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WEED CONTROL IN FRUIT CROPS - WHAT'S NEEDED

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The aim of this paper is to suggest methods of developing herbicide treatments to meet the needs of British fruit growers. It is addressed mainly to the agrochemical industry and government financed organisations. It is also addressed to growers and independent advisers because they can also play a vital part in developing the new treatments needed to achieve the high standard of control required to prevent weeds having an adverse affect on British fruit production.

By agricultural standards the area of fruit crops in the UK is small, totalling some 70,000 hectares. The area is declining, but new plantings are more intensive and more dependent on herbicides. Production is mainly in the traditional fruit growing areas but there is more soft fruit, especially strawberries for 'self-pick', in other areas. New crops may be introduced but the areas will probably be small; for instance, the recent fashion for planting vines has only amounted to about 280 hectares.

Current practices

Fruit growers were quick to accept herbicides. For instance, simazine which was introduced for soft fruit in 1959 was being used on 68% of the blackcurrants surveyed by Bristol University in 1962 (Roach, 1966). There is a continuing increase in the use of herbicides because they are more effective, more convenient and cheaper than traditional methods of weed control. They have permitted certain new growing techniques such as early strawberry production in low tunnels and blackcurrants in beds. Other changes, including the intensification of apple production, have been dependent on herbicides but were probably not stimulated by them. In this instance the main factor was the need for earlier cropping which meant small trees with branches too close to the ground for conventional orchard floor management.

Although herbicides have made it possible to grow blackcurrants in closely planted beds new plantations have wide rows to accommodate the mechanical harvesters which have largely replaced hand pickers. Mechanical harvesters are also being developed for strawberries, apples and raspberries. This machinery will probably dictate changes in husbandry, but herbicides will continue to play a vital part in preventing the unwanted vegetation that would otherwise foul the picking mechanism and compete with the crop.

Most soft fruit receives overall herbicide, whereas most tree fruits still have grassed alleys and herbicide-treated tree rows. The width of the strip containing the trees is determined by the spread of branches and the width of the mowing machine used on the alleys. Eliminating all orchard-floor vegetation (including the grassed alleys) offers considerable advantages (Atkinson & White, 1976). The small proportion of such orchards results from concern over possible loss of traction and rutting where there is no sward. With a little encouragement it should be possible to persuade individual growers to check this on a few small areas before committing their entire orchard.

Conventional booms and nozzles are suitable for strawberries and some bush fruit but modified or special equipment is needed to spray under trees and between bush or cane fruit. The low volumes and high pressures still used on many holdings effectively reduce the number of days suitable for spraying. Flood jets, which operate at low pressures, seem to be generally effective despite their uneven distribution. On some farms the boom has been replaced by a single off-centre nozzle which covers either half or the entire tree row strip.

Current herbicides

The Weed Control Handbook lists 28 herbicides that can be used in fruit. This, along with manufacturers recommendations, Ministry of Agriculture, Fisheries and Food leaflets and the Agricultural Chemicals Approval Scheme list of Approved Products forms the basis of current herbicide usage.

Simazine is the most important component of most programmes and with its wide spectrum and low cost is likely to remain so. Other soil-acting herbicides are also used. They include chlorthiamid, dichlobenil, propyzamide and terbacil for the control of perennials in top, cane and bush fruit; lenacil and terbacil for specific annuals such as Polygonum aviculare (knotgrass); chloroxuron, lenacil and trietazine/simazine to control annuals in strawberries at times when simazine alone would be damaging.

For many years simazine was applied only in the spring (except in strawberries, which are damaged in the spring). Now it is also applied in the autumn or early winter to control late germinating annuals. This ensures there is enough simazine in the upper layers of the soil to give control of early spring germinating weeds even though the soil surface is dry. This is important because previously when the spring treatment was applied to a dry soil it was sometimes ineffective against the early germinators. The autumn application also enables the spring application of simazine to be delayed. This is an advantage where foliage-applied herbicides have to be applied to control perennials. It is convenient to mix them with simazine, but they are more effective when applied later than the normal time for simazine.

Paraquat is still widely used, especially where there has been no autumn application of simazine and there are overwintered weeds. In orchards it is being replaced by low doses of aminotriazole which, in addition to controlling the annuals, also checks many perennials. Aminotriazole also complements the activity of the growth-regulator weedkillers that are now widely used in spring and early summer. When paraquat is mixed with the growth-regulators there is a reduction in the long-term control of perennials.

Many of the treatments used in fruit are outside label recommendations. For instance, reports received indicate that much of the aminotriazole used in apples is applied at only quarter to half the recommended dose. There are very few label or leaflet recommendations for the widely used growth-regulator weedkillers. Simazine is widely used in newly-planted crops, but there is only one label recommendation. Propyzamide is used in strawberries to control Agropyron repens (common couch) even though most commercial crops are excluded from the label recommendations, either because they are grown as matted rows, or because the soil is too light.

Glyphosate is recommended as a directed spray in apples and pears between leaf fall and green cluster. Free-standing weeds can be treated with Croptex Herbicide Glove in any fruit crop. Some growers are using the Glove, even though it is less well suited for clumps of broad-leaved perennials than the wild-oats for which it was designed. Many more growers are 'spot-treating' with a lance or knapsack. Others are applying glyphosate as a general directed spray in orchards when the trees are in leaf.

Chlorthiamid and dichlobenil would solve many of the problems of emerged annuals and perennials. The main reason they are not widely used is because growers believe them to be too expensive!

Problems

There are problems in controlling weeds in fruit. Some are technical, others are economic or managerial. They all reflect the generally high standard of control of most weeds that is possible with the existing treatments, and growers commitment to herbicides. Technically there are two basic problems - the occasional failure of soil-acting herbicides and inadequate long-term control of perennials.

The failure of soil-acting herbicides is usually associated with the dry soil conditions sometimes encountered. It can be difficult to avoid these conditions with spring planted crops where there is no irrigation. There are, or should be, fewer problems in established crops since the surface of an undisturbed soil remains moist longer than that of a recently cultivated soil. It is also possible to apply treatments earlier in the spring because there is no need to wait for soil conditions which are dry enough for planting.

Annual weeds that occur in relatively small numbers can rapidly become a major problem if not controlled and allowed to seed. For instance, Polygonum aviculare (knotgrass) increased in strawberries when only chloroxuron and simazine were available. When lenacil was introduced for this crop it controlled knotgrass, but not Veronica spp (speedwells). They were then a problem until trifluralin and trietazine/simazine were introduced. Changes in the species composition of a field occur more slowly. This means it is possible to anticipate potential problems given a list of the species present and a comprehensive list of weed susceptibilities for the herbicides to be used.

Annual weeds are usually widely distributed and require overall treatment. Perennials, in contrast, often occur in isolated patches that are suitable for 'spot treatment'. This allows considerable savings in the amount and therefore cost of herbicide used. More important, only a small part of the crop is treated and therefore put at risk. This makes it feasible to use treatments that would not be safe for overall application.

Many perennial weeds still cause problems. Agropyron repens (common couch) is the most widespread and is a continual threat because of its ability to spread rapidly. It is still difficult to control in strawberries, although this situation could change rapidly if alloxydim-sodium lives up to its early promise. Broad-leaved perennials including Convolvulus arvensis (field bindweed), Cirsium arvense (creeping thistle) and Equisetum arvense (field horsetail) are less widespread but generally more difficult to control. Other species, including Heracleum sphondylium (hogweed), Potentilla reptans (creeping cinquefoil), Cardaria draba (hoary cress), Polygonum amphibium (amphibious bistort) are troublesome locally.

Most perennials regenerate from roots or rhizomes present when fruit was planted. They were probably not serious in the previous crops because they were suppressed by a combination of cultivations and competitive crops.

