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STRATEGIC PLANNING FOR WEED CONTROL - A RESEARCHER'S VIEW

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INTRODUCTION

The object of this paper will be to give a very simple broad view of the biological background to the development of control strategies. Wild-oat, *Avena fatua* has been used throughout as a reference species with other species being introduced for comparison. It is intended to show that weed species differ greatly in their population biology and response to cultural practices. However, it is too easy to become enmeshed in very detailed discussions of species, husbandry methods, herbicide use etc. This leads to debate about fine detail rather than the overall concepts. This paper therefore concentrates on some broad descriptions of weed populations, a discussion of the speeds at which different species can move from one level to another and the relationships between such population changes and the need for weed control. Finally some suggestions are made on the possible development of weed control strategies.

Weed Population Classes

It is convenient, when beginning to consider strategic approaches to weed control, to rank population densities on a logarithmic scale (table 1). Weed populations have been ranked in seven orders of magnitude. Only in the highest three groups can the potential yield loss due to weeds equal or exceed costs of treatment; this is only very likely at the two highest ranges. However, the economic thresholds are much lower for especially vulnerable crops, notably seed crops, so weeds such as *Avena fatua* or *Galium aparine* can be economically important at levels 100 to 1000 times lower than those likely to reduce yield significantly. At populations below 1 plant/hectare plants are not weeds but "wild flowers". At what level can a weed be regarded as eradicated from a field or farm? Do we mean eradicated as a "weed" i.e. a species of economic significance or eradicated as a species? I suggest that eradication is a very strong descriptive word and that some stringent statistical description is needed. A weed can only be regarded as eradicated from a farm when it no longer has to be considered in farming policy planning. The precise population level at which this occurs will vary with species. I suggest that a potentially important weed is not "eradicated" until there is less than 5% probability of finding a single specimen on the whole farm. Many people, including I suspect the organisers of this conference, probably accept a less rigorous definition. By any definition there is a great gulf between economically significant weed populations and eradication.

Two factors of critical importance must be mentioned at this point: The soil seed burden and the potential for population growth.

The population of seed in the soil will normally be an order of magnitude or so higher that the observed plant populations in crops suitable for the development of the weed species concerned. When measured over a period of time, therefore, populations of plants and seeds in the soil will each be a reflection of the other to some extent. However, in real life we must be aware of the exceptions to this generalisation. At one extreme, species with very long lived seed may often be present in the "seed bank" in substantial quantities although no seedlings have established for many years. At the other extreme we have species with relatively short lived seed such as Avena fatua and Alopecurus myosuroides. With these it is much less common for plants to be absent from cereal crops if seed is present in the soil although it can occur. There may be other situations where the population of plants at any one moment is not a true reflection of the abundance of the species.

Table 1

Some definitions of weed densities

Population	Short description	Notes - with special reference to cereal crops
OVER 100/m^2	Very severe	Certain to cause yield loss. Probably so severe that tactics of control may be critical for maximum economic return e.g. time of treatment may be critical. Double spraying may be justified.
10-100/m^2	Severe	Yield loss usually but not always greater than the cost of spraying. Contamination of harvested produce likely.
1-10/m^2	Serious	Some competition/interference probable but only likely to repay costs of spraying in case of weakly competitive crops and/or some especially pernicious weeds e.g. Galium aparine.
0.1-1/m^2	Moderate	Not competitive in many crops but an obvious latent threat. Differences in the cosmetic effect become apparent between different species e.g. at this density Avena fatua looks very bad Alopecurus myosuroides much less serious.
0.01-0.1/m^2	Light	Very unlikely to have a measurable effect on yield but still a latent threat. Could affect quality of grain for some trades.
0.001-0.01/m^2	Very light	No effect on yield or quality. Avena fatua can be rogued by hand.
0.001-0.001/m^2 (1-10/ha)	Economically unimportant	Would probably pass field inspection for a seed crop or very easily rogued by hand. If not rogued Avena fatua not likely to exceed 1 seed/tonne of grain produced.

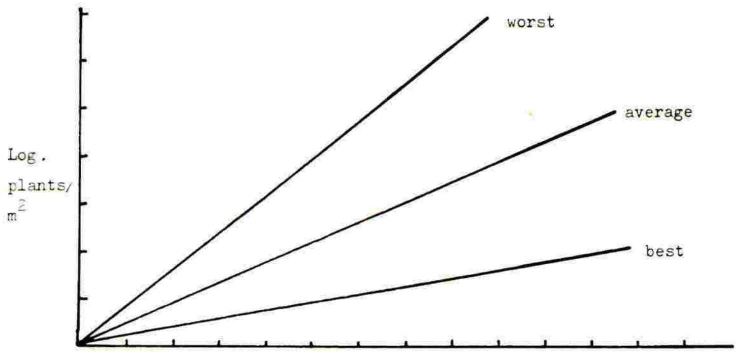
The potential for population change is a vital factor in determining the practical significance of low populations. This is considered in the next section.

Rates of Population Change

Avena fatua. Selman (1970) recorded populations at Boxworth Experimental Husbandry Farm over a number of years in land cropped continuously with spring barley. He concluded that the average rate of population increase in land not treated to control the weed was just under x 2.8 p.a. This average figure concealed wide variation between individual years and Figure 1 shows Selman's average, best and worst multiplication rates plotted logarithmically. For the sake of simplicity, the graphs are shown as straight lines, suggesting that the rate of increase is not affected by population density. This is not of course true. At lower populations the major factor controlling weed productivity is competition from the crop and this effect overrides minor changes in weed population. However, by the time plant population nears 100/m^2, intra specific competition will be significant (Rauber, 1977, Wilson, B.J. pers. comm.), and the reproductive rate much reduced.

Fig. 1

Avena fatua population increases in uncontrolled situations
(after Selman 1970)



In WRO experiments each surviving plant has produced, on average, 50 to 100 seeds. The seeds are dormant and moderately persistent but not all, of course, survive to perpetuate the infestation. Early work suggested that the decline of seeds in the soil was quite rapid, at around 80% loss per annum. More recent work (Wilson, in press) suggests that this decline may be slower, 50%, in the first year but even more rapid, 90%, in subsequent years.

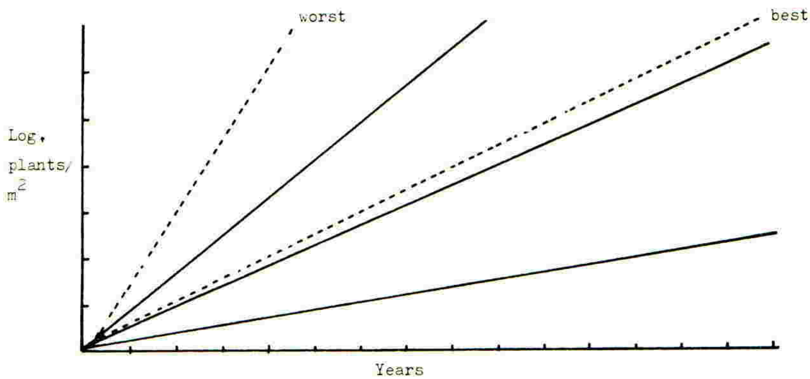
Extrapolation of these basic data to produce simple models results in estimates of potential population increase which accord very well with Selman's field observations and some of these models are discussed later.

Alopecurus myosuroides. This is a far more productive species than A. fatua. It, too, is limited mostly by the counter competitive ability of the crop but in a normally competitive crop one would expect to find 2 to 4 heads per plant producing a total of 200 to 400 seeds. Alopecurus is far more likely to produce seed of poor viability than is Avena, with individual samples ranging from 45 to 77% viable (S.R. Moss, personal communication). These data were obtained from serious to severe infestations but a recent review (Kemmer et al., 1980) suggests that production of seeds with poor viability may be especially likely at low population density because this is an out breeding species and insufficient pollen for effective cross fertilization may be present at these low densities. This suggests that the population increase in Fig. 2 may be inaccurate at both ends of the range.

Nonetheless my colleague S.R. Moss and I have produced a range of population increase values for A. myosuroides and these are produced in Fig. 2 superimposed on the graphs for A. fatua. It has to be noted, however, that the date for A. fatua were originally obtained in continuous spring barley cropping but our observations and crude predictions for Alopecurus assume continuous winter cereal cropping. It will be seen from Fig. 2 that Alopecurus has far greater potential for population increase than Avena though the difference is not entirely commensurate with the difference in seed production. This is because seeds of Alopecurus are less dormant than those of Avena and more prone to death or premature germination before they are incorporated into the soil reserves or germinate successfully in a crop. This fits in with the general view that A. myosuroides is a more rapidly invasive weed but more vulnerable to cultural factors than A. fatua. In UK and Northern Europe it is highly dependent on winter cereal cropping, though this is not true throughout all of its range. In more southerly areas it occurs more frequently in spring cereals and other spring sown crops and is therefore less vulnerable to control by crop rotation.

Fig. 2

Alopecurus myosuroides population increases in uncontrolled situations superimposed on the Avena fatua graphs from Fig. 1



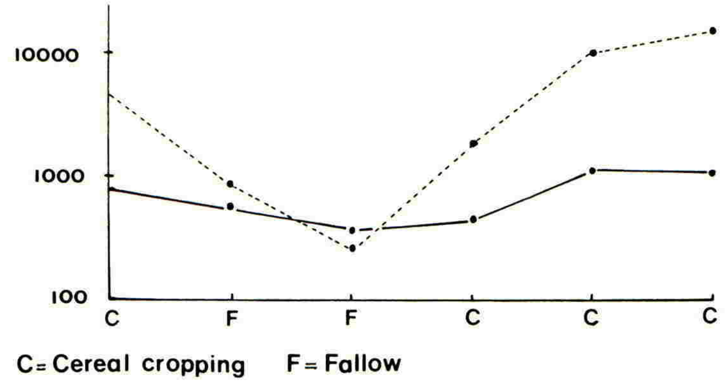
Contrasts in Weed Survival Strategies and their Relevance to Control Strategies

There is not space here to review all the vast range of arable weeds but it may be useful, to look at some contrasting strategies for survival. So far we have discussed two species. Avena fatua with a moderate potential for population increase matched by relatively short lived seed and therefore a similar potential for decline in the absence of seeding. By contrast, Alopecurus myosuroides showed more of a tendency to "boom or bust". Potential reproduction rate was much higher but the seed is slightly more short lived and less dormant so the faster potential build up is matched by faster potential decline. As a further contrast Fig. 3 shows data from some early work by Brenchley and Warington (1936). The data is graphed logarithmically to accord with the earlier figures. It shows seed populations of Alopecurus mycsuroides and Veronica hederaefolia over a five year period. For two years the land was fallowed and populations declined but built up early again in the following three years of cereal cropping. The remarkable population stability of V. hederaefolia is quite apparent from Fig. 3 and, once again, it appears that the potential for increase is very roughly matched by the potential for decline.

The British weed flora has been evolving over a period of thousands of years and clearly only those species with successful strategies for survival are still here to trouble us. It appears that one element necessary for success in a weed may be this ability to match rates of increase and decline.

Fig. 3

Log. Seed populations/m^2 of Alopecurus myosuroides & Veronica hederaefolia (Source: Brenchley & Warington, 1936)



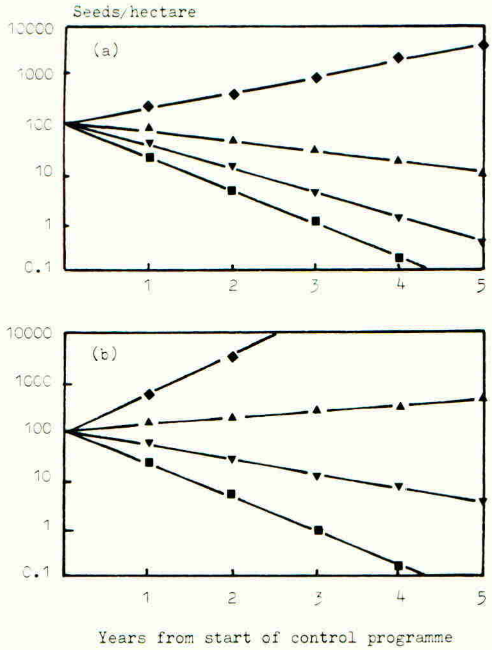
Our purpose is not to discuss weed survival strategies but agricultural control strategies. However, the two are linked, particularly with regard to the central decision of this session "eradication or containment". The weed types which respond to intensive control measures (e.g. Alopecurus) are able to regenerate very rapidly if the control programme lapses even for one season. Conversely the weed types which will be slow to regenerate in this way are likely to take an extremely long time to eradicate.

Personally I doubt if eradication is a valid goal for any UK weed except Avena spp. and then only in special circumstances.

The Relationship between potential for population change and the use of Herbicides

Cussans (1975) reviewed the then current state of knowledge on population dynamics of wild-oats and produced some extrapolations which are reproduced in Figure 4. These relate to continuous spring barley cropping and some of the assumptions made could usefully be modified in the light of subsequent research. However, since the background for these assumptions is explained more fully in the original paper, the original figures have been reproduced. Two basic rates of population increase are postulated; mouldboard ploughing with stubbles untouched till November/December to allow maximum natural death of seeds leads to an annual increase of x 2, whilst early tine cultivation without mouldboard ploughing leads to a x 5.4 p.a. increase. If no seeding is allowed it is assumed that the annual rate of decline of seed reserves is x .2 in each case. (We now know this is an oversimplistic assumption and that there are differences between tillage systems but it is still a reasonable approximation.) These graphs suggest that the seed from plants surviving herbicide treatment delays the rate of population decline appreciably. Even a herbicide reducing seed formation by 95% in the most favourable cultural system delays the achievement of 99% reduction of the seed burden by one year compared to nil seed return. In the least favourable cultural system, the delay is even more marked and a herbicide only reducing seeding by 80% would allow the population to increase.

Fig.-



Calculated changes in wild oat population, expressed as a logarithm of seed numbers per hectare in December over a period of 5 years. (a) Assumes mould-board ploughing in December each year and 70% mortality of freshly shed seed each autumn. (b) Assumes an early tine-cultivation system and 15% mortality of recently shed seed each autumn. ◆, no control measures. ▲, annual use of a herbicide reducing seed formations by 80%. ▼, annual use of a herbicide reducing seed formation by 95%. ■, complete elimination of seeding.

The development of strategies - How can we progress?

The worst case

Some management systems are so vulnerable to weeds that a first reaction is that this whole exercise is just wasted words. A good example would be the continuous growing of winter cereals by minimum cultivation techniques. This seems to be ideal from the soil management point of view and has proved a simple economic system in recent years. Unfortunately it creates conditions so favourable to the development of black-grass that annual spraying will almost certainly be needed. The only questions to answer are tactical rather than strategic and the answers may often depend on which other species are present.

Even this situation really needs monitoring of weed populations on a regular basis. Any farmer so totally dependent on herbicides and spending so much money on them should be trying to assess weed numbers regularly. If populations are increasing consistently, however slowly, the system is breaking down. It may be solved by some new herbicide development but the farmer should know that things are getting out of hand before they do so. Conversely if populations are declining, however slowly, there may be scope for economy or it may become possible to contemplate growing crops which had been considered too risky because of the danger of weed infestations.

The best case

In a situation where, through rotation and/or other cultural practices, the potential build up is sufficiently low to be easily contained by herbicides, then a choice of strategies is possible.

1. Eradication is theoretically possible.
2. Populations could be allowed to build up and then be sprayed when an economic threshold is reached.
3. Some arbitrary threshold could be used instead. Probably well below the economic threshold to allow for unusual seasons etc.
4. If our knowledge of population biology could be used to predict weed behaviour then populations could be contained by planned use of herbicides.

A simple example of strategic planning for control of A. fatua

Let us assume a system in which cultural control measures have been adopted as far as practicable. Three years in grass reduces the seed population of the soil considerably but 30 seeds/m^2 remain. We have to plan the herbicide use for five years of cereal cropping before the land is, once again, sown to grass.

We will produce population dynamics models of three herbicide strategies all costing the same. All share the same inputs. These are assumptions based on our experimental work.

1. Each mature plant produces 50 seeds. Of these 30 are lost through straw burning, premature germination etc. 20 enter the soil.
2. In the soil, the decline of seeds is:

   50% in year 1
   90% per annum thereafter.
3. The ratio of successfully established seeds:seeds

Old seed reserves	1 : 5
New (1st year) seeds	1 : 10
4. A herbicide is available which will reduce seed production by 90% at the normal dose. A half dose of this herbicide will reduce seed production by 75%.

The three models

(i) The populations of plants and seeds are allowed to build up for two years, until a threshold is exceeded. Thereafter, three years of spraying prevents yield loss and reduces the seed population, although this is still greater at the end of the 5 year cycle than at the beginning.

Model (i)

Years	1	2	3	4	5
Plants/m^2	6	12.6	37	33	17
Plants/m^2 After spray	n.a.	n.a.	3.7	3.3	1.7
Old seeds/m^2	3	60	130	50	38
New seeds/m^2	120	250	74	66	34

(ii) The herbicide is used for the first three years of the five but not the last two. For the same expenditure, populations throughout the period are lower than in (i) but the seed population still increases over the five year cycle.

Model (ii)

Years	1	2	3	4	5
Plants/m^2	6	2	1.7	0.85	2.1
Plants/m^2 After spray	0.6	0.2	0.17	n.a.	n.a.
Old seeds/m^2	3	6.3	2.6	1.9	8.7
New seeds/m^2	12	4	3.3	17	42

(iii) The herbicide used at the full dose for one year and for the following four years at a half dose. At the same cost this regime achieves the lowest overall plant populations and decreases the seed population over the 5 year period.

Model (iii)

Years	1	2	3	4	5
Plants/m^2	6	2	2.3	2.3	2.4
Plants/m^2 After spray	0.6	0.5	0.56	0.56	0.59
Old seeds/m^2	3	6.3	5.6	6.2	6.2
New seeds/m^2	12	10	11.3	11.2	11.8

Overall Summaries

Model	Mean plants/m^2 over 5 years	Seeds/m^2 at end of 5 years
(i)	5.5	72
(ii)	0.8	51
(iii)	0.6	18

Some readers may feel that this exercise has made the whole problem seem too easy. They should reflect that the best model has ended with 18 seeds/m^2. If three years of grass then reduces this by 90% to 1.8 seeds/m^2, this will mean that the entire 8 year rotation has only reduced populations by one of the orders of magnitude listed at the beginning of this paper.

However, this exercise is far from satisfactory. All the inputs are reasonable but they are all based on averages. In reality all aspects are variable, whether biological or concerned with herbicide performance. If these ideas are to be developed we need more information on weed population biology and more sophisticated modelling techniques. We need to be able to compute degrees of risk for each strategy instead of assuming an average response which seldom occurs in agriculture.

CONCLUSION

I took this paper as something of a challenge to speculate a little. However, there is a serious purpose. Arable agriculture has become almost totally dependent on herbicides and spends a small fortune every year on their use. I suggest we should give more thought to why farmers spend this money and how they might rationalize its use.

I have concluded.

1. Eradication is not a practicable goal for many farmers or growers but may be theoretically attainable with some of the grass weeds.
2. There is a huge gap between weed levels which are seriously damaging and those which can be ignored with impunity. This means that many farmers are managing their weed populations for future benefit rather than controlling them to achieve yield responses.
3. We need more information on "Cost benefit analyses" of weed control and on population biology.
4. If we are to give sound advice on choice of cultural systems and the interaction between cultural and chemical methods we need population modelling techniques as well as direct experimentation.

