish satisfactorily in the autumn and was redrilled in the spring.

1988/9 1st Test Year

The plots which were fallowed in 1987/8 were sown to winter wheat in autumn 1988. These plots will be harvested. Initial indications on weed problems show that at no site has a carryover of weeds led to any significant problem.

TABLE 4. Density (/m^2) of various weed species in treatments at 5 sites (1987/88).

Site (date recorded) Boxworth (19 May)	VC	BB	Sp	OSR
1. Chemical fallow	13.0	11.2	0.4	0.0
2. Bare fallow	0.5	0.6	3.4	3.2
3. Italian ryegrass	8.9	1.3	0.3	0.0
4. Continuous cereal (20 April)	n.a.	0.0	1.6	0.3
5. Natural regeneration	8.7	7.6	0.1	0.0

Bridgets (5 May)	VC	BB	B-G	Sp	Chi	F.Pan	Pop
1. Chemical fallow	3	16	1	0	0	1	0
2. Bare fallow	7	3	4	2	0	202	41
3. Italian ryegrass	86	4	2	4	0	23	19
6. Forage rape	95	23	1	9	2	44	26

Drayton (5 April)	VC	Poa	W-O	Sp
1. Chemical fallow	31.7	72.9	0.0	0.0
2. Bare fallow	3.0	2.2	4.4	0.3
4. Continuous cereal	n.a.	15.9	11.3	0.0

Gleadthorpe (14 April-9 May)	VC	Poa	May	Chi	F.Pan
1. Chemical fallow	29.0	478.2	9.5	4.9	0.0
2. Bare fallow	16.7	44.2	22.1	22.4	0.3
3. Italian ryegrass	2.1	35.3	24.1	30.8	0.1
4. Continuous cereal	1.2	24.6	5.1	4.3	0.4
5. Natural regeneration	28.1	483.8	4.0	3.3	0.0
6. Forage rape	8.5	66.9	70.1	30.6	0.1

High Mowthorpe	VC	Poa	Sp	Chi	Cle	Pop
1. Chemical fallow (20 April)	156.5	13.2%*	1.6	0.0	14.9	0.0
2. Bare fallow (20 April)	23.0	0.0	0.9	0.0	0.9	0.0
3. Italian ryegrass (1 July)	57.4	1.0+	0.0	0.5	31.0	3.5
4. Continuous cereal(20 April)	n.a.	0.0	0.0	0.0	0.0	0.0

Key: BB = barren brome (*Bromus sterilis*); B-G = black-grass (*Alopecurus myosuroides*); VC = volunteer cereals; *Poa* = *Poa* spp; W-O = wild-oats (*Avena fatua*); Chi = chickweed (*Stellaria media*); Sp = speedwells (*Veronica* spp); May = mayweeds, (mainly *Matricaria matricarioides*); OSR = volunteer oilseed rape (*Brassica napus*); F.Pan = field pansy (*Viola arvensis*); Cle = cleavers (*Galium aparine*); Pop = poppy (*Papaver rhoeas*).

* assessed as % ground cover

\+ rough stalked meadow grass (*Poa trivialis*)

n.a. not applicable

1988/9 Treatment Year

New sites established on the same farms are showing similar trends. The results are shown in Table 5. 1988/9 differed from the previous season by the earliness of heading and therefore the date of the first cut. Later, the season was very dry and, on the lighter sites in particular, growth had stopped by early July. Despite this the number of cuts was substantially unchanged from the previous season.

TABLE 5. Frequency of cultivation/mowing 1988/9.

Site	Italian rye-grass		Natural regeneration		Bare fallow
	Date of 1st cut	Number of cuts	Date of 1st cut	Number of cuts	Number of cultivations
Boxworth	31 March	4	19 April	4	1
Bridgets	25 April	3	25 April	3	4
Drayton	1 April	4	14 April	5	1
Gleadthorpe	11 May	3	11 May	3	1 + 2 glyphosate
High Mowthorpe	7 June	3	7 June	2	3

At 2 sites (Boxworth and Drayton), repeated mowing changed the habit of black-grass, brome spp and volunteer cereals so that seed heads were progressively lower after each cut. Another observation was that where the mower was mounted behind the tractor the rolling effect of the tractor wheels could allow strips to remain uncut and therefore seed early.