Attempts at pre-planting control of perennial weeds in a fallow often fail. The theory is to encourage shoot growth which is then sprayed with a translocated herbicide, usually glyphosate. In practice, perennials that have been suppressed for several years do not respond rapidly. In the first season there is often insufficient shoot growth to provide the optimum target for maximum herbicidal effect. Even when there is vigorous weed growth, and it is sprayed under optimal conditions, there will probably be some regrowth in the year after treatment. Therefore, some form of post-planting control is inevitable, and this must influence the worthwhileness of pre-planting treatments.

There are other perennials that can be troublesome in fruit including some, such as clover, that establish from seeds. This has become a serious problem in strawberries because the clover is very competitive and kills the strawberries in infested areas. Sedum acre (biting stonecrop, golden stonecrop, wall pepper) is another unlikely weed. Several UK growers have reported it in orchards and blackcurrants. Other wild and cultivated plants could also become 'weeds'. Endymion nonscriptus (bluebell) and daffodils can be found in cane fruit, while asparagus occurs in apples. Are these the weeds of the future? Some of them are controlled by existing treatments and all that is needed is more comprehensive weed tables. This is true of Sedum acre, in experiments in Holland it was controlled by diuron and terbacil (van Staalduine, personal communication).

It is more difficult to show that a treatment is safe to the crop and obtain clearance under the Pesticides Safety Precautions Scheme (PSPS) than to find a treatment that will control weeds. In the past there have not been too many problems with clearance because the older herbicides were cleared for a wide range of edible crops and the agrochemical industry co-operated in obtaining clearance for relatively minor uses. Newer herbicides have more restricted clearances and economic pressures might prevent the agrochemical industry being as helpful as they would wish. If this leads to the restriction of non-label uses it would create serious problems for fruit growers.

Mixtures are a special case because of the increasing need to combine the properties of two or more active ingredients or commercial products. There are label recommendations for mixtures of contact and soil-acting herbicides and for sequential applications of soil-acting herbicides. They are usually for two products which are obviously complementary, any major gaps in their weed spectra being on different species; each product is used at the normal dose. Controlling weeds that are only partially controlled by the components of a mixture is more difficult. There is scope for more mixtures in which the main component controls most of the weeds and the second component is required to control only one or two species. This opens up the possibility of adding small amounts of herbicide that is very active against these weeds, even though it may not be safe on the crop at the dose needed for general weed control.

Solutions

It is naive to expect too much from new herbicides because of the small potential market. There is scope for new active ingredients and new formulations, especially of soil-acting herbicides whose activity is less dependent on soil moisture. They could replace simazine if they were cheap, but even this relatively large horticultural outlet is small by agricultural standards and not very attractive to manufacturers.

Success is more likely to come from the further development of herbicides already marketed for other UK crops. These chemicals are, by definition, already available and cleared for operators and wild life. The recent WRO work with propachlor and ethofumesate on strawberries demonstrates this approach. Propachlor and trifluralin have complementary weed spectra and are used extensively in vegetables. Trifluralin is already recommended in strawberries and it has been shown that propachlor is also safe in strawberries, either alone or with trifluralin (Clay, 1978). Residue data are being obtained by the manufacturers in the hope that there will be a label recommendation. Good progress has also been made with ethofumesate. In ADAS trials it has controlled established clover in strawberries. The WRO work on crop response has been favourable. Again the manufactuter has co-operated and it is hoped that there will be commercial clearance.

Progress is slower with products not already on the market. Pendimethalin serves as an example. It has been investigated as an alternative to trifluralin in strawberries. It does not have to be incorporated and could therefore be used on established crops. It would also be easier to use in newly-planted crops. It has performed well in crop tolerance trials (Clay, 1978; Lawson & Wiseman, 1978) but there are no residue data yet and its availability for strawberries will probably depend on its introduction for the control of Alopecurus myosuroides (black-grass) in winter wheat.

Many problems can be solved with the older off-patent herbicides such as 2,4-D amine which controls many broad-leaved perennial weeds. For several years there has been a tentative recommendation for 2,4-D amine in the Ministry of Agriculture leaflet STL 23 (now HSF 21), but until recently it has seldom been used. As a result of detailed experiments there is now a much better understanding of the factors determining crop tolerance (Davison & Bailey, 1978). Guidelines have been laid down and many growers are now using 2,4-D amine, accepting that there are risks to the crop. This is not a label recommendation, and is unlikely to become one.

There is often disappointment with the level of long-term control of perennials, perhaps because growers expect too much. Better control is sometimes possible with more precise timing and higher doses (Davison, 1976). There are more opportunities for this approach in fallows than after the crop has been planted. However, the difficulty of achieving adequate shoot growth in a fallow has been mentioned. Pre-planting treatments might be more successful if more than one year was allowed; even so complete control is unlikely.

The proceedings of this and previous British Weed Control Conferences contain many research reports on weed control in fruit. Most of them are from government financed organizations and describe conventional randomised and replicated field experiments. Some describe the effects of applying the same herbicide for several years, and others the merits or otherwise of non-cultivation. More recently they have included other aspects of crop management. This is clearly important to growers - but probably of less interest to the agrochemical industry, even though a change to overall herbicides in orchards would double or treble the area to be treated.

Experimental methods

Are conventional experiments the most efficient method of finding new treatments? In fruit great value is placed on a few replicated field experiments and the statistical significance of the results. But differences of less than 10-20% are unlikely to be statistically significant ($P = 0.05$) whereas much smaller losses would be of financial significance, and many growers can detect a 20% reduction by eye. While such experiments are suitable for investigating the effect of specific factors they cannot indicate reliability because there are too few of them. For instance, it is usual with soil-acting herbicides to compare several doses, and it is assumed that if a high dose is safe at a few sites on a range of soils the normal dose will generally be safe. Seasonal variation is covered by carrying out the experiments over two or three seasons. In practice, large differences in response can be caused by variation in environmental factors such as soil moisture, at the same site, over a period of a few days. For many herbicides more useful formation would be obtained by reducing the number of doses and applying them on more than one date.

New herbicides are usually compared with an existing commercial treatment. This is useful in determining levels of weed control but less useful in assessing crop tolerance. The latter can be achieved by comparison with a treatment that is normally damaging. For instance, if simazine is included as a damaging standard in newly-planted strawberries (it normally damages newly-planted crops and established crops in the spring) and there is no damage it can be assumed that the conditions of the test were not conducive to damage; therefore, there is no justification for elation about new herbicides that also appear safe.

Foliage-applied herbicides also give variable results. For instance, when glyphosate was applied to individual shoots of apple trees there was occasionally severe damage. It was confined to certain trees at specific sites and it could be correlated with any one factor (Davison, 1974). Therefore for both soil- and foliage-applied herbicides there is a need to be able to either identify the factors determining field tolerance, and hence variability, or simply have enough trials to predict performance in commercial use relative to that of standard treatments.

Methods of evaluating soil-applied herbicides in sand-culture are being developed at WRO (Clay & Davison, 1978). It is now possible to determine the relative inherent tolerance in a simple pot test. Herbicides are applied to fruit plants growing in sand, thus ensuring that they come in contact with the roots. This is how propachlor, pendimethalin and ethofumesate were selected for strawberries. They have all performed satisfactorily in the field. With this method large numbers of herbicides can be screened quickly and efficiently, and positive results are always obtained. The next stage will be to develop a method to indicate the influence of soil type and soil moisture. This should reduce the need for detailed field experiments. So far the sand-culture results have enabled conventional field experiments to be concentrated on the most promising treatments.

Reliability can be determined with a large number of simple trials, or even unreplicated plots. With most simple trials it will only be possible to detect differences visible to the human eye. The main value of this approach is that it is possible to cover a wider range of environments and types of husbandry than is possible in detailed experiments.