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NOTES

STRATEGIC PLANNING FOR WEED CONTROL: ERADICATION OR CONTAINMENT

AN ADVISERS VIEW

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Summary Factors involved in weed containment are discussed. It is assumed that weed eradication, though possible on a field basis is unlikely on a national or regional basis and that farmers are normally striving to achieving degrees of containment. There is a lack of precise information about many of the factors involved which leads to difficulties in making objective recommendations about the economics of aiming at different containment levels. Main points for consideration in a weed containment policy are listed and it is suggested that aiming for a weed free environment will not always be desirable.

INTRODUCTION

Complete eradication of current problem weeds on a national scale in the UK is unlikely to be achieved. The biological factors that make plants successful as weeds and the high cost of enacting and enforcing legislation against established problem weeds are the two main reasons for taking this view.

There are, however, precedents for the elimination of specific weeds from agricultural land. *Lolium temulentum* (Darnel) once a serious problem in winter wheat, disappeared in the UK with the advent of seed cleaning. In Norway stringent legislation against *Avena fatua* has enabled cereal growing to be resumed in areas which a century or so ago lost all value as cultivated land due to the presence of wild-oats.

A search of the recent literature reveals no reports of complete eradication though containment is tending towards it. In the USA an intensive and expensive programme against *Striga asiatica* (witchweed) is reported as being well on the way to eliminating the weed from American agriculture through systematic control, quarantine and regulatory procedures (Eplee 1979). Similarly, in Tasmainia, a ten year programme against cotton thistle is nearing the stage of complete elimination (Hague 1979) through advisory, inspection and enforcement activities backed up by noxious weed legislation.

During the UK National Wild-oat Advisory Programme (Attwood 1978), legislation against wild-oat was frequently discussed. Northern Ireland tightened the rules about imported grain and raised cereal seed standards. However, replies to parliamentary questions about *Avena fatua* and other weeds suggest that further legislation for England, Wales and Scotland is unlikely.

DEGREES OF CONTAINMENT

Advisers are normally faced with considering degrees of containment rather than total eradication. At one extreme the level of containment may entail the total elimination of a weed from a field for a season or longer, which leads to much confusion in discussion if terms are not defined closely at the outset, since this is often termed eradication. When a weed is sufficiently noxious (for example wild onion in pastures grazed by dairy herds or wild-oat in seed oat crops) it must be eliminated from the field or that field must be avoided for the original purpose. At the other extreme, carpets of weeds present in crops may be of no economic significance to that crop, an example here is Poa annua present at harvest in a cereal crop that was free from this weed early in its life.

In many cases annual weeds only offer serious competition to crops early in their life. For instance, sugar beet kept weed free between weeks 4 and 8 after drilling have yielded as well as those weeded throughout their life (Scott et al 1974 and 1976). Consideration of ease of harvesting, however, makes the removal of later germinating tall growing weeds such as Chenopodium album (Fat hen) important.

FACTORS INVOLVED IN ECONOMIC CONTAINMENT

The adviser faces many diverse situations in trying to work out economic containment levels for weeds in crops. The sort of factors involved include:

1. Average yield response curves to major weeds and weed associations.
2. Yield responses to weed removal at different potential yield levels.
3. Modifications of the response curve with relative time of crop and weed emergence, together with seasonal and cultural influences on this.
4. Germination periodicity of weeds in different seasons.
5. Modifications caused by timing and degree of control.
6. Cost effectiveness of control methods.
7. Effect of weed presence on pests and diseases in the crop.
8. Effect of weed presence on crop quality, saleability and premiums obtainable.
9. Effect of weed presence on ease of handling the crop and carrying out field operations.
10. Long-term effects of allowing weed seed return in the field.

Elliott (1978) reviewed the economic objectives of weed control in cereals and concluded that the most damaging effects of weeds is in the reduction of crop yield. He found that there was very little quantifiable evidence to assist in defining the economic effects of weeds on ease of harvesting, cleanliness of grain sample and other factors. In relation to the major effect of weeds on yields he suggested that the present state of knowledge does not permit a reliable prediction of the onset and consequences of weed competition from either grass or broadleaved weeds in cereals. The same is true of other crops.

In the case of weeds such as Avena fatua with dormant seeds forming a reservoir in the soil it would be helpful to be able to sample the soil and obtain an estimate of the numbers and viability of those present. This would be useful in knowing when to stop using wild-oat herbicides after 2 or 3 years of successful control with no seed return. Systems of assessing weed seed burdens in soil are available and are used in weed experimentation but they are considered too laborious and cumbersome to be provided as an advisory service at present.

There is very little information available to help advisers make objective recommendations based on a consideration of the factors involved.

GAPS IN OUR KNOWLEDGE

As regards some of these factors crop plants themselves must be considered as weeds. Annually seeding beet, self-set potatoes and shed grain all present major problems. Currently, for example, farmers are suffering penalties in the cereal intervention market through cereal admixture, having too much barley (from self sown grain) in their wheat. These problems have been discussed at some length at previous conferences and Cussans (1978) has pointed out the lack of knowledge of the biology of many crops as weeds. The same is true for many non-crop plant weeds. In view of the massive amount of field work that would be required to define the response curves just for common crop weed associations and to sort out the biological interactions it is a situation that seems likely to continue.

The recent working party which met at the Weed Research Organisation to report on what was known about the field behaviour of Bromus sterilis and other Bromus spp was a useful step forward. However, advisers generally need to be much better briefed on such information on weed biology as is available to be able to improve their subjective assessment of likely weed effects in different seasons. Trying to build a "weed predictive" model and testing it in practice reveals the full range of information required and exposes our ignorance. The research report by Mortimer et al in this session and their poster displays are of interest in this respect.

In the absence of good weed population/crop yield response data a figure frequently used by advisers in discussion is the crop weight value equivalent of the cost of the treatment proposed. Thus, advisers refer to a low cost cereal spray treatment as needing only a $\frac{1}{4}$ cwt/ac (31 kg/ha) of extra grain to cover it. Mainly subjective assessment of the likelihood of achieving this yield gain is then made. This is clearly unsatisfactory and is a further indication of a large gap in knowledge that needs to be filled.

CONTAINMENT PROBLEMS

It is easier to tell a farmer growing high yields to spray low populations in an attempt to contain the weed at the lowest level than the man with below average yields. The spray treatment equivalent value in terms of crop weight represents a diminishing percentage of the total crop (and potential "profit") as the crop yield increases. An example for cereal weed sprays adapted from Elliott (1978) is given at Table 1. The last 2 columns represent the percentage yield increase needed to cover the chemical cost envisaged.

Table 1
Cereal Weed Control: "Grain Equivalent Value"

Herbicide Type	Approx Current Cost £/ha	Equivalent Wt of Grain* kg	Grain Weight as % of Yield of 5t/ha	Grain Weight as % of Yield of 7.5t/ha
Simple hormone	5	50	1.0	0.7
Complex broad-leaved weed mix	13	130	2.6	1.7
Cheaper autumn broad-leaved weed and some grasses	20	200	4.0	2.7
Wild-oat post-emergence spray	34	340	6.8	4.5
Expensive grass and broad-leaved weed material	47	470	9.4	6.3
Expensive barren brome sequence	63	630	12.6	8.4

*at £100/tonne

Crop yield level changes, crop value variation and herbicide price change mean that this type of table must be constantly updated as the relativities alter. This type of table does not bring out the point that in crops with a low yield potential the yield response from controlling a given population is likely to be far greater than in a crop with a high yield potential (North and Livingston 1970).

There is a tendancy for the development of ever broader weed spectra in commercial products and mixtures used on arable crops and many sequential programmes are now recommended. This greatly increases the chance of a weed that is resistant to the treatment becoming a dominant problem. Should we not be developing more selective materials that are specific to a narrower range of weeds so that we can "ring the changes" more often? This approach envisages a high degree of containment of serious weeds (such as wild-oat and blackgrass) combined with a lower level of containment of less aggressively competitive weeds. This is a debatable point and unlikely to be popular advice. The majority of people wish to aim for a weed free environment.

Where sequential herbicide applications seem desirable it is not always known whether or not they will be safer or more damaging to crops, especially where short time intervals between applications are involved. This caused problems for advisers when labels rarely mentioned other manufacturers' recommendations but it is good to note the present degree of co-operation between manufacturers who, having recognised the needs of farmers with a wide range of weed types, obtain the clearances and agreements between Companies which allow many mixtures and sequences to be presented as label recommendations.

THE CHANGING SITUATION

As forecast a decade ago (Attwood 1970) weed populations are being changed by difference cultivation regimes and different cropping patterns; currently by a big swing to earlier autumn sown cereals. This leads one to wonder whether we can alter weed populations in favour of adequate control by existing herbicides by slight alterations in cultural practice.

What are the implications of new herbicide introductions? Does the new ICI material fluazifop-butyl discussed in this session, together with existing materials such as alloxydim-sodium, clofop-methyl and others for use in broad leaved crops offer sufficient long-term control of grass weeds to warrant a closer investigation of the use of alternative crops amongst cereals in terms of weed management over a rotation?

Much information on weeds in crops is gathered each year and then tends to be lost. Is it an impossible task to gather together and analyse such information in an easily accessible store to give an earlier warning of new weed crop problems so that biological information together with cultural and herbicide control measures can be developed in good time? We do not always spot developing weed problems early enough and weed monitoring is important. The adoption of different headland policies some years ago might have stopped *Bromus sterilis* becoming a serious field problem on some Eastern Counties farms. It is hoped that research and advisory activities now developing will enable this weed to be contained at levels well below those which will have a measurable effect on the UK national cereal production.

MAIN CONSIDERATIONS IN A CONTAINMENT PROGRAMME

The main points for consideration in deciding the degree of weed containment desirable are:-

1. Crop yield response to weed removal.

2. Do the weeds affect crop management? For example, *Polygonum aviculari* (knotgrass) and *Chenopodium album* (Fat hen) in potatoes and sugar beet or dense grass weeds in cereals slowing combined harvesting.

3. If partial control allows seed return is the weed likely to increase to a level that constrains future cropping? For example, leaving annual beet to seed has made some land unsuitable for future sugar beet cropping.

4. Will the crop saleability (quality) be affected? For example, wild-oat in seed cereals or porridge oats; *Solanum nigrum* (black nightshade) berries in vining peas.

5. Does the weed presence encourage serious disease risks? For example, potato ground keepers in seed potato crops; self sown cereals forming a "green bridge" for cereal diseases; *Agropyron repens* carrying cereal "take-all" disease.

6. What is the interaction between weed competition and other factors affecting crop production? For example, the combined effect of blackgrass presence and cereal root diseases such as "take-all" can be serious in second and third wheat crops and demands a higher degree of weed control than is necessary in a first wheat crop.

CONCLUSIONS

Consideration of these points will make it apparent that some weeds will require a very high degree of containment, though perhaps on a field or a farm rather than a national basis, which might be defined as being as near complete eradication as is biologically possible. With other weeds where yield alone is the main consideration and long term effects, crop quality and other factors can be ignored the economic analysis of trial results will often show a financial benefit from quite low levels of control. In other words one can live with quite high populations of some weeds.

For major individual problem weeds sufficient information can be pieced together to make an effective advisory recommendation based on integrated methods of control. However, for mixed weed populations in most crops there is little information and containment level is more often than not determined by pride or depth of purse.

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STRATEGIC PLANNING FOR CONTROL - ERADICATION OR CONTAINMENT

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I manage a 120 hectare family farming company in South Lincolnshire. The soil type is very fine sandy loam, and the cropping range includes cereals, potatoes, sugar beet, vining peas, carrots, parsnips and cauliflower.

I also have a non-financial interest in an associate company farming 240 hectares of medium and heavy silt loam soils. Of this second area, only approximately one third is suitable for potatoes and sugar beet. The rest is predominantly cereals, with a combinable break one year in five or six. This break has been dried peas, but from next year we are going to introduce oil seed rape as well, and widen the pea rotation.

When I returned to the family fold three years ago we were in a quandary on the heavy land. We were not sure whether we were direct drillers, minimal cultivators or traditional cultivators. We do now have a strategy which we follow reasonably closely. For autumn sown crops we have our own form of minimal cultivations, trying to avoid water problems such as temporary 'ponding', and attempting to attain a good crop root system. We still plough for spring sown crops.

In any weed control programme, good drainage is crucial. From a 15% area efficiently drained in 1978, we shall have all the land underdrained every 20 metres by the end of 1982.

Our maintenance of break crops on the heavy land, and retention of ploughing, are controversial, but the break crops and the ploughing do indirectly reduce our herbicide bill. So far, we have very little sterile brome (*Bromus sterilis*); neighbours who have persisted with winter cereals and minimal cultivations have eventually run into problems with grass weeds. Suffice to say with sterile brome, that at this time where we see any quantity, we rotary cultivate.

Apart from sterile brome, on the heavy land our strategy is very much one of containment. An economic containment policy does not allow the luxury of full rate autumn herbicide and full rate spring herbicide for grass weeds, unless a field's past history is so bad that one has no choice. We were doing exactly that, but we think that now, we may reduce the bombardment. Similarly, roguing of wild oats (*Avena* species) within a containment policy is not considered essential. Each year we diagrammatically plot weed infestations indicating as clearly as possible the area involved and the degree of infestation. This is the simple but essential basis to the herbicide strategy for the following year.

For the first two cereal crops after a ploughed break, we have started to use the reduced rates of specialist black-grass herbicides, such as chlortoluron, in the autumn. In the following spring we are prepared to use the full rate of wild oat herbicides, if it appears to be necessary. For the following cereal crops, if the black-grass (*Alopecurus myosuroides*) has started to build up, we will use full rate chlortoluron or isoproturon in the autumn followed by no, or a reduced rate of, wild oat herbicide in the spring. Not only is there a reduction in herbicide expenditure, but we suspect that by using reduced rates we are damaging our host crop to a lesser degree. Presuming our weed control is reasonably successful, we expect to achieve a positive yield response by reducing the damage. We are very conscious of the damage potential of herbicides and suspect that there is some experimental evidence that in the absence of weeds many herbicides will reduce a crop's yield. I will admit that we do at times abuse chemicals, mainly because of inclement weather at the correct time of application. Drift onto susceptible neighbouring crops and pressures of work are two other common reasons. We find that after chlortoluron and isoproturon herbicides, that wild oats emerge late in the spring and are weakened. This is, of course, the basis of a sequential herbicide policy at reduced rates. We do not find wild oats until the third and fourth week in April. Indeed, from this time we have normally two weeks before the wheat crops reach the second node stage in which to apply whichever is necessary of the chemicals for broadleaved weeds, wild oats, stem shortening and eyespot (Pseudocercosporella herpotrichoides).

Couch grass (Agropyron repens) is effectively contained by glyphosate either in the host crop after it has reached the relevant stage, or in winter barley stubbles. It is an excellent but expensive chemical and we do need a rainfast competitor to reduce the risks involved with glyphosate.

Within a containment policy, it is often a difficult decision whether to spray again for broadleaved weeds after chlortoluron or isoproturon applications. Frequently, the infestation is such that we know that the increase in crop yield is unlikely to compensate for the cost of spraying. However, even when containing weeds we must think about the future, and population build up after weed seed has dropped. Also, there are limits to most farmers' ability to turn a blind eye to weeds showing up out of the top of a crop. An indication of the changes in spraying strategy is the frequent sight, now, of perennial thistles standing above cereal crops in July. In some cases we spray a whole field if our spring crop inspections indicate general infestation; in some cases we just spray the outsides or part of a field, and in some cases we do not spray at all.

The two weeds that are building up on our heavy land are speedwells (Veronica spp.) and cleavers (Galium aparine). We think cleavers is worthy of eradication even in a containment situation. Apart from its competitive nature it can make harvesting exceedingly tiresome and it is very difficult to clean out during 'dressing'. Why is CMPP no longer reliable for cleavers? Are the pre-emergence herbicides hardening it? The most effective chemical we have now is the expensive but admirably safe bentazone with dichlorprop. Where the speedwells are really thick we will be using reduced rate ioxynil/bromoxynil herbicides in the autumn.

We know that the cereal crop is suffering a margin squeeze. As well as chasing increased yields farmers are searching for cost reductions. In many cases fixed costs have been reduced as far as possible. Of the variable costs, herbicides are contributing up to 40% of the total. I do not think the other variables will be readily reduced. It is the herbicide percentage that we will be attacking.

On the medium silts the crop rotation involves cereals three years in five; on the light silts this drops to two years in five. The obvious result of this is a more varied herbicide attack and a greater frequency of ploughing. We try to grow as many cereal crops as possible on these soils for seed production. It is the premiums that one hopes to achieve with these seed crops that must finance the weed eradication policy on this sector. We are referring to eradication both within a growing crop and, hopefully, complete removal of such weeds as wild oats, black-grass and cleavers in the long term.

Where black-grass is present, we still use chlortoluron or isoproturon on these soils followed by roguing of wild oats in the summer. For seed growing we prefer to use triallate granules with methabenzthiazuron because triallate either kills wild oats or leaves them easily rogueable, but we do not find this combination efficient for black-grass. Our experience with broad leaved weed herbicides such as methabenzthiazuron and a trifluralin/linuron mixture is that they are reasonably effective, but Polygonum weeds do break through in the late spring, and we tend to be spraying for them between the first and second node stages of the host crop.

One of the major problems that has come forward in recent years is the volunteer cereal. This is clearly a result of successive cereals within a rotation and non-ploughing. It is not uncommon now to see wheat in barley and vice versa. What is sometimes forgotten is the significant lowering of revenue from the relevant crop due to competition within the crop, and down-grading of the produce. It is clearly a farmer problem; I do not think many farmers expect the production of sprays to take wheat out of barley or barley out of wheat.

In the 'cash' crops that we grow it is, again, volunteer plants that occupy much attention at the present time. The weed beet is a menace for which the policy of eradication is the only alternative. The weed or volunteer potato is often said by farmers on the silts to be their main weed problem. Weed beet has been catastrophic in areas of Norfolk and the Lincolnshire Wolds, in that it has taken fields out of sugar beet production.

The volunteer potato is firstly a great competitor in crops such as carrots, sugar beet and parsnips; it also, obviously, perpetuates and aggravates eelworm populations and may act as host to blight. As we tighten potato rotations on suitable soils the problems of this weed are manifest.

With 'cash' crops, the weed control strategy varies from eradication to containment - depending on the nature of the problem. The strategy will take into account cost, required crop yield and quality, disease carry-over, and ease of harvesting.

The standard ploy is to apply the pre-emergence herbicide in as favourable conditions as possible, and follow up with the post-emergence after inspection of the weed spectrum. The effect of this policy is dependant on the season, good management and luck. However, even if the elements are against us, the days in which gangs of people were sent out to complete the weed killing programme by hand hoe are largely gone. If the crop will yield well, and is going to be easily harvested, we do not worry about a few weeds. The cauliflower crop is one exception to this in that on our silts, cauliflowers do seem to benefit from the soil loosening resulting from hand hoeing.