Some weeds not normally found have appeared this season, especially in the natural regeneration plots. These include round-leaved fluellen (Kickxia spuria) at Boxworth and Drayton. At Bridgets red bartsia (Odontites verna) and wild mignonette (Reseda lutea), which are rarely seen on the farm, and Venus's looking glass (Legousia hybrida), were found. Both Venus's looking glass and Kickxia spp are listed by the Botanical Society of the British Isles as rare arable weeds.

DISCUSSION

Annual grass weeds present a major threat to cereal production because of their competitiveness. Although seeds are characteristically of short lived dormancy they may display considerable persistence. For example seeds of wild-oats (Avena fatua) may survive 3-4 years (Wilson, 1981) and black-grass greater than 4 years (Moss, 1985). Seeds of Italian rye-grass may persist in the soil for up to seven years (Rampton and Ching, 1970). Seed output varies considerably between species with wild-oats producing on average 200 seeds/plant, barren brome 400 seeds/plant and black-grass as many as 800 seeds/plant in the presence of a crop. This reproductive capacity may be greatly exceeded in the absence of crop competition. Many growers hope to use set-aside to restrict weed problems and to reduce herbicide inputs on the farm. These trials show that cutting early and frequently is necessary to prevent seed return. After the mild winter of 1988/9, cutting in April was required to achieve this although in the previous season waiting until the normal time, middle/end May was possible. More frequent cutting was needed on the heavy soils (4 or 5 cuts) than on the less moisture retentive soils (where up to 3 cuts sufficed). Annual meadow-grass is often the dominant species of arable seed banks (Roberts and Chancellor, 1986). Its low stature is likely to preclude mowing as a means of reducing seed return. In addition this species is favoured by minimal cultivations and thrives in the absence of crop competition. This is shown by its abundance on the chemical fallow and natural regeneration plots where there was no soil disturbance or crop competition. It was hoped that a competitive sward of Italian rye-grass would smother weeds (Wilson, 1988). In practice establishment was patchy and as a result insufficient weed suppression resulted.

The weed flora encountered was largely a reflection of the soil type and not the treatment. For instance field pansy and poppy, which are typical of light calcareous soils, were found in largest numbers at Bridgets whereas mayweeds, which are prevalent on light sandy soils, occurred at Gleadthorpe (Froud-Williams and Chancellor, 1987). Venus's looking glass and wild mignonette are also typical of chalky soils (Salisbury, 1961) although the re-appearance of these species may reflect the absence of herbicides to which they are particularly sensitive and they may be encouraged by the lack of applied nitrogen. Kickxia spp are typically associated with the heavier soils, especially clay (Froud-Williams, 1982). Generally, all the major weeds encountered reflect the previous autumn sown cereal rotations in that they are mainly autumn germinators. Volunteer cereals were the only weed common to all sites.

In rotational set-aside there is little chance for perennial weeds to establish. This will be studied in the permanent fallow series starting this year. Despite suggestions to the contrary one year rotational fallow has allowed rare species of weed to re-appear.

On the limited evidence of the first years under rotational fallow the control of weeds may require intensive mowing to prevent a return of annual grass seeds. The lowest levels of weeds were recorded on the bare fallow and chemical fallow treatments but neither of these options are available to participants in the set-aside scheme. However despite relatively high weed counts in the fallow year frequent mowing to prevent seeding of Italian rye-grass and natural regeneration appears to have been sufficient to prevent problems in the subsequent wheat crop.