There are many problems that could be solved with treatment developed almost entirely on the basis of unreplicated plots. This approach is particularly relevant for spot treatment and problems with no alternative solution. It could, for instance, be used to test the safety of glyphosate as an overall spray on blackcurrants and gooseberries in the dormant season. Limited experimental evidence has shown that glyphosate can be used safely in both crops (Stott, et al., 1974). A large number of individual bushes (100-200) would be sprayed in the period from October through to April either by experimenters, advisers or technical representatives in their normal visits to blackcurrants or gooseberries. The only equipment needed would be a sprayer suitable for spraying a single bush with a pre-measured dose of glyphosate. Each bush could be labelled and a note made of the date and percentage leaf fall (in autumn) or leaf development (in spring). Any differences in leaf development, growth or cropping could be noted on subsequent visits. In this way sufficient information for a recommendation would be obtained quickly, and with relatively little effort.

Recommendations

There are label recommendations for most of the basic soil-applied herbicide treatments; many are approved under the Agricultural Chemicals Approval Scheme. It is hoped that the agrochemical industry will continue with such recommendations. Some labels have 'growers risk' recommendations which are also very useful. But there are many crop/weed situations not covered by label recommendations and unless these needs can be met the value of the basic treatments will be undermined. Fortunately, there is a tradition of 'unofficial' recommendations made by company representatives, ADAS and others. These are accepted in good faith by most growers.

The Agricultural Chemicals Approval Scheme accepts 'provisional' recommendations for minor uses. These also help to bridge the gap between conventional recommendations and an unofficial recommendation. The ACAS defines minor uses as "the minor use of a product on a major crop, or any use of a product on a minor crop, or the use of a product for the control of a pest/disease/weed in occasional circumstances". This only applies to products with an approved use. If the ACAS considers all fruit crops to be 'minor crops' there is considerable scope for 'provisional' uses.

Many growers are prepared to use treatments for which there is insufficient information for the usual label recommendation, provided they have enough information from trials or commercial usage to make the decision. The results that appear in the proceedings of the British Weed Control Conferences can provide a valuable lead but it would be better if there was ready access to the results of other trials done in the UK. Ideally the results should be summarized in a way that is intelligible to growers and indicates the extent of experience and the probability of success.

Growers are anxious to comply with the spirit of the Pesticides Safety Precautions Scheme. They know that label recommendations have been 'cleared', but it is difficult to find out about other cleared uses. It would be a great help if there was a list of uses that have been 'cleared'.

Growers appreciate that the agrochemical industry cannot devote all the resources needed to provide the information necessary for recommendations on minor crops and for minor uses. But failure to control weeds can have serious consequences, which is why growers are prepared to accept risks, provided they have the information on which to make a decision.

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INDIGENOUS SPECIES IN PERSPECTIVE

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Summary: Some indigenous grasses, such as Yorkshire fog (Holcus lanatus) and sweet vernal (Anthoxanthum odoratum), are often more productive than sown species, in pure stands, especially at <200 kg N ha^{-1}; others, such as meadow grasses (Poa spp.), bent (Agrostis tenuis) and sheep's fescue (Festuca ovina) are usually less productive.

The seasonal pattern of growth of meadow grass and Yorkshire fog is similar to that of ryegrass (Lolium perenne); sweet vernal is earlier, but meadow grass is later. Sheep's fescue, red fescue (F. rubra) and bent have a more uniform growth pattern.

Meadow grasses and Yorkshire fog are slightly more digestible than ryegrass; sheep's fescue and red fescue are less digestible.

Animal output from indigenous grasses is usually equal to that from sown grasses, when treated similarly.

Herbage yields often increase slightly when indigenous species invade sown swards, and temporarily decrease when they are removed (e.g. by herbicides). Neither treatment has much effect on animal output.

Environmental conditions and management have the greatest effects (>95%) on herbage production and animal output; species composition has little effect (<5%).

Species are the indicators or symptoms of environmental conditions and management; they rarely cause appreciable differences in output. Pasture improvement should treat the underlying causes of low output and not obliterate the symptoms, by removing indigenous species.

INTRODUCTION

Much effort and money is expended in eliminating indigenous species from pastures in Britain. Methods include applying herbicides, applying herbicides with minimal cultivation (e.g. one-pass seeding), and complete cultivation and resowing. To what extent is this expenditure justified?

Presumably the expenditure is made in an effort to increase profit, rather than for purely cosmetic reasons. Since expenditure is increased, additional profits can only be achieved by increasing income enough to more than offset the additional expenditure. This can only be achieved by increasing animal output which, in turn, might be brought about by increasing the herbage production and/or herbage quality. To what extent does this occur?

Before attempting to answer these questions, we need to define the term "indigenous species". In a sense, almost all pasture species (sown and unsown) are indigenous, since they are all native to Britain; lucerne (Medicago sativa) is one of the few exceptions. In the present context, I presume that "indigenous" means "not sown", though it seems often to be used in the sense of "species not usually sown" or "disapproved" species. These last two categories have changed considerably; such species as crested dogstail (Cynosurus cristatus), meadow grasses (Poa spp.) and sanfoin (Onobrychis sativa) were once sown but are no longer sown. For the sake of simplicity, I shall define "indigenous" as unsown species and will concentrate on "indigenous grasses".

I shall first of all consider the herbage yield of "indigenous" grasses, compared with that of sown grasses, then go on to consider differences in herbage quality, and the effect on animal output.

HERBAGE PRODUCTION

The relative yield of "indigenous" and sown grasses can be considered in several ways: (i) in pure stands, (ii) in mixtures with legumes, or (iii) in mixtures of species of their own kind (i.e. either indigenous or sown). Of these, (ii) and (iii) are most realistic, since (i) rarely occurs in practice. In addition, and especially in the context of this conference, it is important to consider the performance of mixtures of sown and indigenous species. We need to know, in particular, the effects of changing the relative proportions of sown and indigenous in swards, since herbicide treatments and sward "renovation" are used to manipulate the ratio of sown to indigenous species.

In pure stands, some indigenous grasses (e.g. Yorkshire fog, sweet vernal and sometimes creeping bent (A. stolonifera)) often yield 5-20% more, and occasionally 40% more, than sown species (e.g. Jacques 1963, Morris and Thomas 1972, Haggar 1976); the sown grasses yield about the same as each other (Snaydon 1979). On the other hand, some indigenous grasses (e.g. common bent (A. tenuis), red fescue, sheep's fescue, crested dogstail, and meadow grasses) often yield 5-25% less, and occasionally 50% less, than sown grasses in pure stands (Cowling & Lockyer 1965, Anslow and Green 1967, Morris and Thomas 1972, Haggar 1976). In general, the indigenous grasses tend to be relatively more productive at low N inputs (<200 kg N ha^{-1})(Haggar 1976), and at higher altitudes (e.g. Morris and Thomas 1972). I suspect that at least some of them would also be more productive when P or K was deficient, pH was <5.5, or the soil sometimes waterlogged, though there is little direct evidence for this.

Since indigenous species are, on average, as productive as sown species, at least under the conditions that are likely to exist in farm practice, why do they have a reputation for lower yields? I think that there are two main reasons. Firstly, research workers normally make their comparisons under ideal conditions, when all nutrients (N,P,K etc.) are adequately supplied, soil pH is 6-7, soils are well drained, and the swards are cut, usually infrequently. These are the conditions that will tend to favour the sown species, but they rarely exist in practice. Under normal farm conditions, when N applications are usually <150 kg ha^{-1}, where P is often deficient, pH <6.0, and soils poorly drained, indigenous species are likely to be at least as productive as sown species. Indeed, the fact that well over half of the lowland grassland area of Britain is permanent pasture, in which indigenous grasses predominate, indicates that indigenous species are competitively superior, and probably higher yielding, in most farm conditions. Secondly, the fact that indigenous grasses predominate in unproductive pastures has induced agronomists to conclude that the species themselves are unproductive. This conclusion is false, as we have just seen; indigenous species are as productive as sown species, given the same conditions. The indigenous species are not the cause of the low production. Both low production and dominance by indigenous species are the result of poor environmental conditions and poor management. It follows too that we will not change the productivity of pastures simply by changing the species composition; production will only be increased if the environment and management are improved (see below).