It is interesting to note how many mixtures are being used now, some recommended and some not. Examples of these are pyrazone/ethofumesate for sugar beet, monolinuron/metribuzin for potatoes, chlorthal-dimethyl/propachlor for onions and chlorbromuron/metoxuron post-emergence for carrots. The control spectrum is that much greater and we are using lower rates than we would have been, if the chemicals were being used individually. Although these combinations are more expensive we are, hopefully, doing less damage to the crop. Also, hopefully, any risks of residual herbicide damage to subsequent crops are lessened.

I have mentioned disease carry over through weeds. We are very aware of the potential of couch grass to carry over the violet root rot fungus (Helicobasidium purpureum) for carrots and take-all (Gaeumannomyces graminis) of cereals. Another weed becoming more prevalent - especially in lettuce crops, is groundsel (Senecio vulgaris). Again, it is supposed to be a carrier of lettuce mosaic virus.

Ideally, such weeds should be eradicated. Employees who cut cauliflowers present very strong cases for eradication of small nettle (Urtica urens), as does the beet harvester operator for knotgrass (Polygonum aviculare).

I remember in 1975 and 1976, at my previous employment, we pursued an extreme eradication policy. During those warm summers we had several patches of Cuscuta spp. in the carrot crop. We walked miles of carrot bed to spray out every patch. Even two years ago, we were still 'spotting' thistles in parsnips with a hand sprayer and glyphosate. The hope was that we would eradicate thistles and the heavy cost would be spread over the whole rotation. Unfortunately, it has not worked very successfully. Even on our light silts thistles are an increasing and worrying problem.

Finally, I would like to return to sugar beet and potatoes. Until now, our policy for weed beet has been to hand pull all bolters. There is, however, this interesting development of applying glyphosate making use of the height differential between the bolters and the beet crop. The non-drip wick principle used could well have applications for other problem weeds, such as thistles and volunteer potatoes in carrots and parsnips. The other development is the low rate, low volume, high pressure application of herbicides to sugar beet. There are practical problems for the farmer, such as drift, and rating of sprayers for high pressure, but the experimental work is very encouraging. Both these developments are either low cost or they represent a reduction in cost. I maintain that herbicides for the sugar beet crop are still the least reliable and any improvements are welcome.

On our light silts with potentially high multiplication rates of potato cyst eelworm (Globodera spp.), we grow spring wheat after potatoes. Although we have regularly averaged more than six tonnes/hectare of spring wheat in the past seven years, we accept that we can achieve bigger yields with winter wheats. However, with the spring crop we do not worry about spraying potatoes off early and sacrificing yield. We are able to work the land during frosty weather to kill a greater percentage of tubers in the soil. Also, the spring wheat variable costs are less and invariably the corn fetches a premium for high protein levels. The greatest reward will come if we can crop potatoes more frequently on these soils. We hope to try a spray of glyphosate into the spring wheat crop the following summer, if we still have high populations of volunteer potatoes.

In conclusion, the higher potential output from land, the more a herbicide policy moves from containment to eradication. This is partially offset by the present economic climate which is making demand for most products more elastic.

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THE MECHANISMS OF ACTIVITY AND SELECTIVITY OF THE WILD OAT HERBICIDES

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Summary The mechanisms of activity and selectivity of barban, benzoylprop-ethyl, chlorfenprop-methyl, diclofop-methyl, difenzoquat, flamprop-isopropyl, flamprop-methyl and tri-allate are reviewed. All these herbicides inhibit the processes of cell division and cell elongation at the shoot apex but the biochemical sites of interaction are uncertain. This apical activity can be considered as the primary action of these compounds, however, several have effects on other biochemical systems. These secondary effects can lead to confusion when assessing herbicide activity and selectivity.

The five propionate compounds are dependant on hydrolysis to their free acids for complete activity, whereas barban, difenzoquat and tri-allate appear to require no chemical transformation to be active.

Selectivity of benzoylprop-ethyl, diclofop-methyl, flamprop-methyl and flamprop-isopropyl is dependant on their relative rates of hydrolysis and subsequent detoxification to inactive components. Barban detoxification is greater in tolerant species. The selectivity of chlorfenprop-methyl and difenzoquat appears to be based on differences in sensitivity at the site of action. Tri-allate selectivity may be related to morphological differences in germinating wild oats and wheat, which reduce the amount of chemical entering the whole plant.

INTRODUCTION

The need to control Avena spp. in cereals has resulted in the development of several "wild oat" herbicides in recent years. The ideal requirements for a wild oat herbicide include ease of application, wild oat susceptibility at all growth stages and for all species, and minimal effects on the crop. Although several of the "wild oat" herbicides satisfy some of these requirements, none satisfies them all (Holroyd, 1976). This has resulted in herbicide recommendations which are dependant on crop species and cultivars, wild oat species, growth stage of wild oat and crop and time of year.

The toxicity of these herbicides is dependant on a number of factors: retention by the wild oat; absorption and translocation to the site(s) of action; metabolism to an active component and/or lack of degradation to inactive products; and activity at the site of action. Crop tolerance is dependant upon the absence or reduction of one or more of these factors.

This paper reviews the activity of eight "wild oat" herbicides; barban, benzoylprop-ethyl, chlorfenprop-methyl, diclofop-methyl, difenzoquat, flamprop-isopropyl, flamprop-methyl and tri-allate (figure 1), highlighting the mechanisms of selectivity of these compounds.

Barban

Barban (4-chloro-2-butynyl-m-chloro-carbanilate) gives post-emergence control of wild oats in barley and wheat. Barley is generally more tolerant than wheat but there are major differences among the varieties of either species (Pfeiffer, Holmes and Phillips, 1960; Rylands and Mears, 1967; Jacobson and Anderson, 1972). Growth stage and temperature also affect the tolerance of wheat to barban (Friesen, 1967; Neidemyer and Nalewaja, 1974).

Barban has two phytotoxic effects, a primary effect on the apex and a secondary chlorotic effect on foliage (Hayes, Pfeiffer and Rana, 1965). Susceptible plants show dark-greenish pigmentation and morphological alterations (Shimabukuro, Walsh and Hoerauf, 1976). Barban activity at the shoot apex and other meristematic tissues induces hypertrophy and vacuoles in cells which disrupt their shape and arrangement (Shimabukuro, et al, 1976; Kobayashi, Tamasue and Ueki, 1977). Barban caused a rapid inhibition of cytokinesis and cell elongation in wheat roots (Burström, 1968). These effects were reversed by the addition of thymidylic acid and auxin and it was suggested that the herbicide reduced activation of IAA, kinetin and metabolites. These metabolites are necessary for cell division and initiation of cell elongation. Mann (1967) proposed that barban caused contraction of chromosomes which delays the onset of transcription of hitherto inactive genes which are vital for normal mitosis. Ladonin and Svittser (1967) suggested that barban disrupted the synthesis of messenger RNA causing abnormal cell division. Ladonin (1967) also showed that barban accelerated the conversion of nucleotide triphosphates to di- and mono- phosphates, particularly ADP, AMP, CDP and CMP. The depletion of ATP disrupted RNA and protein synthesis and normal cell division. An uncoupling of oxidative phosphorylation and stimulation of RNAase activity have also been reported as a result of barban action (Ladonin, 1966; Ladonin and Beketova, 1972).

There have been several reports on the mechanisms of selectivity of barban. The rates of translocation and chemical transformation were similar in oat and wheat but the rate of barban absorption by shoot tissue was greater in the susceptible oat (Kobayashi and Ishizuka, 1977). Concentrations of free barban were higher in the leaves of susceptible barley and wild oat biotypes compared to the resistant biotypes (Jacobson and Anderson, 1972). The concentration of free barban was also higher in the stem of susceptible wild oat compared to tolerant wheat, due to increased degradation in wheat (Shimabukuro et al. 1976). Up to 24 h after treatment levels of barban were found to be higher in wild oat than in wheat, whereas, after 48 h, the levels were similar. This short time difference was considered important in selectivity because the inhibitory effects of barban were equally as rapid (Shimabukuro et al. 1976; Kobayashi and Ishazuha, 1974).

Ladonin (1967, 1970) found that in wheat shoots, ATP consumption did not occur as rapidly as in wild oats. He concluded that this ability of wheat to retain ATP may play an important role in the energetic detoxification of the herbicide.

Benzoylprop-ethyl

Benzoylprop-ethyl (ethyl (±)-2-(benzoyl-N-3,4-dichloroanilino)) propionate gives control of wild oats in wheat when applied to the crop between early tillering and the appearance of the first node (Chapman, Jordan, Moncorge, Payne and Turner, 1969; Bowden, Jordan, Moncorge and Turner, 1970; Stovell and Bowler, 1972). Some height reduction of the crop occurs but this did not reduce crop yield (Bowden et al. 1970; Stovell and Bowler, 1972). Benzoylprop-ethyl causes inhibition of growth, rather than wild oat death and crop competition is suggested to play a role in control (Chapman et al. 1969; Hill and Stobbe, 1978).

The activity of benzoylprop-ethyl is dependant on its conversion to the free

free acid, benzoylprop (fig. 1). This, unlike the parent ester, shows some phloem translocation from foliage to the stem where it inhibits cell elongation (Jeffcoat and Harries, 1973). It has also been reported that benzoylprop-ethyl inhibited cell division in wild oats and that these combined effects caused reduction in length and diameter of internode cells, number and diameter of vascular bundles, length of internodes, diameter of culms and length of leaf sheaths and blades (Morrison, Hill and Dushnicky, 1979).

The selectivity of benzoylprop-ethyl is dependant on its relative rate of de-esterification and the subsequent detoxification of the acid to inactive conjugates. De-esterification was fastest in oat and slowest in wheat. The rate of detoxification in wheat prevented accumulation of phytotoxic levels of the acid, but in oat, although detoxification rates were higher, phytotoxic levels of acid occurred due to the faster rate of de-esterification. In barley, de-esterification was slower than in oat but detoxification failed to prevent some accumulation of the acid (Jeffcoat and Harries, 1973).

Although similar rates of benzoylprop-ethyl degradation have been reported in wheat, oat and barley seedlings (Benyon, Roberts and Wright, 1974) a lack of benzoylprop-ethyl hydrolysing esterase activity was reported in wheat (Hill, Stobbe and Jones, 1978). This was suggested to be due to the presence of an esterase inhibitor in wheat, as wheat extracts inhibited in vitro wild oat esterase activity. This inhibitor was suggested to be the selective mechanism against benzoylprop-ethyl in wheat.

Chlorfenprop-methyl

Chlorfenprop-methyl (methyl 2-chloro-3-(4-chlorophenyl) propionate) is a highly selective herbicide used to control wild oats in a variety of crops including wheat, rye and sugar beet. (Fedtke, 1972). There is a difference in the response of the different wild oat species to chlorfenprop-methyl, Avena fatua is sensitive, A. ludoviciana is slightly tolerant whilst A. sterilis is moderately resistant (Hack, 1973). Varieties of cultivated oat (A. sativa) show varying degrees of tolerance to chlorfenprop-methyl (Strychers, van Himme and van Bockstaele, 1972). The susceptibility of A.fatua differs with growth stage. Plants at the 1-4 leaf stage are more sensitive than older, vigorously tillering plants (Martin, Morris and Rieley, 1972).

Chlorfenprop-methyl causes necrotic spots followed by wilting, cessation of growth and gradual plant death. (Fedtke, 1972; Bergmannova and Taimr, 1980). A large increase in soluble reducing sugars and amino acids, particularly y-amino-butyric acid, corresponded to a rapid decay of starch, protein and RNA in treated leaves. These changes indicated activity of amylase, protease and ribonuclease enzymes, which are normally inactive and compartmentilised in the cell. It was proposed that the action of chlorfenprop-methyl was on the membrane components causing rupture of the intracellular compartments, releasing these hydrolytic enzymes which caused leaf autolysis (Fedtke, 1972).

More recent reports indicate that chlorfenprop-methyl primarily inhibits auxin-mediated cell responses, such as cell elongation, proton release, and auxin uptake, transport and metabolism, in coleoptiles of A. sativa and Zea mays (Andrev and Amrhein, 1976; Fedtke and Schmidt, 1977). The product of chlorfenprop-methyl hydrolysis, the free acid chlorfenprop (fig. 1) has been reported as the active compound and a membrane site of conversion has been proposed (Fedtke and Schmidt, 1977). Membranes have also been implicated in herbicide action by Bergmannova and Taimr (1980) who reported an inhibition of ^{32}P uptake and transport in treated A. fatua. Susceptibility of A. fatua increased when chlorfenprop-methyl was applied in the proximity of the meristem (Hack, 1971). Therefore the activity of chlorfenprop-methyl appears to be centred on membranes causing leaf cell autolysis and an interference with auxin activity in meristematic tissues causing growth retardation.

The rates of penetration and hydrolysis of chlorfenprop-methyl were similar in tolerant and susceptible *A. sativa* cultivars and could not account for herbicide selectivity (Fedtke and Schmidt, 1977). In both tolerant and susceptible plants chlorfenprop-methyl and/or the free acid was present close to or at its site of action and it was suggested that selectivity was due to differences at the site of action (Fedtke and Schmidt, 1977).

The detoxification of chlorfenprop-methyl has been reported in wheat coleoptile segments either by conjugation with cysteine or by degradation (Collet and Pont, 1978). Since there is no evidence that such a mechanism exists in susceptible wild oats this could be an additional tolerance mechanism in wheat.

Diclofop-methyl

Diclofop-methyl (methyl-2-4-(2,4-dichlorophenoxy)phenoxy propionate) gives post-emergence control of wild oats and foxtails in cereal crops (Miller and Nalewaja, 1974; Friesen, O'Sullivan and Vanden Born, 1976). Diclofop-methyl interferes with meristematic activity resulting in inhibition of root and shoot growth (Koecher and Lotzsch, 1975; Friesen *et al*. 1976). Cell elongation appears to be a target for diclofop-methyl activity as it reduced IAA - stimulated cell elongation in coleoptile segments (Shimabukuro, Shimabukuro, Nord and Hoerauf, 1978). Diclofop-methyl also reduced stem elongation resulting in abnormal spacing between developing leaves (Brezeanu, Davis and Shimabukuro, 1976).

The action of diclofop-methyl was suggested to be due to a direct or indirect inhibition of fatty acid biosynthesis, causing decreased phospholipids, displacement of individual lipid constituents and reduced ^{14}C-acetate incorporation in treated seedlings (Hoppe, 1977).

In addition, diclofop-methyl has a secondary contact action resulting in a decrease in chlorophyll content and photosynthetic activity (Koecher and Lotzsch, 1975; Chow and LaBerge, 1978). Inhibition of photosynthetic translocation to the roots, reduction in ATP content and sugar accumulation in the shoots were also reported (Chow and LaBerge, 1978). Ultrastructural damage following diclofop-methyl treatment was also extensive with cloroplasts particularly affected (Brezneasu, *et al*. 1976). Increases in leaf cell membrane permeability occurred before the appearance of visible injury (Crowley and Prendeville, 1979).

The contact action of diclofop-methyl appears to result from a loss of membrane integrity (Brezneau *et al*. 1976; Crowley and Prendeville, 1979) and changes in photosynthetic activity and subsequent chlorosis occur as a result of this initial action.

Diclofop-methyl is rapidly hydrolysed to its free acid, diclofop (fig. 1) and herbicide toxicity has been attributed to both these compounds (Shimabukuro, Walsh and Hoerauf, 1979; Todd, 1979). Diclofop-methyl causes membrane disruption and subsequent chlorosis whilst the free acid moves symplastically to the meristematic areas where it interferes with cell division and cell elongation (Todd, 1979).

The selectivity of diclofop-methyl is unlikely to be due to differences in penetration and translocation (Todd, 1979). Diclofop-methyl hydrolysis was similar in tolerant and susceptible species (Todd, 1979; Shimabukuro *et al*. 1979). However, selectivity has been suggested to be due to differences in the detoxification of diclofop (Todd, 1979; Shimabukuro *et al*. 1979; Donald and Shimabukuro, 1980). In tolerant wheat, diclofop was converted to hydroxy diclofop and conjugates and tolerant barley formed phenoxy-phenol and conjugates, all of which are inactive

(Gorbach, Kuenzler and Asshauer, 1977; Todd, 1979; Shimabukuro et al. 1979). In susceptible wild oat, a major reaction is the conversion of diclofop to the ester conjugate which is irreversible (Shimabukuro et al. 1979; Todd, 1979). This ester conjugate is proposed to act as a pool for active diclofop in wild oat and contributes significantly to susceptibility of this species.

Difenzoquat

Difenzoquat (1,2 dimethyl-3, 5-diphenyl-1, 4-pyrazolium methyl sulphate) gives post-emergence control of wild oats, at growth stages from 2- to 3-leaf through to early stem elongation, in cereals (Shafer, 1974). Barley appears more tolerant than wheat (Shafer, 1974; Miller, Nalewaja, Pudelko and Adamczewski, 1978) and wheat tolerance is dependant on cultivar (Shafer, 1974; Anderson and Arnold, 1975; Behrens, Ekikkad and Smith, 1974; Miller and Nalewaja, 1975; Blank, 1976; Miller et al. 1978).

Difenzoquat has a contact effect on treated foliage causing chlorotic and necrotic damage (Friesen and Litwin, 1975; Pallett and Caseley, in press). This may be due to an interference with leaf cell membrane integrity (Pallett in preparation). However, the primary site of action appears to be cell division and cell elongation in the apical meristem, inhibition of which causes arrested growth, prolific lateral tillering and main shoot death, (Shafer, 1974; Friesen and Litwin, 1975; Pallett and Caseley, in press). Increased activity of difenzoquat resulted when it was applied near to the apical meristem (Friesen and Litwin, 1975; Walter and Bischof, 1976; Coupland, Taylor and Caseley, 1978). Friesen and Litwin (1975) also reported extensive chromosome abnormalities and cell necrosis in the shoot apex.

The selective action of difenzoquat in wild oat and barley cannot be accounted for by differential foliar penetration, translocation or metabolism (Sharma, Vanden Born, Friesen and McBeath, 1976). Retention, absorption, translocation and metabolism were also similar in hard red spring wheat cultivars with differing degrees of tolerance (Blank, 1975). Similar results were also obtained in tolerant and susceptible UK spring wheat cultivars (Pallett and Caseley, in press). Cell elongation was similarly inhibited in these cultivars but DNA synthesis was more sensitive in the susceptible cultivar and it was proposed that this differential inhibition may be a selective factor for difenzoquat (Pallett and Caseley, in press). There is no evidence, to date, to suggest that this is the mechanism of selectivity in wild oats.

Flamprop-isopropyl

Flamprop-isopropyl (isopropyl (±)-2-(N-(3-chloro-4-fluorophenyl)benzamido) propionate) gives control of wild oats in barley (Warley, Sampson, Tipton and Morris, 1974; Haddock, Jordan and Sampson, 1975). Wild oat control is optimal when the crop is at a stage when it can offer the greatest competition (Mouillac, Lejeune, Haddock and Sampson, 1973). Flamprop-isopropyl has been shown to inhibit cell elongation in both leaves and the stem of oat but to be without effect on barley (Mouillac et al. 1973). Flamprop-isopropyl is converted to the free acid, flamprop (fig. 1) which is readily translocated via the phloem to the elongating cells of the stem (Jeffcoat and Harries, 1975). The parent compound is considered relatively non-phytotoxic as the conversion to the acid is less in tolerant barley.