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DESIGNING INTEGRATED LOW-INPUT FARMING SYSTEMS TO ACHIEVE EFFECTIVE WEED CONTROL

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ABSTRACT

The most difficult problem in designing low-input farming systems is control of weeds, and herbicides account currently for 85% of total U.S. pesticide use. There is a need for integration of inputs to farming systems since they all influence weed control. Complete control of all weeds may not be necessary since some ground cover not only decreases pest and disease problems but also minimizes soil erosion by wind and water. If use of herbicides for weed control is decreased, ancillary techniques are needed. These include: (i) Mechanical cultivations such as primary, secondary, post-planting and fallow tillage (ii) Cultural techniques including: rotations, use of competitive or allelopathic crops, allelopathic crop residues, intercropping, relay intercropping, and living and dead mulches (iii) Biological weed control involving: use of natural enemies, mycoherbicides, genetic engineering, and herbicides derived from natural compounds. These techniques must be combined into integrated farming systems involving integrated weed management, use of weed thresholds and modelling.

INTRODUCTION

Before the use of chemical herbicides after the Second World War competition from weeds was an important factor in yield loss and weeds were controlled through crop rotations and mechanical cultivations. Chemical weed control has been extremely successful and has expanded rapidly so that, in the U.S.A., herbicides accounted for 85% of total pesticides use in 1988, with 226, 112 and 37 million pounds used on corn, soybeans and cotton respectively (Regnier and Janke, 1989). In the U.K. in 1987, the costs of herbicides used on winter cereals were more than 20% of the total variable costs in production of the crop (Sim, 1987). The usage of herbicides has increased with the rapid development of no-tillage and conservation tillage techniques since the 1960's, because these tend to increase herbicide use. However, in the 1980's there has been overproduction of some crops in the U.S. and Europe and an increasing awareness of the adverse effects of pesticides, including herbicides, on ground-water pollution, soil erosion and food contamination (Edwards et al. 1989). This has led to schemes for leaving land uncropped in both the U.S. and U.K. (Dodgson, 1988) and considerable pressure to adopt lower input/more sustainable agricultural practices and farming systems (Edwards, 1987). In the U.S.A., many farmers have begun to lower chemical inputs, due to their increasing costs and lower returns for crops. This has resulted in the U.S. Department of Agriculture providing funding in 1988 and 1989 for a Lower Input/Sustainable Agriculture Program (L.I.S.A.) which has catalysed a considerable increase in research into lower-input farming systems as well as into extension and farmer education. There has been a corresponding interest in such agricultural practices in Europe and the U.K. which has been stimulated by the government plan for payment to farmers for setting aside land (Hansard, 1988), as well as pressure from environmental groups. There is good evidence from demonstration farms in West Germany and The Netherlands (El Titi, 1989; Vereijken, 1989) that chemical inputs can be lowered very considerably, without significant loss of yields and with increased farm income due to the lower costs of chemicals (Havlicek and Edwards, 1989). Lower fertilizer insecticide and fungicide inputs can be compensated for in a variety of ways. However, when herbicide use is decreased, weed control creates major problems for lower input farmers.

TECHNIQUES FOR WEED CONTROL IN LOWER INPUT SYSTEMS

Non-chemical methods of weed control range from traditional techniques that pre-dated herbicides to innovative methods that are still largely experimental. There is currently great potential for novel weed control techniques and for the development of integrated weed management programs.

Mechanical Weed Control

As agriculture expanded, hand-weeding became inadequate and mechanical cultivation techniques were used for weed control. Methods have ranged from hand hoes, ploughs and other horse-drawn implements, to tractor-drawn implements in the 20th century (Timmons, 1970). Equipment continues to improve and recent innovations include the development of row-crop cultivators designed to work in conservation tillage systems, and development of flame, or thermal control of weeds. Control of weeds by cultivation has four approaches: Primary tillage which involves breaking the soil in the fall or spring with the moldboard, chisel, or disk plough, prior to planting, neither chisel or disk ploughing completely invert the soil and some crop residues are left on the soil surface. Secondary tillage involves further seedbed preparation using lighter equipment such as disk- or spring-tooth harrows, and field cultivators. Selective or post-plant tillage involves rotary hoes or light harrows used at planting time and shortly after crop emergence, and interrow tillage with row crop cultivators after crop emergence. Fallow season repeated tillage controls perennial weeds, and decreases populations of weed seeds.