SEASONAL PRODUCTION

It is often stated that indigenous species are later in spring than sown grasses, but there is little evidence to confirm this. On the contrary, where seasonal patterns of growth have been carefully measured (e.g. Morris and Thomas 1972, Haggar 1976), some indigenous grasses (e.g. sweet vernal and Yorkshire fog) reach growth rates of 10 kg $ha^{-1}d^{-1}$ several days earlier than ryegrass; most other indigenous species, including bent and red fescue, are at least as early as ryegrass (Morris and Thomas 1972, Haggar 1976). Why, once again, do indigenous species have a reputation which they do not warrant? I think the reason is that, in the poor permanent pastures,where indigenous species predominate, nitrogen is deficient and spring growth late. However, given adequate spring nitrogen, indigenous species are just as early as sown species. On the other hand, it is true that many indigenous grasses cease growth several weeks earlier than ryegrass in autumn (Morris and Thomas 1972, Haggar 1976).

Some indigenous grasses (e.g. meadow grass and Yorkshire fog) have a seasonal growth pattern very similar to that of ryegrass, with a very marked spring peak (Anslow and Green 1967, Haggar 1976). Some other species (e.g. bent and red fescue and sheep's fescue) have a more even growth rate during the season (Morris and Thomas 1972, Haggar 1976). This pattern would, in many cases, better match animal requirements and allow greater ease of management, though it may be less suitable for conservation cuts.

HERBAGE QUALITY

Another "myth" that is widely held is that the herbage quality of indigenous grasses is less than that of sown grasses. The digestibility of some indigenous species (e.g. meadow grass and Yorkshire fog) is slightly greater than that of ryegrass (Haggar 1976). Other species (e.g. bent and sweet vernal) are as digestible as ryegrass (Thomas and Morris 1972, Haggar 1976), though some others (e.g. sheep's fescue and red fescue) are less digestible than ryegrass (Thomas and Morris 1972, Haggar 1976), but are still as digestible as some other sown species, such as cocksfoot.

SPECIES IN MIXTURES

Many of these differences, in herbage production, seasonal growth and herbage quality, disappear when the two groups of species are separately grown with a legume. For example, bent yields up to 50% less than sown grasses when grown alone (Cowling and Lockyer 1965, Morris and Thomas 1972), but yields the same as sown grasses when grown with white clover (Henderson et al. 1962, Cowling and Lockyer 1965). Since, the clover content of the sward was greater with bent than with sown species (especially cocksfoot and timothy), the quality of herbage on the bent sward would be greater. The addition of clover to the sward also tends to reduce differences between species both in the seasonal pattern of herbage yield and response to N fertilizer (Henderson et al. 1972). We see, therefore, that the relatively small differences between indigenous grasses and sown grasses, when grown in pure stands, tend to disappear when grown in mixtures with white clover; these conditions predominate in British agriculture.

Most experimental comparisons of mixtures of indigenous grasses versus mixtures of sown species have been made by comparing mixtures of sown grasses in sown leys versus mixtures of indigenous species in uncultivated permanent pasture. This is not a completely valid comparison, since ploughing out the old permanent pasture releases large reserves of mineral nutrients that have accumulated, giving the ley an initial benefit of greater fertility. As a result, if N inputs are modest, the herbage production of the ley exceeds that of permanent pasture in the first two years (e.g.

Mudd and Meadowcroft 1964), though the difference decreases with time; the difference does not occur if more N fertilizer is added (C.H. Mudd pers. comm.).

ANIMAL OUTPUT

Obviously, the differences in herbage production, seasonal growth pattern and herbage quality, between indigenous and sown grasses, are small and inconsistent, depending on environment, management, the other species present (e.g. legumes) and the particular species considered. However, in the final analysis, it is animal output which is all-important and animal output cannot be reliably predicted from herbage production or quality. It can only be measured by careful and valid experiments. Only a few of the experiments that have been carried out to compare indigenous and sown grasses are valid. Most used "put and take" systems of stocking, or different stocking rates on the two sward types, or even different fertilizer applications on the two sward types.

No studies of animal performance on a range of indigenous and sown species, in pure stands, have been made in the United Kingdom. Collins and Murphy (1979) surveyed studies carried out in Eire and concluded that, over a surprisingly wide range of N fertilizer use, stocking rate, management and years, with and without clover, indigenous species rarely produced less animal output than sown species. Some species, e.g. Yorkshire fog, frequently produced more animal output than ryegrass. Several comparisons have been made in U.K. of mixed stands of sown species versus permanent pasture, though this type of comparison is not entirely valid, for the reasons already considered. The most intensive study, in which the stocking rate was the same on both sets of swards, was made by Eyles (1963), though the comparison is made even more difficult by the fact that different amounts of hay were cut. Animal production from indigenous species (permanent pasture) was identical to that from sown species (ley) at the lower stocking rate. At the higher stocking rate, production was less on the indigenous species but the stocking rate was so high that both sward types collapsed after three years. Mudd and Meadowcroft (1964) made a more extensive study, but used variable stocking rates (i.e. a "put and take" system). They found that milk production was greater on the sown species (ley) in the first two years after reseeding but, in the following years, it was greater on unsown indigenous species (permanent pasture). Over three series of 4-5 year periods, milk production was slightly greater on indigenous species, largely because of the lost production in the establishment year. They concluded that permanent pasture was more profitable, mainly because of lower costs, the outputs being similar. Elliott et al. (1978) have demonstrated the high potential of indigenous species for meat production, when adequately managed, though there was no direct comparison with sown species.

MIXTURES OF SOWN AND INDIGENOUS SPECIES

The evidence considered so far indicates that both herbage production and animal output from swards of indigenous grasses are comparable with that from swards of sown grasses, given the same conditions. This is true whether the species are grown in pure stands, in mixtures with a legume or in complex mixtures of species.

In the context of this conference, it is more important to know the effects of various proportions of sown and indigenous species on herbage production, and ultimately on animal output. This information is important because herbicides are frequently used to manipulate these proportions; herbicides are used both to directly reduce the proportion of indigenous species, and to increase the proportion of sown species by renovation. It should theoretically be possible to deduce the performance of different ratios of sown and indigenous species from their performances in pure swards. In practice it is rarely possible to make such predictions accurately, even for herbage production (Trenbath 1974), so the effects must be investigated experimentally. Most of these studies have involved the use of herbicides to manipulate the relative abundance of sown and indigenous species; in most cases, only herbage production has been measured, and there is little information on animal output.

Herbage Production

When correctly used, herbicides usually reduce the content of indigenous grasses and increase the proportion of sown grasses, especially ryegrass, though the proportion of broadleaved species and meadow grasses may also increase in some cases (Oswald et al. 1972). As a result of these changes, the total herbage yield of the sward is usually reduced for 6 months after treatment (Allen 1969), or even for one year (Allen 1968). Yields subsequently increase and may temporarily exceed the untreated sward (Allen 1969) or may equal it. The annual herbage yields, in the first year after treatment, are usually reduced; other papers in this section confirm this (e.g. Faulkner; Griffiths et al.; Haggar and Passman). No one seems to have followed the effects of a single application for more than a year, though I suspect that the swards quickly revert to their former composition and yield, unless the environment and management have also been changed.

Similar results have been obtained in studies of the invasion of sown swards by indigenous species. For example, when sown pastures were invaded by meadow grasses (Wells and Haggar 1974), the yield of the "contaminated" sward was normally 10-20% greater than that of the pure sown sward. The greatest yields were obtained with 25-50% meadowgrass. Smith and Alcock (1976)(see also Smith 1979) have also shown that invasion by bent grass, Yorkshire fog and couch grass does not reduce the herbage yield of the sward; changes in animal output have not been studied. Most of these studies have been carried out under intensive conditions of fertilizer use (200-400 kg N $ha^{-1} y^{-1}$), and cutting/grazing management, when the sown species might be expected to be more productive. Indigenous species might be expected to be more productive under more normal conditions, common in agriculture practice.