The selectivity of flamprop-methyl was shown to be dependant upon an interrelationship between the rate of hydrolysis and subsequent detoxification of the acid. The rate of hydrolysis to flamprop was relatively high in susceptible oat, suggesting a greater esterase activity in this species than in barley (Jeffcoat and Harries, 1975). In addition the accumulation of a third chemical component has been suggested as a detoxification mechanism as it prevents the accumulation of phytotoxic amounts of flamprop in barley. In oat the formation of this component would seem unable to prevent high levels of the acid (Jeffcoat and Harries, 1975).

Flamprop-methyl

Flamprop-methyl (methyl (±) -2-(N-(3-chloro-4-fluorophenyl)benzamido) propionate), an analogue of flamprop-isopropyl, gives control of wild oats in wheat (Roberts, 1977). Flamprop-methyl, applied as a post-emergence spray, was found to be more active against wild oats than the other aminoprionates, benzoylprop-ethyl and flamprop-isopropyl (Haddock, Jordan, Mouillac and Sampson, 1974; Chow, 1974; Jeffcoat, Harries and Thomas, 1977). Maximum control of wild oat with flamprop-methyl is obtained when applied before main stem elongation and as a result of its higher activity was less dependant on crop competition (Jeffcoat et al. 1977).

The activity of flamprop-methyl is dependant on its hydrolysis to flamprop (fig. 1) which is readily translocated to the stem apex (Jeffcoat, et al. 1977). The mode of action of flamprop is similar to that of benzoylprop, interfering with both cell division and cell elongation causing a reduced and disrupted vascular system (Morrison et al. 1979). This may be important in causing severe retardation of higher internodes, leaves and apical development.

Selectivity of flamprop-methyl is similar to its analogue flamprop-isopropyl (Jeffcoat et al. 1977). In the susceptible oat, hydrolysis to flamprop was greater than in wheat and although subsequent detoxification by conjugation occurs, it fails to prevent toxic levels of the active acid in the susceptible species (Jeffcoat, et al. 1977).

Tri-allate

Tri-allate (S-(2,3,3-trichloroallyl)-diisopropyl-thiocarbamate) controls wild oats in wheat and barley either by pre- or post-emergence applications (Holroyd, 1968; Miller, 1973). Plants affected by tri-allate show discoloration and malformation (McKercher, Ashford and Morgan, 1975). Herbicide activity appears to be greatest when temperature and moisture are conducive to growth, although toxicity decreases with increasing soil organic matter (McKercher et al. 1975; Banting, 1967).

The mode of action of tri-allate and thiocarbamates in general has been attributed to a wide variety of metabolic pathways (Ashton and Crafts, 1973). Soil surface applications of tri-allate interfered with epicuticular wax deposition by inhibiting fatty acid metabolism (Billet and Ashford, 1978; Bolton and Harwood, 1976). The processes of mitosis and chloroplast electron transport are also sensitive to tri-allate (Banting, 1970; Mikhno, 1973; Robinson, Yocum, Ikuma and Hayashi, 1977), however the primary effect appears to be an interference with cell elongation or expansion (Banting, 1970; Billet and Ashford, 1978).

Evidence on the mechanism of selectivity of tri-allate is limited. Barley seedlings treated with tri-allate vapour accumulated greater amounts of tri-allate than similarly treated wild oat seedlings and therefore differential uptake is unlikely to be a mechanism of selectively (Thiele and Zimdahl, 1976). Uptake and translocation do not appear to account for the selectivity of the thiocarbamate analogue, diallate which also controls wild oats in cereals (Nalewaja, 1968). Shallow soil incorporation increases selectivity of tri-allate due to physiological differences between wild oat and wheat. Germinating wild oat has a mesocotyl which raises the meristematic region into the treated soil whereas wheat has no mesocotyl and the sensitive meristem is protected by more mature leaf tissue when it passes through the treated soil. (Fryer and Makepeace, 1977).

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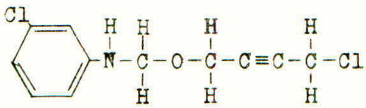
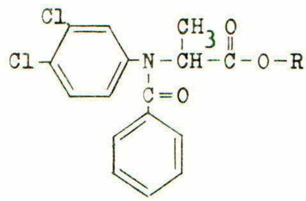
Figure 1. The structures of the wild oat herbicides

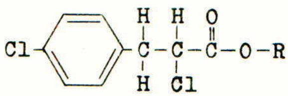


Barban



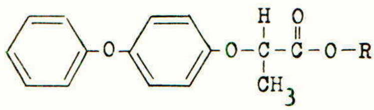
Benzoylprop-ethyl R=C_2H_5

Benzoylprop R=H



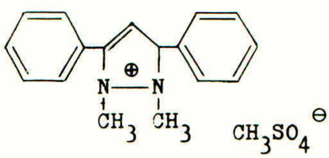
Chlorfenprop-methyl R=CH_3

Chlorfenprop R=H

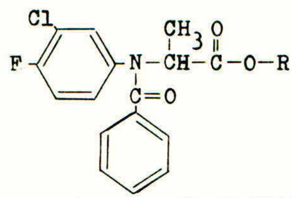


Diclofop-methyl R=CH_3

Diclofop R=H

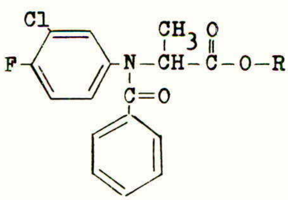


Difenzoquat



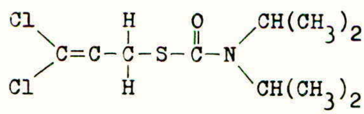
Flamprop-isopropyl R=$CH(CH_3)_2$

Flamprop R=H



Flamprop-methyl R=CH_3

Flamprop R=H



Triallate

POTENTIAL FOR BREEDING TRIAZINE RESISTANCE INTO BRASSICA SPPS

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Summary: Current research and potential for transferring triazine resistance from a weed into economic crops, is described. The species involved are *Brassica campestris* (Polish rapeseed), *B. napus* (Argentine rapeseed and rutabaga) and *B. oleracea* (kale and cabbage). A back-crossing technique using the weed as the female parent and cultivated rapeseed cultivars as recurrent pollen parents, was initiated to incorporate the triazine resistant cytoplasm intraspecifically into *B. campestris* (2n = 20) cultivars and interspecifically into *B. napus* (2n = 38) cultivars. Subsequently, triazine resistance was transferred intraspecifically in *B. napus* to rutabaga cultivars. Interspecific transfer of triazine resistance to *B. oleracea* (2n = 18) from *B. napus* has met with limited success so far. *In vivo* and *in vitro* screening of genotypes produced confirmed resistance to chlorotriazine herbicides. Further backcrossing and field selection could lead to the development of pre and post-emergence control of broadleaf weeds in these crops using triazines.

INTRODUCTION

Genetic variation in the herbicide tolerance of weeds could be used to modify the genotype of economic crops, so as to raise their level of genetic tolerance. Prospects of registering new herbicides are not encouraging, because of more stringent registration regulations pertaining to toxicological data and increasing costs of research and development. Therefore, there exists a need not only to devise alternate methods to improve the use of proven registered herbicides, but also to widen their selectivity in crop/weed communities, particularly with the minor crops. Herbicide manufacturers seem to be placing their main emphasis on the weed control in major crops, because of their large market potential. The introduction of herbicide tolerance genes into economic crops could be utilized to increase crop safety and promote improved crop husbandry practices.

Triazine resistance has been regarded as a possible solution to the control of problem weeds like *Brassica kaber*, *Thlaspi arvense* and other broadleaf weeds in rapeseed, *Brassica campestris* and *B. napus*. These weeds not only affect the yields of rapeseed quantitatively through competition, but also qualitatively as reflected in grades based on levels of erucic acid, implicated in heart disease, and thioglucosinolates which are goiterogenic. Trifluralin is presently used as a preplant incorporated herbicide, but there is a need for more effective herbicides than those currently registered in Canada to control broadleaf weeds at the pre and post-emergence stages. The use of triazine herbicides with rapeseed production would not only lower weed control costs, but also improve seed grading and permit earlier 'swathing', thereby decreasing pod shattering and reducing harvest losses. In Western Canada, rapeseed is grown in rotation with wheat, and the use of triazines in the rapeseed crop could decrease the incidence of broadleaf weeds in the subsequent wheat crop. The problem of triazine resistant volunteer rapeseed seedlings from shattered pods, appearing in the wheat crop, could be controlled by maintaining the current practice of using phenoxy herbicides in wheat. Atrazine residues could be a problem on the heavier soils and where the growing season is shorter. However, the use of less persistent chlorotriazines or as-triazines could prevent residue problems, where triazine sensitive crops are planned for the following season.

This paper describes current research on the transfer of triazine resistance into economic crops of the following species, *Brassica campestris* (Polish rapeseed), *B. napus* (Argentine rapeseed and rutabaga) and *B. oleracea* (kale and cabbage).

METHOD AND MATERIALS

In the breeding programme, the progenies produced following each backcross are screened for crop resistance to triazines, using various *in vivo* and *in vitro* tests.

The laboratory *in vivo* test consists of growing seedlings in pots in growth rooms maintained at 15°C during an 8 h dark period and 20°C in light for 16 h. Light intensity is 13 klux supplied with fluorescent and incandescent bulbs, and relative humidity 65 ± 5%. Two weeks after emergence, the plants are treated with 3 kg/ha atrazine using a moving nozzle laboratory pot sprayer. Phytotoxic symptoms in susceptible plants are evident within 1 week and are rated on a 0 - 10 scale (0 = no effect and 10 = complete kill). The other *in vivo* test involves field screening in plots using a bicycle wheel mounted sprayer. Seedlings are sprayed at the post-emergence stage with atrazine 3.0 kg/ha.

In vitro tests consist of Hill reaction determinations with isolated chloroplasts and chlorophyll fluorescence assay using leaf discs. With the Hill reaction determination, Nobel's (1974) technique for the rapid isolation of chloroplasts is used with a buffer solution consisting of 0.34M sucrose, 0.01M KCl and 0.05M phosphate at pH 6.8. Chlorophyll concentration is estimated using the method of Arnon (1949) and the chloroplast suspension is diluted in buffer to 100 μg chlorophyll/ml. DPIP (2,6-dichloro-phenolindophenol) dye is used as an electron acceptor and made up to 0.12mM in buffer. Atrazine at 10^{-4}M in buffer is used as the inhibitor. The reaction mixture is placed in a water-bath maintained at 14°C and illuminated with a 500-watt incandescent lamp (24 klux) for 4 min. Absorbance is measured in a Bausch and Lomb Spectronic 20 spectrophotometer at 620 nm. Atrazine at 10^{-4}M inhibits the photochemical activity in chloroplasts isolated from susceptible plant biotypes but not in chloroplasts from resistant biotypes.

The chlorophyll fluorescence assay is carried out on 8 mm diameter leaf discs, using a Plant Productivity Fluorometer Model SF-10 (Richard Brancker Research Ltd., 27 Monk Street, Ottawa, Ontario, Canada K1S 3Y7). It is known that Photosystem II (PS II) emits 2 to 6% of its absorbed excitation energy as fluorescence, whereas Photosystem I is weakly fluorescent at room temperature. Characterization of the light-induced changes of chlorophyll fluorescence in dark adapted chloroplasts has become an accepted means of characterizing PS II reactions (West *et al* 1976). Inhibitory processes or compounds that block electron transport on the reducing side of PS II stimulates the rise in fluorescence (Zankle *et al* 1972). The technique consists of floating leaf discs in solution of 0.05M phosphate buffer at pH 7.5, with and without 1 x 10^{-4}M atrazine for 2 to 4 h in the dark at room temperature. Following herbicide uptake, the discs are blotted dry and illuminated with a sensing probe that provides controlled monochromatic illumination centred around 670 nm, and at the same time collects the resulting fluorescence and transmits it to a photo diode sensor, which displays a meter indication of fluorescence output. Chlorophyll fluorescence in atrazine susceptible plants is 2 to 3 times greater than in atrazine resistant plants. The chlorophyll fluorescence assay is non-destructive of the entire plant and results are available within a few hours.

RESULTS

Rapeseed: An atrazine resistant weed biotype of B. campestris from Quebec was used as a source of cytoplasmically inherited triazine resistance for transfer into cultivated rapeseed. The objective was to incorporate the cytoplasm of the triazine resistant weed (2n = 20) into B. campestris cultivars 'Candle' and 'Torch' and B. napus cultivars 'Tower', 'Altex' and 'Regent' (2n = 38) through hybridization and backcrossing. Intraspecific transfer of resistance within B. campestris presented no problems in maintaining 2n = 20 chromosomes, with a triazine resistant cytoplasm. However, with the interspecific cross only three fertile 38 chromosome progeny were identified among backcross (BC_1) progeny of wild B. campestris x Tower (recurrent pollen parent) despite of hundreds of pollinations having been attempted. Many of these pollinations produced deceptive results; pods developed without seed, a type of 'false pregnancy'. All F_1 and BC_1 of all crosses between wild B. campestris (female) and cultivated rapeseed (recurrent pollen parents), were screened using a moving nozzle laboratory sprayer. All the plants were resistant to 3 kg/ha atrazine or cyanazine. Hill reaction analysis showed no loss of atrazine resistance through five generations of backcrossing. Chlorophyll fluorescence assays confirmed atrazine resistance in Candle BC_3 genotypes, with low increase in level of fluorescence following 10^{-4}M atrazine uptake over 4 h. In field trials, BC_3 and BC_4 progeny survived post-emergence application of 3 kg/ha atrazine and cyanazine, while their pollen parents 'Torch', 'Candle', 'Tower', 'Altex' and 'Regent' were killed by both the treatments. Currently, progenies of Candle BC_5 and Tower BC_5 are being multiplied in the field for subsequent testing in herbicide and variety trials, as a prerequisite stage for official registration as new cultivars, depending on their comparative performance. Selection of low erucic acid and glucosinolates, important economic traits in rapeseed, are being closely monitored through the programme.

Rutabaga: A program was initiated to develop biennial triazine resistant rutabaga cultivars from annual lines of triazine resistant rapeseed B. napus with 2n = 38. F_1 seedlings were obtained by crossing the annual triazine resistant line (female) with rutabaga cultivars 'Laurentian' and 'York' using bud pollinations. Very good seed set was obtained in controlled environment growth rooms. Repeated backcrossing over three generations using the rutabaga cultivars as pollen parents was completed, and resulted in biennial genotypes with 'swollen root' traits. Cold treatment vernalization was used to hasten flowering in these biennial lines for breeding purposes. Atrazine resistance was confirmed in F_1 and backcross progeny using laboratory in vivo and in vitro methods described earlier. Currently, backcrosses are being monitored for atrazine resistance, using chlorophyll fluorescence as the only in vitro test in the laboratory. Further backcrosses are in progress to complete nuclear substitution, prior to extensive field selection for economic traits and herbicide field evaluation.

Kale: Interspecific crosses with annual and biennial B. napus as the female parent and kale and cabbage B. oleracea (2n = 18) as pollen parents, has so far met with little success in producing any seed. The use of 'recognition pollen' (Knox et al 1972) resulted in better pod formation, but no mature seed.

DISCUSSION

Physiology and Genetics of resistance

The resistance of biotypes of annual broadleaf weeds to triazines has been reported in Senecio vulgaris, Amaranthus spp, Chenopodium spp, Ambrosia artemisiifolia, Brassica campestris and several other species as reviewed by Bandeen and

Stephenson (1980). The atrazine resistant biotype of B. campestris was first reported in Quebec by Maltais and Bouchard (1978). The mechanism of resistance in some of these weed species was not based on differential uptake, translocation or metabolism of triazines between resistant or susceptible biotypes (Jensen 1980). The resistance was due to the differential function of the Hill reaction in isolated chloroplasts (Radosevich 1977; Souza Machado 1977). This was considered to be a newly discovered mechanism of resistance to triazines centred in the chloroplast, and afforded a much higher level of resistance than had been previously utilized by Warwick (1976). Recent studies have demonstrated that chloroplast membranes of triazine resistant weeds have been modified, such that the triazine binding site is selectively lost (Pfister and Arntzen 1979). Chloroplasts containing this genetic alteration continue to function photosynthetically, but a subtle change in their electron transport properties is apparent. Namely, the rate of electron transfer in photosystem II from the primary electron acceptor Q to the secondary electron acceptor B in the resistant chloroplasts, is reduced by more than a factor of 10 (Pfister and Arntzen 1979; Bowes et al 1980). The polypeptide possibly involved at the binding site has an apparent molecular weight of 32 Kdaltons and is considered to be an apoprotein of B (Darr et al 1980).

Studies on the inheritance of triazine resistance in B. campestris by Souza Machado et al (1978) indicated uniparental transmission of the resistance trait, through the female parent. Subsequently, a chlorotic cotyledon mutant was used as a genetic marker, to confirm that the F_1 seedlings from reciprocal crosses of resistant and susceptible biotypes, were indeed true hybrids derived from reduced gametes of both parents and not matromophic plants derived from unreduced gametes (Souza Machado and Bandeen 1980). This aspect of female uniparental inheritance has been recently elaborated on by Darr et al (1980) working at the in vitro level, using atrazine inhibition of photosystem II in isolated chloroplasts and chlorophyll fluorescence as biochemical markers to characterize the inheritance of the modified atrazine receptor in chloroplast membranes. Further studies by Souza Machado and Bandeen (1980) examined the segregation of triazine resistance in F_2 and backcross progeny to determine whether the uniparental effect was controlled by maternal nuclear DNA, cytoplasmically controlled by chloroplast or mitochondrial DNA or an interaction of nuclear and cytoplasmic control. The results supported the hypothesis that atrazine resistance in the wild B. campestris biotypes was controlled by cytoplasmic DNA. Beversdorf et al (1980) also reported the involvement of cytoplasmic inheritance using several backcrosses with B. campestris and B. napus.

Crop breeding potential

The triazine resistant weed biotype of B. campestris belongs to the same species as Polish rapeseed grown commercially in Western Canada, and is a diploid with 2n = 20 chromosomes. Intraspecific transfer of resistance to the cultivated crop is therefore possible because of close similarities in the basic genome. Besides, because of the pattern of cytoplasmic inheritance, the spread of triazine resistance from a resistant rapeseed cultivar to closely related weeds in the field would not be a major threat, as it is not generally transmitted through the pollen (Tilney-Bassett 1975).

With horticultural crops, like cabbage and rutabaga, that are biennial and usually do not 'bolt', the shedding of seed at harvest which normally results in a volunteer weed in the subsequent season, is not a major problem.

There are several Brassica species with different basic chromosome numbers, which have combined to evolve several economic crop species through hybridization and allopolyploidy (U 1935). Therefore, it may be feasible to transfer triazine resistance from _B. campestris_ to some of these closely related species. The three diploid species, _B. oleracea_ (cole crops), _B. nigra_ and _B. campestris_ (Polish rapeseed, Pe-tsai and turnip) have haploid chromosome numbers of 9, 8 and 10 respectively. Hybridization between _B. campestris_ (genome AA) and _B. nigra_ (BB) have given the allopolyploid leaf mustard or oriental mustard, _B. juncea_ (AABB). Similarly, _B. campestris_ (AA) and _B. oleracea_ (CC) have given the Argentine rapeseed and rutabaga species _B. napus_ (AACC). With several of these crops, there is a need for developing more effective pre and post-emergence chemical weed control methods to eliminate broadleaf weeds. The problem could be solved by breeding resistance to triazine herbicides into these crops.