Primary tillage in autumn allows more time for secondary tillage operations in the spring. Shallow tillage avoids burying and preserving weed seeds. Moldboard ploughing suppresses perennial weeds, but chisel and disk ploughing are less effective and decreased tillage favours such weeds. Small-seeded broadleaves and annual grasses are more serious in reduced tillage systems, and large-seeded broadleaf weeds less so (Ross, 1985).

Repeated secondary tillage controls winter and summer annual weeds and repeated shallow tillage stimulates germination of weed seeds in the upper soil, by exposing them to light, abrasion, warmer temperatures, or oxygen. Each flush of weeds following tillage is killed by the subsequent tillage operation which results in decrease in viable weed seeds in the upper soil. There are two phases of post-plant tillage, (i) from planting until approximately one week after crop emergence, shallow cultivation with rotary hoes or harrows controls young weeds. When crop injury is likely with broadcast tools, then row crop cultivators such as shovels, sweeps, shanks, flexible and rigid tines, disk tillers, and rotary cultivators are used. (ii) After one week of crop growth, the period available to cultivate weeds is limited by the height of the crop and the potential for damage to crop roots growing close to the soil surface. Repeated cultivations in fallow seasons are used to control perennial weeds in severe infestations and it one or more seasons of fallow are needed to eradicate a perennial weed fully.

Ridge tillage, which is good for weed control, involves no primary tillage and, at the time of planting, the soil, crop residue, weeds, and weed seeds are scraped off the top of ridges formed the previous season, and dumped between rows, creating a weed-and residue-free seed bed on the top of the ridges. Subsequent cultivations remove the weeds and soil from between the rows, rebuilding the ridges, and rotary hoeing is required to control weeds in the row. This means that weed seeds were removed from proximity to the crop at the time that the crop is planted (Forcella and Lindstrom, 1988). Flame weeding, for pre-plant weed control, involves heating, but not burning weeds; it is at least as energy intensive as current mechanical and chemical control, but gives good control of those spring weeds stimulated to germinate by secondary tillage operations.

The potential for soil erosion is a major disadvantage of using cultivations for weed control, and tillage implements that maintain soil cover with plant residues while controlling weeds effectively are needed. However, systems based on cultivations for weed control tend to involve longer crop rotations, so that any adverse effects of tillage on soil erosion may be compensated partially by better soil cover.

Cultural Weed Control

Cultural control includes the use of rotations, competitive and/or allelopathic cultivars, mulching with allelopathic crop residues, and use of intercropping to increase competition or extend it over a longer period of time during the growing season.

Rotations are one of the most important cultural techniques needed to minimize weed control and are essential to minimize use of herbicides.

Competitive and/or allelopathic crops can control weeds. For instance, van Heemst (1985) ranked 25 different crops for their competitiveness with weeds. Within a crop species, different cultivars have also been found to differ in their competitiveness with weeds (Regnier and Janke, 1979). In general, it appears that crop canopy, leaf angle, leaf shape, or leaf size, all influence crop competitiveness. Interference with weeds by crops may also involve the production of inhibitory allelopathic compounds by the living roots and/or shoots of crops. Production of allelochemicals has been reported in oats, sunflower, cucumber, and sweet potato (Regnier and Janke, 1979). Crops planted in narrow row spacings can suppress weed growth more than when planted in wide row spacings. A reservation on breeding crops, for increased competitiveness or allelopathic potential, is that characteristics contributing to greater overall interference with weeds may also result in reduction of crop yield or yield quality (Duke and Lydon, 1987).