Animal output

Ultimately, animal production is the only important criterion of the value of such herbicide treatments. Unfortunately, few studies have been made of animal output. The expense of animal experiments is usually cited as the reason for the lack of evidence, though the expense is not large in comparison with the cost of electron microscopes or controlled environment facilities. In the absence of such essential information, conclusions must be based on observation or, at best, on survey data (e.g. M.L.C. 1970, Forbes et al. 1978, Peel and Forbes 1978). Both observation and surveys indicate that animal output is somewhat greater when the proportion of sown species is greater. However, it would be extremely dangerous, in view of the evidence already presented, to infer from this that higher proportions of sown species directly increase animal output. A far more likely explanation is that better environmental conditions (e.g. soil pH, NPK status, drainage), and better management (e.g. fertilizer use, grazing/cutting) favour sown species and also lead to higher output. The correlation between the proportion of sown species and animal output are probably not cause and effect, but the result of other factors. This is confirmed by more intensive studies within smaller areas. More than 50 years ago, Hall and Russell (1912) made an intensive study of a series of adjacent pastures in the Romney Marsh, which differed greatly in animal output. They found no consistent differences in species composition between productive and unproductive fields and concluded that "The feeding of a pasture is largely independent of the floral type (species composition), and that whether any particular species of the grasses here considered will be good or poor food depends upon the soil and climatic conditions and particularly on the management". They also found that "the characteristic (of productive fields) was the high rate at which nitrates were produced; they also contained a relatively large amount of total phosphoric acid". Results of the few experimental studies that have been made also confirm that animal output is not related to species composition. For example, Haggar and Elliot (1979) reduced the content of indigenous species of swards, by annual applications of Dalapon, and found that this slightly reduced liveweight gain at all stocking rates. Biennial applications also slightly reduced liveweight gains at low and high stocking rates but slightly increased them at the medium stocking rate.

Herbicide applications to pastures can increase liveweight gains, in some cases, but not for the expected reasons. For example, applications of Dalapon can increase the liveweight gain of lambs in New Zealand (Palmer 1967, Sharp 1968) but the effect seems to be due, in some cases, to an increased proportion of clover in the sward or, in other cases, to reductions in the amount of barley grass which causes damage to the eyes of lambs. These results highlight two important facts. Firstly, the use of herbicides can increase animal output, if it eliminates or reduces the content of some toxic or damaging constituent of the sward. Secondly, it can theoretically increase output if it increases the content of some beneficial constituent; however, the only constituents that consistently and appreciably increases animal output are the legumes (Reed 1972, Thomson 1979).

HOW IMPORTANT ARE SPECIES?

All of the experimental evidence, considered so far, indicates that the differences between sown and indigenous grasses, in both herbage production and animal output, rarely exceed 10% and are inconsistent. Under some conditions, and in the case of some species, indigenous grasses are slightly more productive than sown grasses; in other cases the reverse is true. The differences between the two groups of species are often unpredictable in practice, e.g. the effects of mixtures, and differences between years. On the other hand, some differences are more predictable; for example, sown grasses are slightly more productive when > 200 kg N $ha^{-1}y^{-1}$ is applied, and probably when P and K are adequately supplied, when the soil is near neutral and well drained, and when the pasture is well managed. Most of the grassland in Britain lacks one or more of these requirements, so that indigenous species contribute more than half the herbage production in Britain and ryegrass contributes less than 20%. In these conditions we might expect indigenous species to be at least as productive as sown species.

The small differences (<10%) that exist between species, both in herbage production and animal output, pale into insignificance when compared with the large differences that exist between farms, between years and between fields on a single farm. For example, the herbage production of a single species (e.g. ryegrass) can vary threefold, from site to site and year to year, even when N,P,K, soil pH, drainage and cutting management are all optimised (J. Morrison pers.comm.) the differences can be eightfold when only N supply is suboptimal, and is presumably more when other factors are allowed to vary. Similarly, liveweight gains per hectare commonly vary between threefold and fivefold,from farm to farm and year to year (M.L.C. 1970, Forbes et al. 1978), while milk production per hectare commonly varies between twofold and threefold (I.C.I. 1975, Forbes et al. 1978). Obviously the species composition of the pastures only account for a small fraction (<5%) of the variations in herbage production and animal output that occur; the larger proportion of the variation (>95%) is caused by differences in environmental conditions and management.

CAUSE OR EFFECT?

It is readily apparent, from these considerations, that the large variations in herbage production and animal output that occur in British agriculture are not caused by variations in species composition. Low production, on the one hand, and a high content of indigenous species, on the other hand, are both the result of poor environmental conditions and poor management. In other words, indigenous species are the symptoms and not the cause of low production. It therefore follows that any treatments aimed solely at reducing the content of indigenous species, or increasing the content of sown species, without treating the underlying causes of low production, are doomed to failure. Firstly, without repeated treatment, or ameliorating the underlying deficiencies, the sward will soon revert to its original species composition. Secondly, without improving the environment or management, the productivity will not increase. These are precisely the results that have been consistently found in pactice (see above); yields, are reduced more often than they are increased and swards normally revert within a few years.

The use of herbicides to control indigenous species, in an effort to increase production, is similar to the indiscriminate use of pain-killers or anti-depressants in medicine. In each case, the symptoms are masked but the root causes remain. In each case, there is some danger of harmful side-effects, e.g. initial reduction in herbage yield and a more open sward, susceptible to poaching. In each case, the symptoms return as soon as the treatment is discontinued, because the cause has not been rectified.

CONCLUSION

We cannot afford to mask or obliterate the symptoms without tackling the causes; such treatment is only cosmetic and has little or no practical value, as we have seen. Instead, we must learn to read the symptoms and, when it is economically worthwhile, manipulate the environmental conditions and management to increase production. We need to know which species are indicators of which deficiencies (e.g. N,P,K, soil pH, poor drainage, undergrazing and overgrazing). In some cases we are already fairly sure of the indicator species (e.g. of poor drainage), but it is still surprising how often we seek the quick, cheap and usually ineffective solution, by treating the symptoms and not the cause.

Herbicides can sometimes be a useful subsidiary treatment, which helps to speed the process of pasture improvement. Herbicides are rarely a satisfactory substitute for improving environmental conditions and management. They are most useful when environmental conditions and management are to be changed rapidly and drastically, e.g. reclamation of upland areas or the poorest lowland pastures. They can also be useful in rapidly removing toxic or damaging species, though again this is usually only a poor substitute for good management.

In conclusion, my plea is that we see the value of species, whether they be indigenous or sown, in perspective. They are not important causes determining grassland production; they are symptoms which must be read and acted upon, not masked or obliterated.

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THE PROBLEM OF VOLUNTEER CROPS AND SOME POSSIBLE MEANS OF THEIR CONTROL

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Summary Control methods are reviewed, with particular emphasis on cereals and potatoes as weeds. It is suggested that cultural control methods have been abandoned to a large extent due to the current trend towards intensive methods of crop production. If this trend continues then it is suggested the resulting weed problems should receive more attention from weed scientists, both in respect of studies of the biology of crops as weeds and research into control methods. It is suggested that close liaison with plant pathologists is needed to determine the importance of volunteer crops in the epidemiology of major plant diseases.

INTRODUCTION

Most crops can survive as weeds in subsequent crops and the following list indicates the scale and complexity of the subject:

Wheat, barley, rye, oats, potatoes, daffodils, horse-radish, sugar beet (from crowns or from seed as 'weed beet'), oil seed rape, mustard, the ryegrasses, white clover and the suckers arising from the roots of many fruit and ornamental crops.

This is a formidable list and, if we are to take the subject comprehensively each species should be considered separately in respect of its potential as a threat to other crops, its biology, its response to herbicides and potential control strategies. Such exhaustive treatment will not be possible in this short review. The aim will be to consider the various methods of control, using different weeds as examples but concentrating heavily on volunteer cereals and potatoes.

1. IMPROVED OR MODIFIED HARVESTING TECHNIQUES

The obvious way to eliminate these problems would be to remove the crop completely at harvest and it is tempting for "weed men" to hide behind this possibility. Table 1 gives estimates of the range of losses which may occur with some crops.