The possibility of obtaining crosses within and between _Brassica_ species does vary with the species and cultivars chosen, as well as the condition of the plants and their environment. A recent review by Downey (1980) indicated that although some interspecific crosses have been made fairly easily, others have produced seed only after thousands of pollinations, while some species have never been successfully inter-crossed. These problems are all the more compounded when cytoplasmic inheritance is involved and only one-way crosses must be made, rather than reciprocal crosses.

On a note of caution, the extensive use of the cytoplasm of wild _B. campestris_ to produce triazine resistant cultivars of rapeseed, rutabaga and other horticultural crops could lead to a greater uniformity of the genetic base of these _Brassica_ crops. This genetic uniformity could be interpreted as a general vulnerability to future disease and pest epidemics. A lesson has been illustrated in the past with the 1970 Southern corn leaf blight epidemic on hybrid maize, in which the extensively used Texas cytoplasm proved vulnerable. However, this critism could be levied at most of our major crops which are uniform genetically and therefore impressively vulnerable (Anon 1972). The real main problem which has to be evaluated, is the possibility of undesirable agronomic traits associated with the triazine resistant cytoplasm of the wild _B. campestris_. Plant vigour may be a characteristic that would have to be closely monitored.

The search for herbicide resistance/tolerance at the chloroplast or metabolism level in weeds or wild species related to economic crops, may provide a partial answer to extending the use of our limited arsenal of proven environmentally acceptable herbicides. Utilizing these genetic and plant breeding potentials, together with a program of integrated weed control involving crop rotation, herbicide rotation and mechanical cultivation, could significantly widen the basis for crop-weed management in the future.

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VARIETAL SENSITIVITY OF CEREALS TO HERBICIDES

TESTING METHODS IN FRANCE

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INTRODUCTION

To obtain a provisional authorisation of sale (APV) a herbicide must show efficient weed control and safety to the crop. Proof of selectivity in the principal cereal varieties is demanded by the official services. Moreover, any sensitivity to chlortoluron or metoxuron must be stated in the description of a variety, along with the other characteristics of that variety. The registration committee which proposes to the Minister the acceptance or refusal of a provisional authorisation to sell comprises representatives of the Ministry of Agriculture (Service de la Protection des Vegetaux and Institut National de la Recherche Agronomique, Service de la repression des Fraudes), the Ministry of the Environment and the Ministry of Industry. The Institut Technique des Cereales et des Fourrages (ITCF) is not involved at this level but in the conduct of the experimentation. The agrochemical manufacturers must prepare a dossier in support of their request for an APV. To this end, they entrust part of their trials programme to ITCF which has a regional network of research centres throughout France.

Selectivity sometimes takes a peculiar form; a herbicide is generally selective in a species of cereal but it proves phytotoxic in certain varieties. This does not lead to the rejection of the varieties or the herbicide, if they otherwise possess useful characteristics, but to restrictions on their use. These phenomena are well known and are not analysed in detail in this paper. The methods of testing will, however, be described, taking as an example soft winter wheats, the principal cereal grown in France.

METHODS

Laboratory tests

The method is based on weighing wheat plants that have been grown in pots in growth chambers. Ten seeds are sown in 6 x 6 x 6 cm pots and after about 10 days are thinned to 6 similar plants. Chlortoluron is applied to the soil surface with a syringe shortly after sowing. For each variety 4 doses of the herbicide are applied and an untreated control is left. Each treatment is replicated 3 times and the trials which last 21 days are repeated 4 times in a year. The plants are cut and dried before weighing.

Screening trials

These trials are conducted in the field, on sites as weed free as possible. Bands of herbicide, 2 m wide, are sprayed across bands of wheat varieties, 1.2 m wide. Each product is applied at 3 doses, that normally recommended (n), 2n and 3n. There is no replication within a trial; its place is taken by the number of trials conducted. Visual observations are recorded on a scale from 0 to 10, with three important classes: 0, 1 and 2 - some symptoms of phytotoxicity but not serious, 3 and 4 - symptoms clearly visible e.g. thinning of plant stand, stunting, delay in growth, discolouration, 5 onwards - unacceptable damage.

Yield trials

These trials are also conducted in the field, on plots without weeds. The effect measured is solely that of the herbicide on the crop. The herbicides are applied at the normal and double doses on plots 20 m^2 with 4 to 6 replicates. The yield of treated plots is compared with that of untreated control plots.

Table 1

Programme of studies of the sensitivity to herbicides of varieties of soft winter wheat

	Laboratory	Field: Screening		Field: Yield
Variety	1st year of study + standards	2nd year of study + standards	3rd year of study (seeking official registration) + standards	standards
Herbicide	chlortoluron	standards	new + standards	new + standards
no. of trials per year		3	9	variable

RESULTS

Yield trials

Table 2

Effect of chlortoluron on the yield of 3 varieties of wheat, tolerant, moderately sensitive and sensitive

	Variety	Clement		Talent		Corin	
	Dose	t/ha	% de t	t/ha	% de t	t/ha	% de t
Pre-emergence	Control	5.47	100	5.13	100	5.50	100
	2.5 kg/ha	5.20	95	5.08	99	5.33	97
	5.0 kg/ha	5.21	95	4.62	90	3.46	63

Screening trials (2nd year of study)

Table 3

Effect of chlortoluron on a variety under study (Hobbit) and on 3 standard varieties (visual scores 0-10 compared to untreated control, in 3 trials)

Dose \ Variety	Champlein	Capitole	M. Huntsman	Hobbit
2.5 kg/ha	1 - 1 - 0	2 - 1 - 0	2 - 1 - 0	2 - 7 - 0
5.0 kg/ha	1 - 1 - 0	3 - 1 - 0	6 - 5 - 1	6 - 8 - 0
7.5 kg/ha	2 - 2 - 2	3 - 3 - 2	7 - 5 - 3	8 - 9 - 2

Screening trials (3rd year of study, variety in course of official registration

Table 4

Effect of chlortoluron on a variety under study (Hobbit) and on 3 standard varieties (visual scores 0-10 in 6 trials)

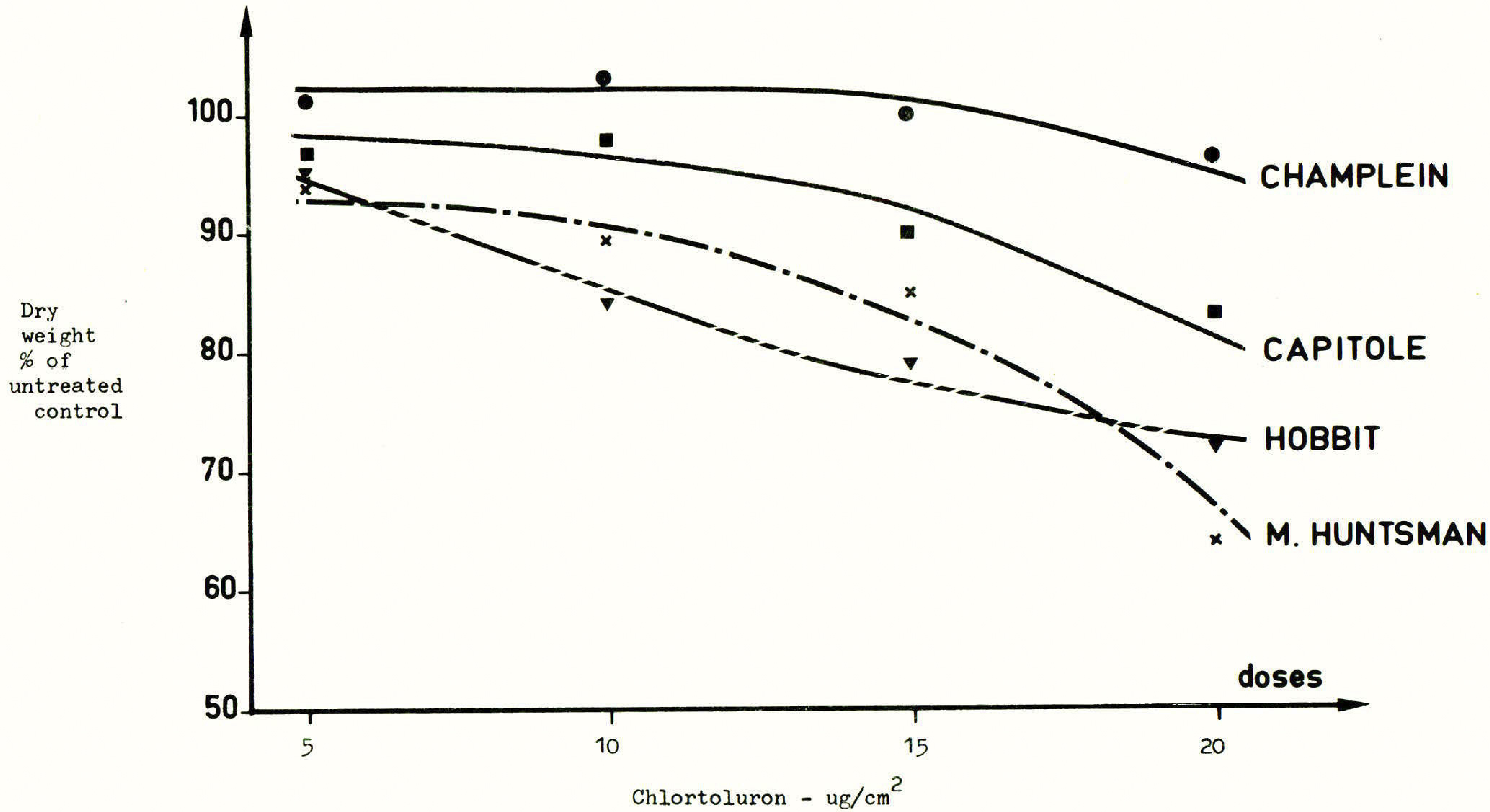
	Dose \ Variety	Champlein	Capitole	M. Huntsman	Hobbit
	2.5 kg/ha	0-1-0-0-0-1	0-0-0-1-1-0	2-2-2-0-3-6	1-0-3-4-4-7
Pre-emergence	5.0 kg/ha	2-1-2-1-1-2	1-2-1-2-1-3	6-5-5-4-5-8	4-7-5-8-8-8
	7.5 kg/ha	2-1-2-3-3-3	2-3-4-3-3-6	9-8-7-8-9-8	9-10-8-10-10-10

Table 5

Effect of diclofop-methyl on 3 varieties of winter barley (visual scores 0-10, in 6 trials)

Dose \ Variety	Sonja	IGRI	AGER
0.9 kg/ha	0-0-0-2-0-0	0-1-0-2-1-0	0-0-0-2-1-1
1.8 kg/ha	1-0-0-4-0-0	2-3-0-3-3-1	1-1-0-4-4-2
2.7 kg/ha	4-1-0-6-2-0	2-3-0-5-4-2	3-3-0-6-6-3

Fig. 1. Sensitivity to chlortoluron - experiment in growth chamber



Laboratory experiments

Table 6

Effect of chlortoluron on a variety under study (Hobbit) and on 3 standard varieties (dry weight as a percentage of the untreated control in 2 consecutive years, 1 and 2)

Dose \ Variety	Champlein		Capitole		M. Huntsman		Hobbit	
	1	2	1	2	1	2	1	2
5 g/cm2	101	88	97	88	94	83	95	-
10 "	103	83	98	83	87	65	84	-
15 "	100	73	90	74	85	54	79	-
20 "	96	65	83	65	64	45	72	-

DISCUSSION

Yield measurement seems to be the most objective method to evaluate the effect of herbicides on cereals. It is clear that the margin of selectivity is small for a variety sensitive to chlortoluron while a tolerant variety can withstand an overdose without damage (Table 2). In trials of this type, new products are compared with standard products on varieties in current use. The criterion of yield is, however, insufficient to predict exactly the effect of the herbicides in practice. Yield is dependant on a large number of factors and it is difficult to determine their relative importance and their interactions. Thus, the yield does not always account for all the symptoms that have been observed in the course of the crop's growth. One has then recourse to field screening trials.

New varieties are included in trial from their second year (Table 3). They are compared with standard varieties and only well established herbicides (the example of chlortoluron has been taken in this paper) are used at three doses, the normal rate of use, double and triple. The value of the first two is self-evident. The use of the triple dose, on the other hand, is not always clear to those co-operating in the trials. Its value lies in defining the safety margin of a treatment. Thus, when moderately severe phytotoxic symptoms show at the double dose, it is necessary to know whether or not a triple dose leads to a complete breakdown in selectivity. If it does the treatment will not be recommended, while if it does not the treatment can be applied providing certain precautions are taken.

The screening trials are carried out on the varieties in their third year of study (Table 4). These varieties are then at the last stage before official registration. It is essential, by then, to know the reaction of the varieties to the principal herbicides. In fact, the area grown for seed is also important. Thus, in 1977, five varieties sensitive to chlortoluron had been registered. In 1978/79 the seed crops of these five varieties occupied around 3,600 ha sufficient to allow the subsequent drilling of about 120,000 ha.

In addition to the standard herbicides, new products not yet authorised are included in the experimentation. The presence of numerous varieties sometimes exposes risks which may not be obvious if only one variety is tested, as one can see from the example of barley in Table 5. Diclofop-methyl was first tried on winter barley at a dose of 900 g a.i./ha. If the trials had been carried out only on the variety Sonja, one would have concluded that the herbicide was selective at that dose. But most varieties, like Igri and Ager, reacted badly to the treatment. The trials were then repeated on the basis of a normal dose of 720 g a.i./ha, at which diclofop-methyl showed a satisfactory selectivity.

To complement the study of the sensitivity of cereal varieties, experiments are conducted in the laboratory. They are carried out on varieties in their first year of study and only chlortoluron is used. Despite the standardisation of the operations and the uniformity of the material, the results are not consistent from one experiment to another, as one can see from table 6. Further attempts will be made to improve their reproducibility. One can, however, state that varieties react in the laboratory broadly as they do in the field. It is then possible to detect easily tolerant and sensitive varieties (Fig. 1). If it can be established that the test is reliable and that it can be extended to other herbicides, laboratory tests could reduce the need for extensive field trials.

CONCLUSION

The system for the study of the sensitivity of cereal varieties to herbicides which has been described above, has been used by ITCF for several years. It has, of course, some drawbacks. Yield, for example, is not measured in all varieties but only in two or three commonly grown varieties. Nevertheless, the large number of visual observations made in the screening trials allow a good appreciation of all varieties and this method, so far, has proved satisfactory. There remain some possibilities for improvement, notably in replacing some of the field trials with laboratory tests; that is the direction in which our programme is now moving.

THE TOLERANCE OF SOME WINTER WHEAT VARIETIES TO THE HERBICIDES 2,4-D, DICAMBA, BENTAZON AND BROMOFENOXIM, DEPENDING ON DOSE AND THE TIME OF APPLICATION

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Summary. During the period 1977-79, the tolerance of 7 varieties of Rumanian and foreign wheat to herbicides based on 2,4-D, dicamba, bentzon and bromofenoxim. The results obtained show that all the varieties tolerated the herbicides very well provided that they were applied at the proper time during tillering. Late treatments, when the wheat plants had got 3-4 nodes or when they had reached the booting phase, reduced both the wheat growth and yield. The wheat varieties may be divided into resistant, moderately resistant and sensitive to late treatments of 2,4-D or 2,4-D + dicamba. Among the herbicides tested, bromofenoxim was the best tolerated by all the varieties, even when sprayed late.

INTRODUCTION

In recent years, herbicide application in Rumania has extended to almost 80% of the whole cultivation area. Most of these herbicides contain 2,4-D, alone or combined with dicamba. The combinated herbicide 2,4-D + dicamba is applied mostly in zones infested by weed species resistant to 2,4-D such as *Matricaria* spp. *Galium aparine*, *Polygonum* spp. *Cirsium arvense* (Sarpe *et al*, 1975). On some agricultural farms it was noticed that the herbicide 2,4-D + dicamba reduced the growth, the development and the grain production of some wheat varieties. This fact was stated already by Bouchet (1969);and Cochet (1973), in 1973 came to the same conclusion. He revealed that the plant resistance to various herbicides depends very much on the wheat variety. As many wheat varieties are cultivated in Rumania it was necessary to study their tolerance to the main herbicides.

METHOD AND MATERIALS

The tolerance of wheat varieties was studied in three localities in order to get information on the main varieties cultivated.

The trials were carried out according to the latin square method with 4 replications, on plots 25 m^2 in size. The herbicides were applied in a volume of 1000 l of water/ha.

Herbicides based on 2,4-D, dicamba, bentazon and bromofenoxim were applied at the 3 doses shown in the table 1-3. The treatments took place in 4 period, growth stage numbers in bracket refer to the decimal code proposed by Zadoks. Chang and Konzak (1974).

Period I - at the phase of full tillering (23) in spring

Period II - at the end of tillering (27)

Period III- when the wheat plants had 3-4 internodes (33)

Period IV - when the wheat plants were in the booting stage (41)

After treatment with herbicides, notes were made according to the EWRS scale, regarding the tolerance of varieties to the herbicides and the efficiency of herbicides in controlling weeds. At harvest the grain yield was determined.

RESULTS

At the research station Simnicu 4 varieties were tested; Ceres, Diana, Dacia and Libellula. The results for the period 1977-79 are shown in table 1. The wheat varieties were heavily infested every year by Anthemis spp. Matricaria spp. Chenopodium album, Polygonum convolvulus, Less frequent were noticed Agrostema githago, C. arvense, Sonchus spp., Thliaspi arvense and Vicia spp. Analysing the results shown in table 1 one can state that in all the varieties treated with 2,4-D + bentazon and bromofenoxium, the weeds were controlled very efficiently and the wheat yields were highest. In the plots treated with 2,4-D or 2,4-D + dicamba the yield benefit was lower in stages 33 and 41.

The level of the yield increase, in all varieties and all herbicides depended very much on the time of application. The highest yield level was reached when the herbicides were applied in the phases 23 and 27. Later on, in the phase 33 and especially 41 the yield increase diminished very much in plots treated with 2,4-D and especially with 2,4-D + dicamba. Extremely important is the fact all wheat varieties tolerated the herbicide bromofenoxim, very well so that even late treatments gave a production increase of 800-900 kg a hectare, whereas the other herbicides caused even a diminution of yields, as compared to the non treated control plots. Most sensitive to the late treatment with 2,4-D + dicamba was the variety Diana and the variety Dacia was most resistant.

Under conditions at the experimental station Livada, the infestation with weeds was much less which permitted a study at the tolerance to herbicides of the varieties shown in table 2. The data presented show that all wheat varieties tolerated the herbicides well, provided they were applied during the stage 23 and 27 combined with dicamba, reduced the growth and the development of the crops, which led to decreased wheat yields, especially in the varieties Sava, Libellula and Dacia. The varieties Ceres and Potaissa were more resistant, while Montana and Turda 195 were intermediate.

At the station Caracal, wheat crops were also less weedy so that there was no yield increase, even when the herbicides were applied during the optimum period, phase 23. Table 3 reveals that the herbicides applied late, in phase 33 and 41, caused the biggest production decrease, especially in plots treated with 2,4-D + dicamba. The variety Dacia was more resistant than Ceres to the herbicides.