Allelopathic crop residues can control weeds. Traditionally, crops such as rye have been planted to compete with weeds, cover the soil in the winter, and improve soil tilth when they are ploughed or disked in the spring. Recent innovations involve planting crops into standing green mulches, or mulches that have been killed by mowing. In addition to the physical weed suppression from the mulch, many plant species, including crops, contain allelochemicals that suppress weeds and other plants. Much current research has focussed on small grains such as rye, wheat, oats, and barley, with considerable research on the allelochemical properties of rye (Barnes and Putnam, 1986), hairy vetch, crimson clover, subterranean clover and has demonstrated significant allelochemical weed suppression by such mulch crops (Regnier and Janke, 1979).

Intercropping and relay intercropping of two crops is used extensively in the tropics to maximize land use and to insure against crop failure (Mercado, 1987). An example of research on intercropping for weed control in the U.S. has involved planting soybeans into no-till winter grain and harvesting both grain and soybeans. The system was designed to maximise the yield of grain and soybean combined (Reinbott et al. 1987), but yields of wheat and soybean tended to be reduced compared to monocropping of either crop. A major benefit of relay intercropping is the provision of a winter cover crop to prevent soil erosion and to suppress spring-germinating weeds. A problem could be a shift to perennial weeds over a period of time because tillage is reduced.

Living mulches can control weeds by intercropping a low-growing cover crop in a summer annual crop such as corn or soybeans (Lal, 1975). The living mulch must establish itself and cover the ground rapidly so as to smother weeds but not provide excessive competition with the main crop. Living mulches do not suppress weeds selectively but also suppress the crop, and must be managed carefully to reduce their competition with the crop. The living mulch must be established at the same time as the crop and planted in bands between crop rows. Competition with crops by living mulches may be reduced while maintaining adequate weed suppression by: selection of less competitive mulches, partial suppression of pre-established mulches with herbicides, use of narrow rows of crop and selection of a competitive crop variety.

Biological Weed Control

There are two different approaches to biological control of weeds; classical biological control and mass-exposure or inundative biological control. The former is used for control of perennial weeds, where a biological agent is introduced in small quantities and allowed to build up to sufficient numbers to keep the weed at economic threshold levels. The inundative approach is more applicable to annual crops and weed problems. A biological agent, usually a fungus, is released in large quantities, sufficient to control the annual weed before it causes reductions in crop yields. Research in both these areas can provide innovative alternative means of controlling weeds.

Classical biological control agents can control perennial weeds; examples include the leaf-eating insect *Chrysolina quadrigemina* (Suffr.) on Klamath weed, the boring insect *Cactoblastis cactorum* (Berg.) on prickly pear in Australia. Other organisms include *Sphacelotheca holci*, a fungus that inhibits seed production by Johnsongrass, the stem and root mining beetle *Oberea erythrocephala* in control of leafy spurge, and the rhinocyllus weevil (*Rhinocyllus conicus* Froelich), in control of musk thistle. Rust fungus, *Puccinia canaliculata* also shows potential for control of yellow nutsedge (Regnier and Janke, 1989).

Mycoherbicides have considerable potential for biological control of weeds since they can be applied in the same way as herbicides for control of annual weeds. Examples include *Colletotrichum gloesporioides* (Penz.) Sacc. f. sp., *aeschynomene* for the control of northern jointvetch in rice and soybeans, and *Phytophthora palmivora* for the control of stranglervine in citrus orchards. Mycoherbicides have no environmental impact or toxicity to humans but their high selectivity can be a disadvantage, because each agent controls only one weed species and most crop fields are infested by several different weed species. Other problems with mycoherbicides are the difficulty of producing and formulating organisms commercially, while maintaining their viability, and the susceptibility of mycoherbicides to fungicides applied to control crop pathogens.