These losses are very significant as a loss of profit but may be even worse as a source of volunteers because some of the lost crop may not be marketable, although viable (e.g. small or green potato tubers or small 'light' grains of barley). Some crops are easier to harvest than others and crops with an indeterminate habit of growth, such as oil seed rape and ryegrass are notoriously difficult.

Two general points have to be made in this context: (i) Harvesting efficiency can be and has been increased by improved design, and careful driving. Lumkes et al (1978) have pointed out that losses of potatoes can be minimised not only by improving harvesting efficiency but also by paying attention to all the operations before and after harvest. This is to ensure that potatoes are not knocked out of the ridges by traffic before harvest, that spillage from trailers and harvesters is avoided. By general attention to detail in this way the return of tubers to the soil is minimised and one feels sure that comparable attention to detail would reduce losses of other crops.

Table 1

Some data on the range of crop losses at harvest

Crop	Yield lost /hectare	Yield lost as %	Potential volunteers /m^2
Potatoes	1-4 tonnes	up to 10	2-30 *
Cereals	30-200 kg	0.75-5	70-470 +
Oil Rape	100-500 kg	4-20	1900-9500
Ryegrass	50-150 kg	10-30	3500-10000

(ii) However much efficiency is improved, harvesting can never be 100% efficient. Harvest is a critical period and, if it is not completed in time, 100% yield loss is possible so there is no economic incentive to slow the operation too much. If we cannot avoid harvest losses, however, it may be possible to reduce the viability of the lost material. The best example of this is the technique of crushing potato tubers developed in the Netherlands and described in these proceedings by Meijer and Frederiks (1978). It is interesting to speculate on whether some analogous possibility exists for cereals and other grain crops. Straw burning must, by analogy with wild-oats (Wilson and Cussans 1975) and black-grass (S.R. Moss, personal communication), reduce the viability of shed corn but it clearly does not kill it altogether.

2. CONTROL BY CULTURAL METHODS

(i) Rotation

Volunteer crops are essentially weeds of intensivity. Potatoes can persist as a weed in cereals for a number of years but not very successfully. Populations barely maintain themselves or, more usually, decline slowly until they are replenished when the land is planted to potatoes again or to a non-competitive row crop. (Doncaster & Gregory, 1948; Lawson & Wiseman, 1978). In contrast to this, potatoes are an extremely successful and aggressive weed in rotations dominated by potatoes, and other row crops, including vegetable crops and silage maize (Lumkes, 1974).

It has to be re-iterated (see Cussans 1976) that rotation is not merely a matter of cropping, it involves herbicide use as well. A successful rotation is therefore one in which the break crops may provide conditions ecologically unfavourable to the weed and/or provide conditions for successful herbicide use. Volunteer cereals in oilseed rape provide an interesting ambivalence. The weed(s) are well adapted and capable of causing very severe yield loss to the crop. However, excellent herbicides are available so rape does qualify as a 'break crop' in respect of these and other grass weeds.

* Agricultural Development & Advisory Service & Potato Marketing Board (1972) The utilisation and performance of potato harvesters. Farm Mechanisation Studies (24) pp 36.

\+ Hughes, R.G. (1974) Crops as weeds. Proceedings 12th British Weed Control Conference 1023-1029.

(ii) Tillage

Non-ploughing techniques are a major cause of the volunteer cereal problem in oilseed rape and in autumn cereal crops. Conversely, ploughing aids the survival of volunteer potatoes by burying the tubers out of the reach of frost and the attentions of rooks and other animals.

Unfortunately, it is not always possible to decide on a system of cultivation wholly on the basis of its effect on weeds. For example ploughing may be necessary after harvesting potatoes to ameliorate poor soil conditions or to dilute residues of a persistent herbicide.

Inter-row cultivation can also be a useful means of control of these weeds. It is however impracticable or uneconomic for many crops such as field beans and oilseed rape.

(iii) Time of planting

We are seeing a trend to earlier sowing particularly of autumn sown crops. 1978 has been rather an exceptional year but, despite a moderately late harvest one is continually hearing of farmers who have planted very large acreages of cereals and oilseed rape early in the season. Many completed their planting by the first week of October, roughly the earliest date at which it was considered prudent to start planting wheat until relatively recently. Such early planting is bound to lead to increased problems with volunteer cereals.

(iv) Cultural control - an overview

Far from providing evidence on cultural control, the foregoing paragraphs have been a catalogue of ways in which farmers are abandoning such methods. All the trends in large scale farming today are towards intensivity. Intensive cereal growing, the increase in winter barley acreage, the trend towards non-ploughing techniques, earlier planting of autumn cereals, severally and collectively are increasing the volunteer cereal problem. At the other end of the scale 25% of the entire arable acreage of the Netherlands is devoted to potatoes and in some regions this rises to 50%. The resulting problem of volunteer potatoes, a national one in the Netherlands, is a minority problem in the U.K. but, where it does occur it tends to be in areas of extreme intensivity of cropping where potatoes alternate with vegetable and processed crops. Weed beet has also become more serious in areas of intensive beet cropping, with sugar beet in some cases grown one year in three.

This trend towards evolution of weed problems caused by cultural changes leads to an ambivalence in the attitudes of weed specialists. On one hand it is our duty to point out the failings of modern techniques. If these techniques are likely to change the weed flora in favour of more difficult weeds then let farmers be warned so that they can at least be prepared, even if they cannot revert to old methods. This principle applies to conventional weed species, of course, as well as the volunteer crops.

On the other hand, we must assume that these trends towards intensivity and away from cultural control of these weeds are not easily reversible. Economic pressures are likely to ensure that they continue. It is therefore equally our duty to find answers to these problems. I suggest, if this is so, that we must start taking crops as weeds more seriously. Potential herbicides must be evaluated, of course, but we also need studies of the biology of crops as weeds.

We also need continuing and purposeful liaison with other disciplines, notably plant pathologists. Their help is needed to enable us to set standards by which to judge the results of our experiments. This is because the standard of weed control required to eliminate weed competition may be quite different to the standard required to prevent carryover of disease inoculum. For example, I have referred to rotation in respect of volunteer potatoes, with the comment that populations are barely maintained in cereals. This is fine from the point of view of the husbandry of the cereals, although just occasionally a cereal crop, particularly a laid crop, may be severely affected by groundkeepers. The low populations of volunteer potatoes which do survive a long cereal 'break' may be unimportant when a 'ware' potato crop follows but not when 'seed' potatoes are grown. Here the criteria for success are much more rigorous. It is by no means unknown for a potato crop to be rejected for seed because of lack of varietal purity or the presence of virus due to volunteer plants. This may occur, albeit rarely, even after 10-12 years of cereals and grass leys.

We know very little of the analogous situation which must exist with volunteer cereals. There are no experimental data on the effect, say volunteer wheat has on the yield and saleability of winter barley, although we can make logical deductions (see Hughes 1974). The effects of volunteers on plant health are much harder to express in numerical terms, although we all accept that volunteers are a source of disease. How clean is clean enough?

3. CONTROL BY HERBICIDES

(i) Selectively in crops

There have been some notable successes and we can achieve good control of volunteer cereals in oil rape, and vice versa. However, in a review such as this it may be best to concentrate on the problems that remain and to consider the possibilities for further development.

(a) Difficult selectivities. The control of cereals is, and must remain a difficult proposition. The pursuit of progress is hampered by the fact that we do not know how much money farmers would or should be willing to pay for control of volunteers. I suggest we need to evaluate commonly used herbicides for their control of volunteers. How effective are difenzoquat and flamprop methyl against cultivated oats? Can metoxuron, chlortoluron and barban be used successfully against volunteers of susceptible varieties? It seems unlikely that the last three will be very consistent in performance but there is a real advisory need to assess the potential of such materials which are known to be useful against other weeds. There is a good analogy here in the use of metoxuron post-emergence in carrots (commonly mixed with linuron). This is an excellent general purpose herbicide and also achieves good control of volunteer potatoes in many cases. It is variable in effect on potatoes, although to some extent the causes of variability are understood (Lutman & Davies, 1976; Lutman, 1977a). However it must remain, at present, the herbicide of choice in carrot crops infested with groundkeepers.