DISCUSSION

All the wheat varieties tested, Dacia, Ceres, Diana, Libellula, Potaissa, Montana, Sava and Turda 195 tolerated the herbicides based on 2,4-D, dicamba and bentazon very well provided that they were applied during the optimum phase during tillering.

When the treatment was carried out late, in the phase 33 and 41 with the herbicides based on 2,4-D and dicamba, the resistance in wheat crops dimished. In this connection the varieties may be divided into resistant, as Ceres, Potaissa, Dacie, moderately resistant, as Montana, Turda 195, Diana and sensitive as Sava and Libellula.

The herbicide bromofenoxium was the best tolerated by all varieites for, even when applied late, it did not reduce plant growth and of grain yields.

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Table 1

The influence of herbicides, depending on doses and time of application, upon the yield of winter wheat at the research station Simnicu

Herbicides	dose kg ai /ha	I time of applic phase 23 kg/ha	II time of applic phase 27 kg/ha	III time of applic phase 33 kg/ha	IV time of applic phase 41 kg/ha
		Variety Ceres 1977-1979			
Control not treated		3902	3902	3902	3902
2,4-D	0.660	+ 455	+ 540	+ 276	+ 199
2,4-D	1.320	+ 522	+ 573	+ 297	+ 125
2,4-D + dicamba	0.57 + 0.07	+ 646	+ 595	+ 327	+ 271
2,4-D + dicamba	1.14 + 0.14	+ 960	+ 967	- 194	- 499
bromofenoxim	2.5	+ 964	+1045	+ 976	+ 792
LSD 5% 346 kg; 1% 460 kg; 0.1% 593 kg					
		Variety Diana 1977-1979			
Control not treated		3892	3892	3892	3892
2.4-D	0.660	+ 495	+ 483	+ 239	+ 158
2,4-D	1.320	+ 569	+ 589	+ 232	- 20
2,4-D + dicamba	0.57 + 0.07	+ 651	+ 631	+ 131	- 626
2,4-D + dicamba	1.14 + 0.14	+ 941	+ 934	- 150	- 936
bromofenoxim	2.5	+ 945	+ 993	+ 847	+ 715
LSD 5% 245; 1% 459 kg: 0.1% 593 kg					
		Variety Dacia 1978-1979			
Control not treated		3647	3647	3647	3647
2,4-D	0.660	+ 355	+ 522	+ 360	+ 231
2,4-D	1.320	+ 447	+ 555	+ 378	+ 207
2,4-D + dicamba	0.57 + 0.07	+ 553	+ 652	+ 310	+ 243
2,4-D + dicamba	0.85 + 0.10	+ 707	+ 822	+ 357	+ 324
2,4-D + bentazon	0.49 + 0.96	+ 484	+ 622	+ 459	+ 339
2,4-D + bentazon	0.66 + 1.44	+ 528	+ 665	+ 532	+ 423
bromofenoxim	2.5	+ 896	+1006	+ 907	+ 814
LSD 5% 351 kg; 1% 507 kg; 0.1% 654 kg					
		Variety Libellula 1978-1979			
Control not treated		2938	2938	2938	2938
2.4-D	0.660	+ 514	+ 516	+ 276	+ 332
2,4-D	1.320	+ 618	+ 611	+ 242	+ 284
2,4-D + dicamba	0.57 + 0.07	+ 801	+ 683	+ 240	- 256
2,4-D + dicamba	0.85 + 0.10	+ 919	+ 909	+ 88	- 589
2,4-D + dicamba	1.14 + 0.14	+1009	+ 974	+ 104	- 514
2,4-D + bentazon	0.49 + 0.96	+ 588	+ 584	+ 310	+ 404
2,4-D + bentazon	0.66 + 1.14	+ 708	+ 645	+ 420	+ 354
bromofenoxim	2.5	+ 988	+ 960	+ 927	+ 966
LSD 5% 365 kg; 1% 485 kg; 0.1% 626 kg					

Table 2

The influence of herbicides, depending of doses and time of application upon the yield of winter wheat at the Research Station Livada

Herbicides	dose kg ai /ha	I time of applic phase 23 kg/ha	II time of applic phase 27 kg/ha	III time of applic phase 33 kg/ha	IV time of applic phase 41 kg/ha
		Variety Dacia			
Control not treated	-	3677	3636	3457	3356
2,4-D	0.660	+ 279	- 153	+ 159	+ 174
2.4-D	1.320	+ 184	- 199	- 283	- 162
2,4-D + dicamba	0.57 + 0.07	+ 76	- 70	- 122	- 425
2,4-D + dicamba	1.14 + 0.14	+ 9	- 26	- 337	-1055
2.4-D + bentazon	0.49 + 0.96	+ 308	- 175	- 221	- 245
2.4-D + bentazon	0.66 + 1.44	+ 307	- 8	- 131	- 115
		Variety Ceres			
Control not treated	-	3633	3956	3626	3662
2,4-D	0.660	- 7	+ 495	+ 307	+ 86
2,4-D	1.320	- 263	- 59	+ 608	- 127
2,4-D + dicamba	0 57 + 0.07	- 437	- 110	- 11	- 407
2,4-D + dicamba	0.75 + 0.10	- 146	- 216	- 381	- 681
2,4-D + dicamba	1.14 + 0.14	- 41	- 389	- 393	- 900
2,4-D + bentazon	0.49 + 0.96	+ 173	- 187	+ 445	+ 109
2,4-D + bentazon	0.66 + 1.44	+ 148	- 233	+ 425	- 112
		Variety Montana			
Control not treated	-	3661	3682	3973	3568
2.4-D	0.660	+ 31	+ 129	- 337	+ 65
2.4-D	1.320	- 268	+ 193	- 747	+ 38
2,4-D + dicamba	0.57 + 0.07	+ 125	+ 137	- 38	- 92
2,4-D + dicamba	0.85 + 0.10	- 240	+ 153	- 338	+ 44
2,4-D + dicamba	1.14 + 0.14	- 85	+ 76	- 506	- 604
2,4-D + bentazon	0.49 + 0.96	+ 184	- 132	- 202	+ 207
2,4-D + bentazon	0.66 + 1.44	+ 299	+ 81	- 193	+ 87
		Variety Potaissa			
Control not treated	-	3840	4055	4036	3858
2,4-D	0.660	- 258	+ 63	- 233	- 203
2,4-D	1.320	- 463	- 166	- 11	- 125
2,4-D + dicamba	0.57 + 0.07	- 246	- 20	- 346	- 184
2,4-D + dicamba	0.85 + 0.10	- 135	0	- 608	- 240
2,4-D + dicamba	1.14 + 0.14	- 319	- 222	- 977	- 404
2,4-D + bentazon	0.49 + 0.96	- 121	- 284	+ 18	- 127
2,4-D + bentazon	0.66 + 1.44	- 63	- 320	- 365	- 299
		Variety Turda 195			
Control not treated	-	4064	3678	3699	3866
2,4-D	0.660	- 172	+ 573	- 64	- 187
2,4-D	1.320	- 606	- 253	+ 47	- 227
2,4-D + dicamba	0.57 + 0.07	+ 85	+ 307	- 353	- 659
2,4-D + dicamba	0.85 + 0.10	- 141	- 4	- 545	-3577
2,4-D + dicamba	1.14 + 0.14	- 314	- 358	- 495	-1141
2,4-D + bentazon	0.49 + 0.96	- 43	+ 62	- 115	- 206
2,4-D + bentazon	0.66 + 1.44	- 63	+ 5	- 375	- 45

Table 2 cont

		Variety Sava			
Control not treated		3519	3585	3641	3625
2,4-D	0.660	- 319	+ 178	- 352	- 520
2,4-D	1.320	- 455	+ 70	+ 166	- 458
2,4-D + dicamba	0.57 + 0.07	- 318	+ 27	- 735	- 985
2,4-D + dicamba	0.85 + 0.10	- 302	+ 250	- 727	-1382
2,4-D + dicamba	1.14 + 0.14	- 510	+ 134	- 994	-1395
2,4-D + bentazon	0.49 + 0.96	- 164	+ 174	+ 152	- 68
2,4-D + bentazon	0.66 + 1.44	- 27	- 94	+ 170	- 370
		Variety Libellula			
Control not treated	-	3280	3291	2896	3203
2,4-D	0.660	- 3	- 75	+ 561	- 234
2.4-D	1.320	- 447	- 273	+ 361	- 258
2,4-D + dicamba	0.57 + 0.07	- 164	+ 100	- 147	-2165
2,4-D + dicamba	0.85 + 0.10	+ 9	- 189	- 196	-1292
2,4-D + dicamba	1.14 + 0.14	- 195	- 237	- 487	-1323
2,4-D + bentazon	0.49 + 0.96	- 214	- 362	+ 336	- 244
2,4-D + bentazon	0.66 + 1.44	- 258	- 521	+ 573	- 371

LSD 5% 370 kg; 1% 530 kg; 0.1% 790 kg

Table 3

The influence of herbicides, depending on doses and time of application upon yield of winter wheat at the Research Station Caracal

Herbicides	dose kg ai /ha	I time of applic phase 23 kg/ha	II time of applic phase 27 kg/ha	III time of applic phase 33 kg/ha	IV time of applic phase 41 kg/ha
		Variety Ceres 1978-1980			
Control not treated	-	4540	4540	4540	4540
2,4-D	0.660	+ 40	+ 270	+ 130	- 120
2,4-D	1.320	- 90	+ 170	- 50	- 410
2,4-D + dicamba	0.57 + 0.07	+ 30	+ 110	- 160	- 320
2,4-D + dicamba	0.85 + 0.10	- 80	+ 110	- 290	- 590
2,4-D + dicamba	1.14 + 0.14	- 250	- 140	- 510	- 830
2,4-D + bentazon	0.49 + 0.96	+ 170	- 40	- 190	- 310
2,4-D + bentazon	0.66 + 1.44	- 70	- 150	- 250	- 320
		Variety Dacia			
Control not treated	-	4310	4310	4310	4310
2,4-D	0.660	0	+ 90	- 130	- 190
2,4-D	1.320	- 130	- 70	- 260	- 310
2.4-D + dicamba	0.57 + 0.07	+ 170	- 100	- 180	- 190
2,4-D + dicamba	0.85 + 0.10	+ 80	+ 30	- 160	- 420
2,4-D + dicamba	1.14 + 0.14	+ 80	- 210	- 380	- 70
2,4-D + bentazon	0.49 + 0.96	+ 190	+ 100	- 130	- 110
2,4-D + bentazon	0.66 + 1.44	+ 50	- 10	- 120	- 100

THE PLANT BREEDER'S REACTIONS TO HERBICIDE TOLERANCE IN CEREALS

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Summary It is the responsibility of the breeder to produce varieties which yield reliably over a range of environments. Simple tests show clear cut varietal differences in tolerance of some herbicides but significant yield losses may occur without clearly visible symptoms. The breeder should warn growers if his varieties are susceptible to damage by agrochemicals, but it is the responsibility of the manufacturer to issue appropriate warnings when a new product is sold.

Resumé C'est la responsabilité du sélectionneur de produire les variétés avec rendement sûr dans une gamme d'environs. Les essais simples montrent les différences claires en tolérance de quelques herbicides, mais défauts significants de rendement peuvent se trouver sans symptômes évidemment visibles. Il faut que le sélectionneur mette les cultivateurs en garde si ces variétés sont sensibles à dégât par les produits agrochèmiques, mais c'est la responsabilité du fabricant de donner les avis propres quand un produit nouveau est vendu.

INTRODUCTION

It is the plant breeder's responsibility to produce new varieties of cereals combining high yield with acceptable grain quality. He must also ensure that his varieties will yield consistently over a range of seasons and environments, and in particular, that they show adequate resistance to the disease, pests, or other hazards to which they may be exposed. The status of agrochemicals such as herbicides in this category is a matter of some debate, for although some may claim that it is the duty of the breeder to produce varieties which are tolerant of the agrochemicals to which they may be exposed, it may equally well be claimed that it is the duty of the chemist to produce products which have no harmful effects on the crops to which they are applied.

In effect, the responsibility is shared between the breeder and the chemist. It is clearly the responsibility of the chemist to ensure that any new chemical he may produce may be safely applied to varieties in cultivation, and if there is any suspicion of varietal susceptibility, to ensure that appropriate warnings are given when his product is sold. At the same time, it is the responsibility of the breeder to test the reactions of his varieties to agrochemicals in common use and to warn users of any potential hazards.

The use of selective herbicides on growing crops has always involved some risk of crop damage, particularly when hormonal weed killers are applied at an inappropriate stage of crop development. But varietal differences in herbicide tolerance have only become important with the rapid spread of grass weeds in cereal crops. Varietal difference in tolerance of barban were reported by Pfeiffer *et al*. (1960) but the problem became more serious when it was found that some widely grown winter wheat varieties were subject to severe damage when exposed to concentrations of the substituted urea herbicides chlortoluron and metoxuron needed for the control of wild oats or black grass (Griffiths and Ummel (1970), van Hiele *et al*. (1970), Smith and Tyson

(1970)). Breeders therefore set up two simple screens to test for varietal differences and to determine the reactions of selections at an early stage in the breeding programme. The former tests used the now familiar technique of sowing long narrow rows of the varieties to be tested, and applying the herbicides at one or more concentrations to short bands at right angles to the drills. Owing to the shortage of seed in the early stages of a breeding programme, the latter tests were normally done on short rows each derived from a single plant of the cross concerned. Half of each row was sprayed with herbicide, normally applied at three times the agriculturally recommended rate, the other half acting as a control. These tests demonstrated very clear varietal differences and a clear cut segregation for tolerance of chlortoluron and metoxuron in crosses between susceptible and tolerant varieties, showing that tolerance of these herbicides was determined by either one or two major genes depending on the cross examined and the climatic conditions immediately after spraying (Lupton and Oliver, 1976).

The relatively simple genetic control of herbicide tolerance and the possibility of testing in early generations showed that selection for tolerance could be introduced as a major selection criterion in a breeding programme. But breeders were naturally unwilling to add yet another character to those for which they had to select, because they realised that to do so would reduce the time and effort available for selection for other characters, and would therefore tend to reduce the efficiency of their overall programmes. While considering what action they should take, this problem was largely solved by the introduction of isoproturon, which appeared to be as effective as chlortoluron and metoxuron in controlling the graminaceous weeds, but much less damaging to the wheat varieties which were susceptible to damage by these chemicals, though there were indications that the safe rate of application to tolerant varieties was more critical (Tottman et al., 1975).

Since this time, several new selective herbicides capable of controlling grass weeds in cereal crops have become available, though some of these may cause severe damage to certain varieties. The breeders have therefore extended their routine testing of new varieties to include application of these chemicals, preferably alone, but if necessary in mixtures, so that they can make recommendations for herbicide application to their varieties. During the last two years, for example, we have tested all our most advanced winter wheat selections for tolerance of barban, benzoylpropethyl, chlortoluron, diclofop-methyl, difenzoquat, flamprop-methyl and isoproturon, all applied at three times the manufacturer's recommended dose. We have found differences in tolerance of chlortoluron, isoproturon, diclofopmethyl and barban (Table 1). Differences in tolerance of benzoylpropethyl and difenzoquat have been recorded in the past but were not evident in these two years. Only flamprop-methyl has proved equally safe on all varieties. Because of the wide range of chemicals available, it is usually possible to find a herbicide suitable for controlling graminaceous weeds in any given circumstances, but by the same token, it has become extremely difficult for the breeder to select his varieties for tolerance to all the wide range of chemicals to which they may be exposed. The responsibility for developing effective formulations which can be safely applied must now rest firmly with the agrochemical manufacturer.

Yield losses in apparently tolerant varieties

It is well known that serious yield losses may be caused by the application of herbicides at high dose rates or at times other than those recommended by the manufacturer. But the control of graminaceous weeds in cereal crops, that is of one grass growing in another, involves a very delicate biological balance which may easily be upset, though the level of yield loss caused may be low and impossible to detect visually. Breeders may however spend many years in producing a new variety which yields five or ten per cent more than those previously cultivated and are unwilling to see their gains lost by an ill advised application of agrochemicals. When applied to severely weed infested crops, farmers may be pleased to accept some loss in potential yield in order to avoid other losses due to weed competition, but such losses may not be acceptable when herbicides are applied for prophylactic reasons, or in order to prevent a low population of weed plants from setting seed.

Little data is available on varietal differences in yield losses due to herbicides applied under conditions approaching those recommended by the manufacturer. A series of such trials has therefore been grown jointly by the Weed Research Organisation and the Plant Breeding Institute (Tottman et al., 1981). In these trials, which are grown under weed free conditions, herbicides are usually applied at double the manufacturer's recommended rate, as it is considered likely that damage caused by such applications would reflect those likely to occur in normal commercial practice when weather conditions and plant stress render the crop unusually sensitive. In one such trial, in which a range of varieties was treated with isoproturon, flamprop-methyl, diclofop-methyl and difenzoquat (Table 2), it was found that the yields of most varieties were significantly reduced by most treatments. In contrast, the visual screening tests had shown no varietal differences in tolerance of flamprop-methyl and difenzoquat and other treatments, such as that of Mardler by isoproturon and of Hobbit, Huntsman and Hustler by diclofop-methyl had shown little sign of visual damage. It is hoped that future tests will include a more extensive series of trials, grown under the auspices of ADAS, to test a smaller range of varieties over a wider range of environments.

It would be impracticable for these trials to test all combinations of variety and herbicide. Even if they did attempt this, the environmental and climatic variation between sites and seasons could not be adequately sampled. It is hoped, however, that the trials will draw the attention of farmers and agrochemical manufacturers to the possibility that significant yield losses may occur even when no crop damage is apparent. Such evidence will, perhaps, limit the present somewhat indiscriminate use of herbicides by some farmers, and may encourage manufacturers to carry out more extensive trials to demonstrate the best use of their products.

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Table 1

Responses of wheat varieties to herbicides 1979 and 1980

Visual scores on small plots receiving three times the manufacturer's recommended rate (high score indicates severe damage)

	Chlortoluron	Isoproturon	Diclofop-methyl	Barban
Avalon	2	3	2	5
Bounty	3	4	1	5
Brigand	7	4	2	5
Galahad	7	5	1	3
Hobbit	8	5	2	5
Huntsman	7	5	2	5
Hustler	7	5	1	4
Mardler	3	3	4	5

Table 2

Yields of wheat varieties sprayed with grass weed herbicides

at twice the manufacturer's recommended rates, 1979

	Control yield t/ha	% Control yield			
		Iso-proturon	Flamprop-methyl	Diclofop-methyl	Difenzo-quat
Hobbit	7.5	60	89	66	62
Huntsman	7.6	70	92	81	83
Hustler	7.0	80	97	92	94
Mardler	6.8	70	91	89	89

LSD (P = 0.05) 10%

THE INCIDENCE OF WEEDS IN GRASSLAND

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Summary The incidence of weeds on 502 grassland farms in England and Wales is presented and discussed with reference to other surveys in the U.K. Farmers thought Cirsium spp. and Rumex spp. were by far the most important weeds. Field inspection showed that infestations of broad-leaved weeds affected 23% of fields, mainly older swards with low fertility. There were serious infestations of Cirsium arvense in 8% of swards; the problem was worst in grazed swards on beef/sheep farms, where fertility was low. Serious infestations of Rumex obtusifolius or R. crispus were found in 4% of swards; intensive dairy farms were worst affected, the problem being associated with high levels of N and P. Ranunculus spp. were prominent on 5% of swards, but only 1% were seriously affected by Senecio jacobea. Juncus spp. were present in 12% of swards. It is suggested that Agropyron repens, Holcus mollis, Bromus mollis, Hordeum murinum and Deschampsia caespitosa are the most undesirable graminaceous weeds; 3% of swards were infested by one or other of these species.