Herbicides from natural compounds can reveal novel chemicals with potential to reduce investments in synthetic chemistry, and a greater likelihood that the compounds will be biodegradable. Allelochemicals with potential as herbicides are coumarins, juglone, and secondary compounds from the terpenoid pathway, such as 1,8-cineole and artemisinin. Microbially-produced toxins have more potential as herbicides, because they are selective and, compared to using the actual pathogens, easier to formulate, less likely to spread disease to non-target species, and their activity is less dependent on environmental conditions. Microbial toxins may be produced by fermentation and used in their natural state, subjected to synthetic modification, or their chemistry used as a basis for producing synthetic herbicide. Anisomycin and bialaphos are products of *Streptomyces* strains and are the first microbial metabolites to be used both indirectly and directly as commercial herbicides; anisomycin is the chemical basis for a synthetic herbicide for rice in Japan and bialaphos is used directly as a herbicide in Japan (Duke and Lydon, 1987). Limiting factors in the development of microbially-produced toxins as herbicides are the low yields produced by fermentation, and difficulty and expense of synthesis due to the complexity of the structures.

Genetic engineering can contribute to alternative weed control in two ways: through development of herbicide resistance in crops and through improved biosynthesis of microbial toxins. Resistance to herbicides could allow greater use of nonleachable and/or rapidly degraded herbicides. Resistance to glyphosate has been introduced by genetic engineering, from bacteria into plants and to several imidazolinones in a corn line. A potential disadvantage of genetic engineering for resistance in crops is increased selection for resistance in weeds, due to increased selection pressure.

INTEGRATION OF TECHNIQUES INTO INTEGRATED FARMING SYSTEMS WITH LOW CHEMICAL INPUTS

All inputs into farming systems whether based on rotations, cultivations, fertilization or pest control have impacts which must be considered for efficient weed control.

Integrated Weed Management

Integrated weed management involves a combination of different weed control practices. It involves a combination of cultural, mechanical, biological, and chemical control measures. Such combinations are important for control of perennial weeds or particularly prolific or competitive annual weeds. Integrated weed management also depends upon knowledge of past weed populations in fields, competitive crop cultivars, crop and soil management practices, regular monitoring of annual and perennial weeds, and spot treatments with selected herbicides. It combines crop rotations, the use of smother crops and competitive crop varieties, and tillage, together, with newer technologies such as intercropping, relay cropping, living mulches, dead mulches, ridge tillage and other cultivations, classical biological control agents, mycoherbicides, and biologically derived herbicides. The use of an integrated pest management philosophy, combined with crop-weed competition models and minimum use of post-emergence herbicides, gives farmers flexibility in low input weed control (Schweizer, 1988).

Integrated Farming Systems

The complex interactions between inputs into farming systems have been emphasized by Edwards (1987, 1989). The main inputs into a farming system are rotations, fertilizers, pesticides and cultivations and since all of these impact strongly on the incidence of weeds, there use should always be based on their potential for decreasing or increasing weed problems. Rotations are critical in achieving weed control; pesticides, such as herbicides have strong effects upon the incidence of pests and diseases; cultivations are of major importance in weed control, and fertilizers grow weeds as well as crops. It seems quite illogical to apply fertilizers over the whole crop area and then apply a herbicide or cultivate between the rows to kill the weeds which rely on the fertilizer for nutrients. There is established technology and equipment for placing the fertilizer exactly where it is required i.e. in the crop row. These interactions are so strong and complex that mathematical computer based modelling may be a critical tool in developing integrated farming systems. Lower input farming systems involve a much better understanding of agroecological systems, particularly since biological inputs must supplant inorganic chemicals.

CONCLUSIONS

Integrated low-input farming systems which provide adequate weed control must be based on much better knowledge of crop ecology and are much more management-intensive than conventional systems which are heavily dependent upon herbicides. We have tested a wide range of techniques and clearly some have a much greater potential value in integrated low-input farming systems than others. In our experiments current practices, which play a major role in non-chemical weed control, include rotations, innovative cultivations, ridge tillage, and use of live or dead mulches. Many innovative practices close to adoption will supplement these as more research is done. Substitution of biological and cultural inputs for chemical weed control is both economically and environmentally desirable.

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