(b) Biological problems. Volunteer potatoes in cereal crops do not normally present an adequate target for herbicides so that, even if intrinsically active materials were available they would be unlikely to achieve satisfactory results in practice. Lutman (1977b) has shown that emergence of potato shoots in cereals is not complete before the crop reaches the jointing stage. In this respect the potato is closely comparable with some other perennial weeds, notably Convolvulus arvensis and Polygonum amphibium.

(ii) Selective application

It has been suggested that chemical selectivity is difficult to achieve but, with some volunteer crops at least, there are opportunities for physical selectivity.

Holroyd (1972) has described how a glove with a pad in the palm impregnated with herbicide can be used to kill wild-oats in cereals. This principle can be used as a labour saving alternative to pulling or 'spudding' in many crop/weed situations. The principle of selective application of a non-selective herbicide can be taken further in row crops. A paper elsewhere in this session (Sijtsma et al., 1978) reviews the use of an inter-row shielded dribble bar system developed in the Netherlands for control of volunteer potatoes with glyphosate in sugar beet and silage maize.

Where the weed is appreciably taller than the crop, or can be easily discriminated in some other way, there may be other possibilities for selective application. MacWhorter (1970) has described a sprayer emitting a horizontal jet of chemical in such a way that the jet either strikes weed foliage or is caught and recirculated. Weed beet has created an interest in this subject, not surprisingly since cutting, which also involves discrimination by height, is the only practicable mechanised means of control at present. The principles which have been employed in experimental equipment are the use of impregnated rollers, conveyor belting coated with thickened herbicide solutions or another approach to the recirculatory sprayer principle (Vigoureux, 1976).

It is apparent that there is a strong case for selective application. This is by no means restricted to volunteer crops. Selective application is relevant on any weeds which are difficult to kill and where physical discrimination is possible. Such weeds range from creeping thistle, Cirsium arvense in strawberries and Populus tremulus in blueberries (see Trevett, 1966) to wild-oats, Avena spp. in cereals.

4. THE USE OF HERBICIDES BETWEEN CROPS

It is sometimes possible to overcome the difficulties of developing a selective treatment by the use of non-selective herbicides at a time of year when no crop is present.

Potatoes can be killed with either glyphosate or aminotriazole, provided there is enough foliage to retain the spray on every shoot. Shoots which have not developed foliage and which are only connected to leaf tissue of other shoots via the mother tuber may survive, sometimes with the deformities commonly associated with very low does of glyphosate (Lutman & Richardson, 1978). Thus early spraying can be ineffective but late spraying, even when tuber formation is well advanced, is effective. With glyphosate, some tubers may survive but they suffer from skin cracking and the eyes produce a mass of non-viable sprouts.

It is therefore possible to exploit the potential of these compounds in two situations; the first occurs when potatoes emerge before sowing a late crop such as dwarf beans or transplanted brassicae. Aminotriazole is not cleared for such uses but glyphosate can be used. Results can be good but the late emergence of groundkeeper potato shoots can reduce efficiency if the crop has to be planted before sufficient foliage has emerged to allow optimum use of the herbicides.

The other possible application of non-selective chemicals is to potato foliage regrowth after the harvest of a crop. All the research has been carried out on cereal stubbles but other crops such as peas could be exploited in this way. This technique can be excellent and field results have been discussed by Baart & Sijtsma (1978) and Lutman (1978). However, in some cases there may be very little regrowth after cereal harvest. Lutman has recorded instances where only 40-50% of the potato plants present in spring barley crops produced green shoots in the stubble. Clearly in such cases the potential effect of a herbicide would be small.

The reason for this poor regrowth appears to be that some plants complete their annual cycle of growth, producing daughter tuber(s) and becoming naturally senescent before cereal harvest. Others although not naturally senescent appear to be so advanced that regrowth does not occur. Mulder and Baart have suggested that early potato varieties are those most liable to poor regrowth, which fits this theory. My colleague Lutman who has developed this theory has accumulated evidence that factors which increase competition in the cereal crops, or in some way prevent the potato from completing its annual increment of growth, tend to increase the degree of stubble regrowth. The factors he has studied include plant density of the cereal crop, winter versus spring cereals and removal of potato foliage in the early part of the season (P.J.W. Lutman, personal communication).

In practice, we believe good results can be achieved with reasonable consistency from applications of these herbicides to cereal stubbles showing good regrowth. Better results are likely following competitive crops of winter cereals particularly winter barley but results may never be entirely predictable because the size and vigour of the shoots which do regrow may mask the presence of large numbers of plants which have not regrown.

Volunteer cereals may also be killed by non-selective herbicides applied between crops. Indeed the only real hope of control, in many cases, occurs when the shed seeds are stimulated to germinate and the resulting seedlings killed by herbicides. Paraquat, aminotriazole, dalapon, or glyphosate can be used but the former is the usual choice unless perennial weeds need to be controlled at the same time. The standard advice (Hughes, 1974) is to prepare a shallow, fine seedbed by early stubble cultivation to encourage maximum germination. In a dry autumn, such as 1978, a number of seeds may fail to germinate until after the next crop is sown. However, the 1977-1978 season was a notable one for volunteer cereals despite a wet harvest, which resulted in many crops sprouting in the ear. It appears that seeds which have started to germinate in this way and then had their germination arrested acquire marked secondary dormancy (D.B. MacKay, personal communication). This phenomenon is not very clearly understood but it is recognised by the seed trade. This could be a serious and much more common feature of the behaviour of cereals as weeds. In the rough irregular seedbeds occurring in cereal stubbles it may be very common for seeds to start germination and then dry out before a successful seedling is produced. This is pure hypothesis but I would suggest that this possibility of secondary dormancy in the field should be investigated. It may be that cereals are better adapted as weeds than we have believed possible. My colleague C. Bastian and I have observed, this summer and early autumn, germination of barley seeds, from depths of 1 to 4 cm in an area maintained free of all vegetation throughout 1978. We believe these seeds were shed as volunteers in 1977 and germinated up to 14 months later. These seedlings were relatively few in number and this persistency does not perhaps have to be taken too seriously. However, I hope it does stress the thesis that we must take these weeds more seriously as targets for biological study as well as empirical testing of control methods.

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CHEMICAL ROGUING OF BULB CROPS

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Summary Paraquat and glyphosate were very effective for roguing tulips, but less so far Narcissi. High concentrations were necessary especially on plants from large bulbs, and early applications were most effective. Paraquat gave a much more rapid kill of foliage than did glyphosate.

The herbicide glove was the most effective means of application giving the greatest bulb-kill in treated plants. It also caused considerable damage to non-treated plants which resulted in yield reduction. The syringe and cocktail sticks methods were also effective in roguing, causing little damage to non-treated plants and no reduction in yield.

A paraquat low pressure aerosol was almost as effective as the syringe or cocktail sticks but it was necessary to allow foam discharge for at least one second per plant to achieve a high bulb kill. It was much more convenient to use than the other means of application.

INTRODUCTION

Roguing of Narcissus and tulip crops means the removal mainly of off-type or diseased plants. Traditionally it involves the digging out of the unwanted plants complete with their developing bulbs. This operation is not only laborious and time-consuming but can cause considerable damage to neighbouring plants particularly in dense stands grown in ridges.

Chemical roguing of bulbs has obviously been considered for many years. Most bulb growers are almost certainly using it in some form, and there has been some research done on the subject (Miller, 1976). However, most information so far appears to be on the level of personal communication rather than in the form of published results.

It appears that paraquat in some form has mainly been looked to for roguing. Applications have been made by herbicide glove, syringes, impregnated cocktail sticks, and more recently by a special low pressure aerosol containing paraquat.