Resumé L'incidence des mauvaises herbes dans 502 fermes à production herbagère en Angleterre et au Pays de Galles est présentée et discutée en faisant référence à d'autres études dans le Royaume Uni. Les infestations des espèces dicotylédones des mauvaises herbes ont affecté 23% des prairies, particulièrement les prairies permanentes qui avaient une fertilité médiocre. Les agriculteurs pensaient que les deux espèces, Cirsium et Rumex, étaient de loin les mauvaises herbes les plus importantes. On a trouvé des infestations sérieuses de Cirsium arvense dans 8% des prairies; le problème était le plus grave dans les pâturages des fermes à production ovine et bovine, où la fertilité du sol était médiocre. Des infestations sérieuses de Rumex obtusifolius et Rumex crispus ont été trouvées dans 4% des prairies; les fermes laitières à production intensive étaient les plus affectées. Le problème étant associé avec les niveaux d'azote et de phosphate élevés. Les espèces Ranunculus étaient prédominantes dans 5% des prairies, mais seulement 1% étaient sérieusement affectées par Senecio jacobea. Les espèces Juncus étaient présentes dans 12% des prairies. Nous pensons que Agropyron repens, Holcus mollis, Bromus mollis, Hordeum murinum et Deschampsia cespitosa sont les graminées adventices les plus indésirables; 3% des prairies étaient envahies par une ou l'autre de ces espèces.

INTRODUCTION

Of the many agricultural crops considered at this conference, grassland is arguably the most complex. How many other authors, before preparing their contributions, had first to question the very concept of the designation of certain plant species as weeds? The question of whether the botanical composition of grassland is of any significance in terms of its output has been for many years a topic of heated debate among grassland workers, and is outside the scope of this paper (see Charles and Haggar, 1979). Contributors to this conference in previous years, e.g. Baker (1962), have tended to regard any constituents of grassland that were not originally sown as weeds, but we have decided to restrict consideration primarily to those broad-leaved and grass species which most farmers actively discourage. This may be because they believe an economic response to treatment can be expected, or simply because they do not find the species attractive. A more complete description of the botanical composition of grassland, including the distribution of the major indigenous grass species, can be found in Forbes et al (1980) and Hopkins (1979).

The existing literature on distribution of weeds in British grassland is limited Reports from Northern Ireland (Courtney, 1973) and Scotland (Swift, 1978 and pers. comm.) on levels of contamination by docks (Rumex crispus/R. obtusifolius) and creeping thistle (Cirsium arvense) have been compared with our own results. Comparison has also been made with the postal survey of docks in grassland described by Haggar (1980). Previous surveys from the Grassland Research Institute have also been consulted, e.g. Morrison and Idle (1972).

METHODS

The results presented here were collected as part of a National Farm Study, carried out jointly by the Grassland Research Institute and the Agricultural Development and Advisory Service. The main aim of the study was to measure the utilized output of permanent grassland and to consider factors affecting its productivity. It was decided to study farms on which grass was the major crop, and the selection was made from farms with at least 50% of their area recorded as permanent grass in the June census. The sample of farms selected for study could not be strictly random as the cooperation of the farmer was required, but comparison of output, stocking rate, fertilizer use and milk yields with national statistics, and samples described by other organizations shows that these farms are quite typical of grassland in England and Wales as a whole. Comparison with agricultural census data showed that this sample differed from the national average in having a smaller proportion of grass described by the occupier as temporary (7%, compared with 22%). However the proportion of grass aged 1-4 years was 17.5% - quite similar to the 21% recorded latterly in the census as being in this age category. Much of the young grass in this sample was, in fact, intended as long-term grassland.

A total of 502 farms was selected, of which 209 were dairy farms, and 293 were beef farms of which approximately half had suckler herds. Each farm was visited by surveyors from the GRI and on average one day was devoted to each farm. The survey commenced in April 1974 and was completed in October 1977. Every grass field was inspected by the survey team, giving a total of 8100 fields, covering 28,000 ha.

The farmer was asked about the age and intended duration of the grass in each field. He (or she) was also asked 'What weed problems do you have in your grassland?' This was to some extent a leading question, although if the initial reaction was that there were weeds but they did not represent a serious problem then no problem was recorded.

The survey team made an estimate of the botanical composition of each sward. Broad-leaved weeds (i.e. any dicotyledonous species other than cultivated legumes) were assessed collectively on the basis of their percentage contribution to the sward. Additionally infestations of docks, thistles and buttercups were recorded, based on arbitrarily defined levels agreed jointly by ourselves and the Weed Research Organisation. The criteria used were (i) the weed should be well distributed across the field, and (ii) there should be more than one plant per 16 m^2 in the case of thistles and docks, or the plant should comprise more than 5% of the sward in the case of buttercups. Incipient infestations, where the weed was sparser or localised but nevertheless was a potential problem, were also recorded. Occasional plants or small patches were ignored. This was purely a visual estimation, and no quadrats were thrown or other measurements made. However, decisions on infestations were seldom problematical since if the weed was distributed across the whole field it invariably exceeded the required density by a considerable margin.

Details of soil type and physical features were also recorded in all fields. Soil chemical analyses were carried out on 2850 fields chosen to represent the grassland areas on individual farms.

RESULTS

a) Perception of weeds by farmers

In answer to the question on weeds, 88% of the farmers mentioned at least one species. The proportion of farmers mentioning each respective weed is shown in Table 1.

Table 1

Relative importance of weeds in grassland, as perceived by farmers

Weed species	Proportion of farmers mentioning it as a problem (%)
Thistles (chiefly *Cirsium arvense*)	50
Docks (*Rumex spp.*)	40
Nettles (*Urtica dioica*)	17
Buttercups (*Ranunculus* spp.)	10
Grass weeds (*Gramineae*)	9
Rushes (*Juncus* spp.)	6
Chickweed (chiefly *Stellaria media*)	5
Ragwort (*Senecio jacobaea*)	4
Redshank/Fat Hen (*Polygonum persicaria*/ *Chenopodium album*)	2
Bracken (*Pteridium aquilinum*)	1
Others (chiefly *Taraxacum officinale*)	5

Thistles and docks were by far the most frequently cited weeds. There were some differences between dairy and beef farms in this respect. Thistles were mentioned by more beef farmers (59%) than dairy farmers (37%), whereas docks were more commonly cited by dairy farmers (54%) than beef farmers (30%). Other broad-leaved weeds were not widely quoted as problems. Grass species, such as soft brome (*Bromus mollis*), couch (*Agropyron repens*) and annual meadow grass (*Poa annua*) were mentioned as weeds by only 9% of farmers.

In a randomly selected sample, with rather more young grass, slightly more problems with annual weeds and weeds of arable rotation would be expected.

b) Broad-leaved weeds

Broad-leaved species collectively

Broad-leaved weeds made a minor contribution (2%-5% of cover) in 64% of the swards and were present at between 5 and 15% of cover in 18% of swards. A further 5% of swards had more serious infestations.

Table 2

Swards classified by total broad-leaved weed content: percentage of swards in each class, within each age category

	Broad-leaved weed ground cover			
	Absent or < 2%	2-5%	5-15%	> 15%
Sward age (years)				
1-8	22	63	12	3
9-20	13	68	15	4
> 20	7	63	23	7

Broad-leaved weeds were more frequent in the older swards (Table 2). In grassland less than 20 years old there was a higher incidence of weeds in swards on suckler beef farms than on either the non-suckler beef or dairy farms.

Soil factors were also related to incidence of broad-leaved weeds with a higher incidence where drainage was impeded or where there was a low soil P or K index. This was most pronounced in the older grassland (Table 3). Soil pH was not related to the overall incidence of broad-leaved species.

Table 3

Broad-leaved weeds in relation to soil P and K status: percentage of swards within each soil P and K index with > 5% cover of weeds

a) Swards of all ages

Index	0	1	2	≥3
P	28	23	20	20
K	29	23	21	17

b) Swards over 20 years old

Index	0	1	2	≥3
P	35	31	25	23
K	38	29	25	20

Specified weeds

Infestations, and incipient infestations, of the major broad-leaved weeds are summarised in Table 4.

Table 4

Percentage of swards with infestations of dock, creeping thistle and buttercup within sward age groups and farm types. Incipient infestations are listed in parentheses

Weed	Age of sward	Dairy farms	Non-suckler beef farms	Suckler beef farms
Dock (*Rumex crispus*, *R. obtusifolius*)				
	1-4 years	9 (11)	5 (10)	4 (12)
	5-8 years	10 (17)	6 (11)	4 (13)
	9-20 years	6 (17)	5 (8)	6 (11)
	Over 20 years	3 (7)	1 (5)	2 (5)
	All ages	6 (11)	3 (7)	3 (9)
Creeping thistle (*Cirsium arvense*)				
	1-4 years	2 (6)	3 (10)	5 (7)
	5-8 years	1 (7)	6 (8)	9 (13)
	9-20 years	3 (9)	10 (17)	10 (18)
	Over 20 years	7 (17)	15 (16)	10 (17)
	All ages	5 (11)	11 (14)	9 (15)
Buttercup (*Ranunculus* spp.)				
	1-4 years	1 (8)	3 (5)	3 (6)
	5-8 years	4 (9)	3 (10)	3 (10)
	9-20 years	4 (8)	2 (12)	5 (10)
	Over 20 years	9 (17)	7 (15)	6 (14)
	All ages	6 (12)	5 (12)	5 (11)

Docks (*Rumex crispus* L. and *Rumex obtusifolius* L.). Both of the major species of dock are widely distributed throughout the British Isles and in many other parts of the world (Cavers and Harper, 1964). In the National Farm Study serious infestations of dock were recorded, mainly in younger swards, on 6% of the fields on dairy farms and in 3% of the fields on beef farms. Sparser or localised (incipient) infestations affected a further 9% of fields (Table 4). These figures are comparable to the results of a recent survey of grassland in the east of Scotland where "heavy infestations" of dock were recorded in 5% of the grassland (Swift, pers. comm.), and with a survey in Northern Ireland in 1969 where docks were listed as "a problem" in 11% of the grassland surveyed (Courtney, 1973).

In a pilot survey of grassland in three areas of south-east England infestations of dock were recorded on 8% of the grassland (Morrison and Idle, 1972). An identical level of dock infestation was recorded in a national sample survey of 1300 farms in England and Wales in 1970-72 (J O Green, pers. comm.). Considerably higher levels of dock infestation were recorded from a postal survey in 1972 of 322 farms in ten grassland districts in the United Kingdom (Haggar, 1980), but this survey was based on assessments by each individual farmer which may have been rather variable. Being organised by local grassland societies there may have been a bias towards dairy farmers, who tend to have more problems with docks. Also, as in any postal survey, the response may have been biased towards those farmers with a particular interest or experience in the subject.

Docks are commonly held to be associated with intensive management including cutting for silage and the application of slurry, farmyard manure and fertilizer N (Haggar, 1980). On some 5% of farms in the National Farm Study docks were a serious problem affecting over 40% of the grassland area. Most of these dock-infested farms were in the dairy category, and silage was made on 85% of them. The average input of fertilizer N, at 150 kg/ha, was also relatively high.

Docks are reported to show a wide degree of tolerance to soil conditions, with Rumex crispus being found on nearly all soils except the most acid, and Rumex obtusifolius on a wide range of soils particularly those rich in soluble P (Cavers and Harper, 1964). In the National Farm Study the incidence of dock infestation was highest on swards with a soil P index of 2 or above. This relationship was most marked on swards over ten years old. Conversely, the relationship between dock and soil K index indicated that docks were associated with a lower soil K status (Table 5). This relationship applied to younger swards as well as on older grassland. There was no evidence that the incidence of docks varied with soil pH.

Table 5

Percentage of swards (all ages) with dock infestations within each soil P and soil K index

Index	0	1	2	≥3
P	1	3	4	5
K	9	5	3	2

Creeping thistle (Cirsium arvense L.). Several species of thistle occur in grassland but the perennial creeping thistle is the most widespread and difficult to control. In the National Farm Study infestations of creeping thistle followed a converse distribution to that of docks, being more common in ageing and old swards, and more frequent on beef farms (10% of fields) than on dairy farms (5% of fields) (Table 4).

In the 1970-72 survey Cirsium spp. were recorded as infestations in 22% of the grassland (J O Green, pers. comm.). Similar levels of infestation (25%) were reported from an earlier pilot survey (Morrison and Idle, 1972). In eastern Scotland thistles were found to be the main broad-leaved weed on grassland with as many as 50% of the swards over 10 years old having "heavy infestations" of C. arvense or C. vulgare (Swift, 1978). In Northern Ireland in 1969, C. arvense was recorded as being "a problem" on 20% of grassland surveyed (Courtney, 1973). Differences between these surveys point to some variation which may be attributed to regional differences, operator bias or between-year differences. However, the results of all surveys emphasise that creeping thistle is very widespread in grassland.

The data collected for the National Farm Study have been used to relate incidence of creeping thistle infestation to soil factors. Infestations were more frequent where soil P indices of 0 and 1 were recorded than at higher levels of available P. Conversely, the species was more frequent on the sites with higher levels of soil K. These relationships were more pronounced in the older swards (Table 6), and on swards 9-20 years old, than on the swards less than eight years old. There was no apparent relationship between creeping thistle incidence and soil pH, but the species was more frequent on soils with satisfactory drainage than where drainage was impeded.

Table 6

Percentage of swards with creeping thistle infestation within each soil P and soil K index

a) Swards of all ages

Index	0	1	2	≥3
P	16	10	7	7
K	6	7	9	12

b) Swards aged over 20 years

Index	0	1	2	≥3
P	19	12	8	10
K	9	10	11	13

In the National Farm Study approximately 6% of farms had widespread incidences of creeping thistle which affected over 40% of their grassland. This group of thistle-infested farms were mainly beef farms using below average levels of fertilizer N (mean of 37 kg/ha). Many were in the upland areas with large sheep enterprises; on average one-third of the total metabolisable energy requirements of the livestock on this group of farms was attributed to sheep.

Buttercups (*Ranunculus* spp.). Three species of buttercup are common in British grassland: *Ranunculus acris* L. (meadow buttercup), *R. repens* L.(creeping buttercup) and *R. bulbosus* L. (bulbous buttercup). In the National Farm Study, and in most other grassland surveys, their incidence has been recorded collectively.

The ecology of these species of buttercup has been described by Harper (1957) and Harper and Sagar (1953). *R. repens* is reported to be the species most closely associated with poor drainage and most capable of withstanding competition from tall grasses as in a growing hay crop. *R. bulbosus* on the other hand is favoured by well-drained soils, especially continuously grazed old pastures. *R. acris* occupies an intermediate position in terms of drainage, but like *R. bulbosus* it is avoided by stock and therefore able to compete under grazing.

In the National Farm Study approximately 5% of all swards had heavy infestations of buttercup, with lesser infestations in a further 11% (Table 4). They were more frequent in the older lowland swards especially where the drainage was impeded. One-quarter of the old swards (over 20 years) had greater or lesser infestations, and of the old swards on sites with poor or bad drainage one-third were so affected.

Other surveys have reported even higher levels of buttercup infestation. In the pilot survey in south-east England 35% of the grassland surveyed, including over 50% of the older grassland, was affected by buttercups (Morrison and Idle, 1972). In the 1970-72 national sample survey some 14% of the grassland was infested by buttercup (J O Green, pers. comm.). In a survey of livestock farms in eastern Scotland one-quarter of all swards contained "heavy infestations" of buttercups (Swift, pers. comm.).

Rushes (*Juncus* spp.). *Juncus effusus* L. is the most common rush species in agricultural grassland in Britain and is a weed which affects much wet land especially in upland areas. Its unpalatability, and consequent competitiveness under grazing, together with the long viability of its seed, can make it a particularly persistent weed (Lazenby, 1955).

In the National Farm Study, rush contributions of up to 5% of ground cover were recorded on 9% of swards and more serious infestations affected an additional 3% of swards. The incidence of rushes was highest in the older grassland, where 20% of swards were affected to some extent, and also highest on suckler beef farms. Approximately 30% of the old swards on suckler farms contained rushes, a third of these being serious infestations. The majority of badly drained swards on beef farms, and many imperfectly drained sites with wet patches, were affected by rushes. But there were many instances, especially on dairy farms, where similar drainage conditions were not associated with rushes; such swards were often subject to more intensive management.

Ragwort (*Senecio* spp., usually *Senecio jacobaea* L.). Ragwort is an occasional weed of grassland and is of particular interest on account of its toxic properties. Infestations are frequently observed in horse pastures. In the National Farm Study, ragwort was recorded as a problem in only 1% of fields. Most of these fields were concentrated on a few farms (mainly dairy) on sandy or light textured soils.

Stinging nettle (*Urtica dioica* L.). Field inspection showed that although some fields, and particularly those in high fertility situations near buildings, contained occasional clumps of nettles, they were very seldom distributed across whole fields. Despite its tall-growing habit and conspicuous appearance the species is generally of minor importance as a weed of grassland.

c) Grasses

'Undesirable' grasses

We have regarded the following five grasses as undesirable species and potential candidates for active control measures by farmers:-

(i) Couch (*Agropyron repens* (L.) Beauv.)
(ii) Creeping soft grass (*Holcus mollis* L.)
(iii) Soft Brome (*Bromus mollis* L.)
(iv) Barley Grasses (*Hordeum murinum* L. and *H. secalinum* Schreb.)
(v) Tussock-grass (*Deschampsia caespitosa* (L.) Beauv.)

A. repens and *H. mollis* are strongly rhizomatous and are serious weeds in an arable situation, and hence in leys in arable rotation, although as components of a mixed sward they can be regarded as reasonably acceptable species since they are not usually rejected by livestock. *Agrostis gigantea* is also a rhizomatous species but because of the difficulties of distinction from other species of *Agrostis* it was not recorded separately in this survey. *B. mollis* and the *Hordeum* species are grasses with large and prominent seed heads. In the case of *Hordeum* these have been reported as causing serious irritation to the eyes, mouth and body of sheep in New Zealand (Hartley, 1976). In the case of *Bromus* the seed heads are unpalatable to livestock under grazing and in hay. The grass is also low in digestibility and protein content (ADAS, 1980). *D. caespitosa* is a densely tufted grass with very coarse leaves. It is unpalatable and can form large clumps which create difficulties in using field machinery.

A contribution to vegetation cover of more than 10% by any one of these grasses was regarded as an infestation. A total of 3.2% of the grassland surveyed was so affected. The relative importance of each grass is shown in Table 7.

Table 7

Proportion of fields with 'undesirable' grass infestations

	Fields affected (%)
Bromus mollis	1.2
Agropyron repens	1.1
Deschampsia caespitosa	0.8
Holcus mollis	0.2
Hordeum murinum and H. secalinum	0.1

Bromus mollis thrives in hay fields where it has the chance to shed seeds before being cut. It was found to be rather more prevalent on beef farms than dairy farms, probably because haymaking is the more common method of conservation on beef farms. Fields with infestations were found in all regions of England and Wales, but were more frequent in East Anglia than elsewhere, over 3% of fields in that area being affected.

Hordeum secalinum, a perennial, is commonly a minor constituent of old pastures, but is rarely found in any quantity. Hordeum murinum is an annual grass which is common on waste ground and roadsides, but is not usually found in grassland in the UK, although it is much more common in New Zealand (Hartley, 1976). It was absent from the great majority of fields in this survey. The few fields found with infestations were in the Eastern region on dry sandy soil and had probably become abundant by seeding on swards thinned by drought.

Agropyron repens is recognised as a weed associated with arable farming (Hubbard, 1968). It was indeed found to be much more common in eastern England than elsewhere; 10% of fields in MAFF Eastern region were infested with it, compared with no infestations at all in Wales. It was found more often on dairy farms than on beef farms; this could be due to higher nitrogen applications which tend to favour the grass. But it was not confined to younger swards (see Table 8).

Table 8

Infestations of Agropyron repens on swards of different ages

Age of sward (years)	1-4	5-8	9-20	>20
Percentage of fields with infestation	1.1	1.8	1.3	0.8

Infestations were almost as common on swards over 20 years old as on recently sown swards, and were most prevalent on those of intermediate age. Other evidence (Smith, 1979; Courtney, 1980) has shown that the proportion of A. repens in swards can increase with age under conditions of cutting and high N. It may be that the high incidence of couch infestations in the east is due as much to climatic favourability i.e. dry summers, cold winters, as to a history of arable cultivation and high N applications. The grass is very common in the Netherlands, where the climate is similar to East Anglia.

Holcus mollis was found in quantity on only a very small number of fields, almost all of which carried swards over 20 years old. The most severe infestations were found on a farm in the South West region with very dry sandy soil which had been managed very extensively, but infested fields were also found a farm in the same region with badly drained clay soils.

Infestations of Deschampsia caespitosa were confined very largely to old swards on heavy soils with impeded drainage. The grass was most frequently abundant in the south-east of England, on low-lying river valley land; almost 3% of fields on farms studied in MAFF South East region had infestations. It was also common in the Pennine areas of Yorkshire and Lancashire. Despite the high rainfall conditions infestations were much less frequent in Wales, where impermeable soils with high groundwater were not common; only 0.2% of fields in Wales were affected.

Other indigenous grass species

As well as the grass species mentioned above, which are widely held to be undesirable, there are many other species found in grassland which few farmers today would consider sowing. The most common of these species are, in order of abundance, *Agrostis* spp. (chiefly *A. tenuis* Sibth. and *A. stolonifera* L.), *Holcus lanatus* L., *Poa trivialis* L., *Festuca rubra* L. and *Poa annua* L. Together these species cover almost half of the grassland of England and Wales. Although they have slightly lower yields than *Lolium perenne* and other sown species under most conditions (Dibb and Haggar 1979), and may be slightly lower in quality and palatability, the differences are not great and the species have no noxious characteristics. Thus very few farmers actively discourage these grasses in established swards, though reseeding may be carried out partly because of their ingress. Changes in management such as increased fertilizer use and heavier stocking generally have the effect of encouraging *L. perenne* at the expense of these species, but this is largely incidental to the main aim of increasing production. Spraying with a low dose of dalapon is one of the few techniques available for the control of the major indigenous species in established grassland (Haggar and Oswald 1979) but it is not widely used. There has, though, been increased interest recently in the control of *Poa annua*, particularly in newly sown swards, by the use of ethofumesate. The following comments on this species are therefore included.

Annual meadow-grass, *Poa annua*, was found in small quantities in a high proportion of fields, particularly on disturbed ground around gateways and drinking troughs. If confined to these small areas, its presence was ignored in this survey. Its frequency as part of the main body of fields of different ages is shown in Table 9.

Table 9

Percentage of swards with different proportions of *Poa annua*

	% contribution to cover					
	0	2-5	5-15	15-25	25-35	>35
Sward age (years)						
1-4	38	35	17	7	2	<1
5-8	46	36	11	5	2	0
9-20	57	26	11	4	2	0
>20	70	22	6	2	<1	0

P. annua was present in quantities of more than 15% in only 2% of old swards, and in 7% of swards less than 20 years old. In many of the swards with large proportions of the grass it was apparent that the sward had been damaged by poaching. In addition, *P. annua* was prominent in young swards where establishment had been poor, and in swards in their third or fourth year where Italian ryegrass was dying out.

We did observe an increase in the number of fields with quantities of *P. annua* following the 1976 drought.

d) Control measures taken by farmers

Each farmer was asked what weed control measures, if any, he took. The results are given in Table 10.

Table 10

Proportion of farmers taking weed control measures (%)

Spraying	36
Cutting (chiefly for thistles)	15
Spraying and cutting	15
Action of some kind	66

Although two-thirds of farmers said that they took action against weeds it is likely that in many cases this would not be a regular weed control programme. Often the farmer would only expect to spray once every few years, and then only on the worst affected areas. Cutting thistles seemed to be carried out on a more regular basis by many farmers.

DISCUSSION AND CONCLUSIONS

As we indicated at the outset, it is not possible to quantify with any precision the extent to which weeds are a problem in British grassland. Grass is grown to provide feed for livestock, and almost all grassland species are consumed by stock to a greater or lesser extent, either grazed in situ or in the form of hay or silage. The extent to which species are avoided by livestock can depend to a considerable degree on management. For example, plants which are completely rejected at a low stocking rate may be consumed when grazing intensity is increased. Thus even if the yield of digestible dry matter, under field conditions, of the various grassland species was known, it would not be possible to predict the effect of varying proportions of species on animal production.

However, for the purposes of this paper we have taken a pragmatic viewpoint of weed status and levels of infestation which we hope is relevant to those concerned with the practicalities of grassland farming. There is broad agreement that most of the species we have considered here are undesirable, and that their presence should be minimized. Erect, conspicuous weeds are more likely to receive attention than less obvious ones; we acknowledge that this is an aesthetic rather than an economic consideration.

We have avoided consideration of species confined largely to the hills and uplands. The national farm study sample did cover a considerable area of such land, but unenclosed rough grazings were deliberately excluded and therefore the sample cannot be taken to represent the situation in hill areas as well as the lowlands.

In the opinion of the farmers participating in this study, thistles are the most important weed of grassland. Their prevalence was borne out by the actual inspection of fields; 8% had infestations and a further 13% had incipient infestations. The thistle problem was worst on grazed fields where, because of their unpalatability, they were able to develop into mature plants; grazing by sheep, as opposed to cattle, appeared to favour thistles, possibly because of greater selectivity and the lesser effect of treading. Fields of low fertility, at least in terms of N and P, were most affected.

Docks were regarded as almost as big a problem as thistles, in fact more so on dairy farms. Field survey showed them to be on average less frequent than thistles, 4% of fields having infestations and a further 9% with a potential problem. Docks, which appear to be reasonably palatable to stock, are more common in conservation fields where they are allowed a period of growth without defoliation. The apparent correlation between low K status and docks could be due largely to the fact that conservation fields tend to have lower K levels than grazing fields. Unlike many broad-leaved weeds docks can compete well with grasses under high levels of N and P.

Buttercups, though mentioned by relatively few farmers, were found to be as common and widespread as docks, being concentrated on older swards in wetter situations. The much higher levels recorded by Morrison and Idle (1972) and Green (pers. comm.) may indicate that the weed is declining in importance, but is still of considerable significance.

Of the grass species we suggest that Bromus mollis is the one most likely to be of concern to farmers in established grassland, and some interest is being shown in the possibility of chemical control. Agropyron repens attracts attention mainly under a ley-farming system; attempts to control it in long-term swards seem unlikely at present. Grass weeds in general are not regarded as problems by farmers, and those species widely accepted as undesirable are only important in 3% of swards.

Although this sample of farms was not intended to represent grassland in England and Wales as a whole we contend that it can be used, given some adjustment for the lower proportion of short-term swards, to give an approximation of the area of land affected by the major weed species. We are also confident that our definition of infestation, at least of the main weed species, concurs reasonably well with the view of the average farmer, and can be taken to represent the level at which some action might be taken. There are 4.1 million hectares of grass over 4 years old and 1.2 million hectares of younger grass in England and Wales. On the basis of this survey there are serious infestations of thistles on 350,000 ha of the older grass and on 50,000 ha of younger grass, making a total of 400,000 ha. Inclusion of the fields with incipient infestations would raise the figure to over 1 million ha. Estimating similarly for docks 140,000 ha of older grass and 70,000 ha of young grass are similarly affected, giving a total of over 200,000 ha. Inclusion of the fields with lesser problems gives a value of over ½ million ha. Similar calculations could be made for the other weeds considered in this paper, although the likelihood of error would be somewhat greater for the less frequent species.

It would be a mistake to assume from these figures that the productivity of large areas of our grassland could be dramatically increased by the removal of weeds. Experimental evidence on this subject is limited, but it is likely that considerably higher levels than the ones we chose would be required before a substantial drop in productivity occurred. But the data can be used as an indication of the relative importance of each species and the areas of grassland that might potentially be subject to weed control measures.

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HERBICIDE USAGE ON POTATOES IN GREAT BRITAIN IN 1980

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Summary The 1980 survey of crop production techniques and costs differs from the last survey in 1977 by covering early varieties as well as maincrops. This may be a contributory factor in the apparent increase in herbicide usage over that period from 65% to 69% of the crop area.

No new chemicals have been recorded in the survey this year. Paraquat is still the most widely used followed by metribuzin. The only chemical noticeably to increase its share was glyphosate, confirming the much greater attention now paid to preplanting treatment of land for potatoes.

Résumé Le rapport au sujet des techniques et des coûts de production de la récolte des pommes de terre en Grand Bretagne en 1980 fournit des renseignements sur les pommes de terre de primeurs aussi bien que des variétes de conservation. Cette différence du rapport de 1977 explique peut-être l'augmentation de la superficie traitée par les herbicides chimiques de 65% en 1977 a 69% en 1980.

Il n'y a pas d'herbicides nouveaux en 1980 et la paraquat est toujours le principal herbicide chimique suivi par le metribuzin. Seule l'utilisation du glyphosate a sensiblement augmenté. Ce qui reflète le fait que les fermiers s'intéressent maintenant beaucoup plus à la préparation du terrain avant de planter les semences.

INTRODUCTION

The Potato Marketing Board (PMB) Survey of Maincrop Potato Production, carried out annually until 1977, is now a triennial event which has been expanded in 1980 to include information on early potato production for the first time. The object of the crop survey is to trace changes in potato husbandry practice and to quantify changes in the cost of production. The analysis of herbicide and other treatment data is a side benefit from the data checks which are essential prior to cost estimation. Data is not yet available on operations from August onwards, and, consequently, no information on haulm desiccation is presented.

The sample selection method was similar to that used in previous years with the exceptions that the frame included the planting returns of all growers down to those with only 0.4 hectare of potatoes, the area above which all potato crops must be registered with the PMB and that all varieties, both early and maincrop, were included. The eligible records were sorted by administrative area and variety and, within these groupings, by the total potato area on the whole farm. From the sorted list survey farms were selected to give a representative sample covering all varieties and scales of enterprise in proportion to their share of production throughout the country.

Producers were first visited by PMB staff after planting to obtain details of all operations and materials used on the crop up to that time. The second stage of data collection is at present in progress following harvesting to collect detailed information on all subsequent operations, including haulm desiccation.

The selection procedure described gave approximately 200 early and 800 maincrop variety fields. The response rate at the time of writing was about 85%. The survey numbers relate to the number of registered producers and total area of potatoes grown in each PMB administrative division in the manner shown in Table 1.

Table 1

PMB Administrative division	Total number of registered producers in 1980	Total area of potatoes in '000 hectares	Number of surveys completed
Southern	3,884	17.9	71
West Midland	6,644	31.1	166
East Midland	5,459	32.4	179
East Anglia	5,744	36.1	198
Northern	5,162	24.5	118
Scottish	5,700	31.9	124
Total	32,593	174.0	856

All estimates are provisional.

The distribution of survey farms is shown with the boundaries of PMB administrative divisions in Figure 1.

Figure 1

Potato production and PMB divisional boundaries

Each dot represents approximately 200 hectares of potatoes

RESULTS

The proportion of the crop area treated is provisionally estimated at 69%, a figure which, although 4% higher than that shown in the PMB's 1977 survey, may be partly attributable to the inclusion of early variety crops in the survey for the first time. (It is essential that the bulking of these crops, with their short growth period of 8 - 10 weeks and open habit, is not impeded by weed competition, but herbicide selection is also constrained by varietal selection).

Regional variations in herbicide usage in 1980 again followed the generally expected pattern with slightly less crop area treated in the drier eastern counties (East Midlands 59%, East Anglia 64%) than in the wetter north, west and south west and are shown in Table 2 and Figure 2.

Table 2

Area of Potatoes receiving various numbers of herbicide treatment in 1980

PMB regions	Not treated		One		Two		Three or more	
			Number of treatments					
	'000 ha	(%)	'000 ha	(%)	'000 ha	(%)	'000 ha	(%)
Southern	3.4	(19)	8.6	(48)	5.5	(31)	.4	(4)
West Midland	10.5	(34)	15.4	(50)	4.4	(14)	.7	(3)
East Midland	13.3	(41)	13.6	(42)	4.6	(14)	.9	(3)
East Anglia	13.0	(36)	18.4	(51)	4.4	(12)	.3	(1)
Northern	7.3	(30)	13.6	(55)	3.3	(13)	.3	(1)
Scottish	6.3	(20)	14.6	(46)	10.1	(32)	.8	(3)
Great Britain	53.8	(31)	84.3	(48)	32.3	(19)	3.5	(2)

The incidence of two or more chemical herbicide treatments reflects the growing awareness among growers of the value of pre-planting treatments to reduce the need for cultivations with their risk of damage to soil structure and growing plants. This now frequently extends back to autumn spraying after cereals to reduce the weed population that forms the foundation for spring infestations.

Weather conditions in 1980 were not conducive to weed growth during the early stages of development of the potato crop. A very wet spell at the end of March delayed spring cultivations and planting. Once dry conditions arrived in early April, planting was very rapid. Warm dry conditions through to the end of May gave good crop emergence which accelerated the competitiveness of the crop and thus the use of post emergence sprays was possibly rather less than it might have been in a more normal season.

Differences in herbicide usage in relation to the potato area of farms and in relation to varieties have been a noticeable feature of past surveys but these analyses are not yet available for 1980.

The extent of use of various types of herbicide classified by their mode of action is shown in Table 3.

Figure 2

Regional pattern of herbicide usage 1980

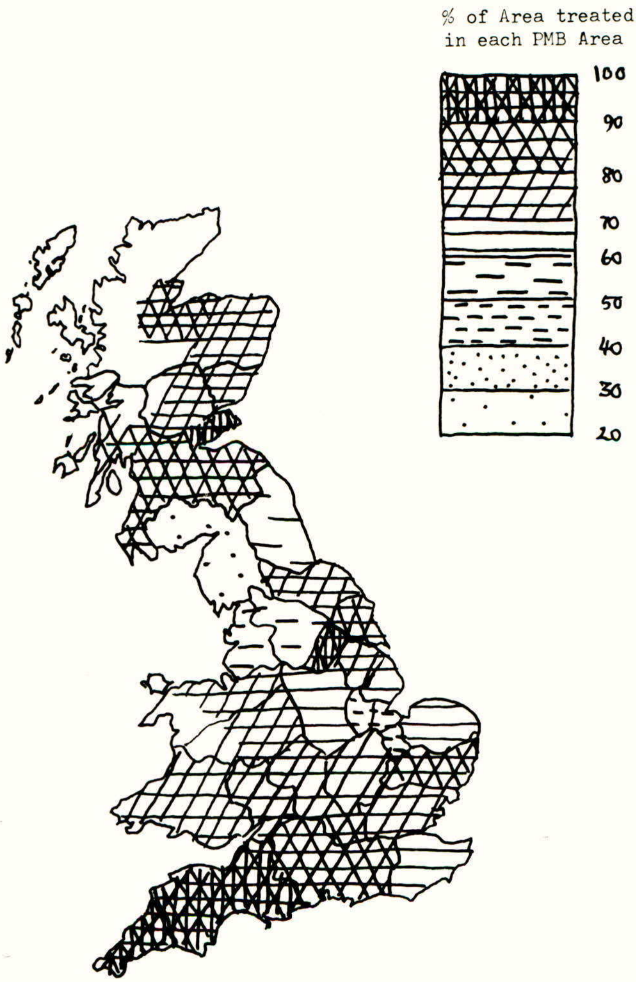

Table 3

Usage of different herbicide types

Action type	England and Wales: Estimated '000 ha	England and Wales: Treated area as % of spray area	Scotland: Estimated '000 ha	Scotland: Treated area as % of spray area
Preplanting	12.3	(10.4)	2.1	(7.1)
Contact pre-crop em	42.3	(35.9)	18.8	(63.5)
Post crop emergence	0.2	(0.2)	-	-
Contact + pre-em + residual	63.0	(53.5)	8.6	(29.1)

The relatively greater use of preplanting chemicals in England & Wales was probably a reflection of the greater time available for preplanting field work in the southern part of the country during the late autumn, winter and spring. Greater use of contact pre-emergence sprays has long been a feature of Scottish potato husbandry.

Use of particular chemicals. Paraquat still heads the list followed by metribuzin. The chemicals are all familiar from earlier surveys and the only one which has markedly increased in popularity in the last three years is glyphosate.

Table 4

Chemical usage expressed as sprayed area

Chemical types (ranked by usage)	England & Wales: Spray hectares '000	England & Wales: (%)	Scotland: Spray hectares '000	Scotland: (%)
All chemicals	94.6	(100)	25.6	(100)
Paraquat	42.3	(44.7)	18.8	(73.4)
Metribuzin	16.2	(17.1)	3.2	(12.5)
Linuron	8.7	(9.2)	6.5	(25.4)
Paraquat & monolinuron	11.8	(12.4)	2.1	(8.2)
Terbutryne mixtures	7.2	(7.6)	1.8	(7.0)
Monolinuron	8.6	(9.1)	-	-
Glyphosate	7.1	(7.5)	0.6	(2.3)
EPTC	4.8	(5.1)	1.3	(5.1)
Linuron mixtures	9.7	(10.3)	1.1	(4.0)
Others	1.2	(1.3)	0.6	(2.3)

The later part of the growth period of the 1980 potato crop favoured vigorous continuous growth of haulms in all parts of Great Britain giving little chance of weed competition. In some places straggling haulms collapsed under their own weight and senescence of the crop was generally earlier than last year even where blight and blackleg were not present. This allowed weed growth through the crop and in those cases haulm desiccants will have had a dual purpose of clearing weeds as well as potato tops prior to lifting. As mentioned above the data on this part of the crop cycle is not yet available for analysis.

DISCUSSION

In the exceptionally wet summer of 1980 the potato crop itself seemed to have a comparative advantage over weed competition but since the weed control programme was largely determined in advance the unusual season influenced herbicide practice very little.

The absence of any new chemicals used on this crop and the relatively unchanged pattern of use is partly a measure of the success of existing products but no doubt also reflects the relatively small size of this product market and the stability of the national potato area as well as the techniques for growing the crop.

The full results of this survey will be available in the survey report during 1981.

Acknowledgements

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NOTES