This paper gives results of experiments on the effectiveness and selectivity of different chemicals and different application methods for roguing Narcissi and tulips.

METHOD AND MATERIALS

The chemicals used were paraquat (20% a.i.), glyphosate (48%), aminotriazole (20%), 2,4,5-T (50%) and mecoprop + 2,4-D (50%), each being tested at a number of concentrations. All trials were on Narcissi and tulips grown in the open at Kinsealy Research Centre. There were at least 4 replications in each experiment. To test the killing power of treatments small plots of 20 widely spaced bulbs were treated at flowering. The effectiveness of the treatments was measured both by observations on the foliage and later by harvesting and recording the survival of bulbs under each plant.

The selectivity of treatments was tested by treating off-types in plots containing 200 bulbs of one type plus 20 bulbs of a readily-distinguishable off-type, planted in ridges at normal density. Damage to non-treated plants was measured by foliar observations and records of bulb yields. The effectiveness of the treatments was assessed by planting all the harvested bulbs the following season and observing the proportion of off-types.

Applications were made in liquid form by herbicide glove, syringe and cocktail sticks, and as a foam by a low pressure aerosol. The glove was used to grasp each plant near the base and was then drawn up over the foliage. Prior to other treatments flowers were harvested, tulip stems being cut off just above the bottom leaf and Narcissus stems broken off near the base. The syringe, delivering 1 ml herbicide per plant, and the aerosol were directed into the bottom axil of tulip and onto the broken stem surface of Narcissus. Cocktail sticks, immersed in herbicide for 10 minutes and soaking up 1 ml per 5 sticks, were inserted into the bottom axils of tulip and the cut stems of Narcissus.

RESULTS

Screening of herbicides

Five herbicides, each at 5, 15 and 30% of commercial strength, were applied by herbicide glove to tulips cv Apeldoorn and Narcissus cv Carlton. Aminotriazole, 2,4,5-T and mecoprop + 2,4-D were relatively ineffective, and results of the highest concentrations only are shown in Table 1.

Table 1

Bulb survival (%) from plants treated by herbicide glove

Herbicide	Concentration (% a.i.)	Narcissi	Tulips
Paraquat	1.0	28	15
Paraquat	3.0	12	5
Paraquat	6.0	15	7
Glyphosate	2.4	20	12
Glyphosate	7.2	17	7
Glyphosate	14.4	10	2
Mecoprop + 2,4-D	15.0	52	42
Aminotriazole	6.0	77	35
2,4,5-T	15.0	60	47

Paraquat and glyphosate at the higher concentrations were very effective especially on tulips. The main difference between paraquat and glyphosate was in the rate of foliage death. The former caused complete collapse of tulip foliage in 3 - 4 days while glyphosate-treated foliage appeared relatively healthy for at least 10 days.

Comparison of application methods

Paraquat and glyphosate, each at 50% of commercial strength, were applied by herbicide glove, syringe and cocktail sticks to Narcissi cv Carlton and tulips cv Rose Copland (Table 2). The two herbicides and all three methods of application gave good results on tulips, but on Narcissi only the herbicide glove was highly effective.

Table 2

Bulb survival (%) from herbicide-treated plants

Method of application	Paraquat (10% a.i.)		Glyphosate (24% a.i.)	
	Narcissi	Tulips	Narcissi	Tulips
Herbicide glove	7	0	2	2
Syringe	15	5	17	5
Cocktail sticks	28	2	20	10

Effect of bulb size and time of application of herbicide

Glyphosate at 5 and 30% of commercial strength was applied by herbicide glove to Narcissi cv Carlton and tulips cv Apeldoorn. Two sizes of bulbs were planted of each crop, and three times of application were tested (Table 3). In Narcissi only the higher concentration gave good results; better roguing also occurred with early application and in plots planted with smaller bulbs. In tulips, bulb kill was high in all treatments except the combination of low concentration of herbicide and large bulbs.

Table 3

Bulb survival (%) from plants treated at three stages with glyphosate at two concentrations

Cultivar	Bulb size (cm)	Concentration (% a.i.) 2.4			14.4		
		Time of treatment			Time of treatment		
		E	M	L	E	M	L
Carlton	12/13	22	42	46	4	5	7
Carlton	15/17	37	33	50	10	7	17
Apeldoorn	6/8	5	0	7	0	2	0
Apeldoorn	10/11	10	17	15	0	5	2

E = 50% bloom; M = 1 week after E; L = 2 weeks after E

Selectivity of application methods

Plots were planted with 200 bulbs of tulips cv Apeldoorn (red flowered) plus 20 bulbs of Golden Apeldoorn (yellow flowered), or with 200 bulbs of Apeldoorn only. The Golden Apeldoorn plants were treated with paraquat at 50% of commercial strength by herbicide glove, syringe or cocktail sticks. Ten days after treatment, observations were made on the number of Apeldoorn plants showing symptoms of paraquat damage (Table 4). The herbicide glove method resulted in severe damage to neighbouring plants, and the other methods caused slight damage. Only the herbicide glove method gave a reduction in yield. When the harvested bulbs were replanted the following season, counts of yellow flowers indicated that all methods were relatively successful in reducing the proportion of off-types.

Table 4

Selectivity and effectiveness of application methods of paraquat in roguing a mixed population (Apeldoorn 91%; Golden Apeldoorn 9%)

Application method	Effect on non-treated plants Plant damage % Affected	 Severity*	 Yield Kg/plot	% Rogues in succeeding crop
Glove	22	4.2	8.2	0.2
Syringe	8	8.7	10.4	0.6
Cocktail sticks	5	9.3	10.1	0.7
Untreated - Apeldoorn only	0	10.0	9.9	0.0
Untreated - Apeldoorn + Golden Apeldoorn	0	10.0	11.1	8.5

* Scale: 0 (complete kill) -10 (no damage)

Effectiveness of paraquat low pressure aerosol

The paraquat low pressure aerosol was tested on small plots of tulips cv Rose Copland. The aerosol was applied to each plant for 0.5, 1.0, 1.5 or 2.0 seconds. Liquid paraquat at full strength was applied for comparison by the syringe and cocktail sticks methods. At harvest, the percentage of plants with viable bulbs was recorded (Table 5).

Table 5

Bulb survival in tulips treated with paraquat aerosol at four rates and with full strength liquid paraquat by syringe or cocktail sticks

Treatment:	Aerosol				Syringe	Cocktail sticks
Duration of treatment (Secs.):	0.5	1.0	1.5	2.0	-	-
Bulb survival (%):	13	7	4	5	2	0

The aerosol gave good bulb-kill but it was necessary to apply it to each plant for at least one second. A longer period of treatment did not increase the response. None of the aerosol treatments were as effective as the syringe or cocktail sticks.

DISCUSSION

Chemical roguing in some form is likely to be adopted more and more by bulb growers. Ease of operation and reliability of bulb-kill will probably be more important than complete selectivity. Although glyphosate leaves slightly fewer surviving bulbs and is a safer material to handle, paraquat has a distinct advantage because it kills foliage so quickly. This is particularly important in roguing virus-infected tulips since it lessens the spread of infection.

The choice of application methods is more difficult. The herbicide glove method is cumbersome and slow and although effective it is liable to cause an unacceptable level of injury to plants close to those being treated. Syringes and cocktail sticks have proved to be both effective and selective and they provide a relatively simple and quick method. However, their use does involve prolonged handling under field conditions of a very toxic liquid in a highly concentrated form.

The advent of the paraquat low pressure aerosol answers some of the needs. It is relatively easy to use and is presumably much safer in operation. An operator may, however, give an inadequate dose unless he is very conscious of the need for an application of one second at least per plant. The need to cut the stem of tulips to minimise the risk of dying foliage injuring neighbouring plants makes the task much more laborious and time consuming. With the solution of such problems and perhaps with some mechanisation of the operation, chemical roguing should become an integral part of modern bulb production.

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