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PLANNED WEED CONTROL IN THE ARABLE CROPS OF EASTERN ENGLAND

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Eastern England is primarily an arable cropping area, although livestock production is an important and integral part of the farming system on many holdings. Some livestock enterprises, such as poultry and pigs, can be self contained but where cattle occur on farms then they are generally closely associated with the arable farming system by utilising by-products from the crops grown or permanent pastures not suitable for arable cultivation.

The range of soil types and the climate occurring in the Eastern Counties have influenced the cropping with the result that a wide diversity of crops are grown.

This range of crops creates problems on the individual farm in that few rotations are limited to less than three types of arable crop and it is probably only on the really heavy soils where there are quite strict limitations on what can be grown economically. It is not unusual for a mixture of 'agricultural' and 'horticultural' crops to be grown on the same farm and even soft, bush and top fruit may be included.

With this very wide diversity of cropping the weed control policy is virtually dictated by each crop in isolation. These are treated individually with little consideration for the rest of the rotation. However, there is an increasing awareness of the need for carefully planned weed control within each crop and in this connection the use of sequential applications is gaining in popularity. In such cases a programme is planned with choice of herbicides to complement one another although adjustments may be made during the growing season if circumstances dictate. Sugar beet is the prime example with more than half of the area grown now being treated with at least two applications. If _Agropyron repens_ is present then weed control for beet will normally commence in the autumn with the use of foliar acting chemicals (for example: aminotriazole, glyphosate, or paraquat) or with the soil-acting herbicide TCA. The basic programme for control of annual broad leaved weeds is the use of products both pre-emergence and post-emergence. The pre-emergence spray can be a soil incorporated or surface application, or may utilise both if, for example, di-allate is used for control of _Avena fatua_ and followed by a surface applied herbicide at the time, or soon after, the crop is drilled. Treatment post-emergence will depend on the stage of growth of the sugar beet and weeds, the health of the crop, and the weather conditions prevailing at the time. The first application is normally phenmedipham and if a further spray is considered necessary it might be one of the many recommended mixtures with phenmedipham (adjuvant oil, barban, ethofumesate, lenacil or pyrazone) or trifluralin. Other crops in which herbicide sequences are being used increasingly include cereals, carrots, onions, peas and horticultural brassicas.

There are three major exceptions to this _ad hoc_ approach to weed control in the arable crops of eastern England - control of grass weeds particularly _Avena fatua_, _Alopecurus myosuroides_ and _Agropyron repens_ - when the use of relatively persistent herbicides are considered - and when crop plants occur as weeds, either from seed or groundkeepers.

Controlling grass weeds

Grass weeds, both annual and perennial, pose important problems in many areas and control both herbicidal and cultural is considered in the context of the whole rotation and farming system rather than on the basis of an individual crop. Control measures do not differ significantly from those practiced elsewhere and have been the subject of many papers at recent British Weed Control Conferences, including reviews by Carpenter (1972), Elliott (1972) and Thurston (1972), and the farmers viewpoint by Jenkinson (1976) at the 1976 British Crop Protection Conference - Weeds.

There are crops that are particularly susceptible to competition from these species which do not have herbicides to give acceptable control. Grassy weeds are rarely uniform in population over a whole farm and every opportunity is taken to place these 'susceptible' crops on the 'cleaner' areas.

In addition, the many row crops that are grown can provide the opportunity for cultural control during the growing season. However, these are really no longer considered 'cleaning' crops certainly as far as perennial weeds are concerned, and in many cases would not be grown on land so infested.

Use of persistent herbicides

The use of persistent herbicides, particularly in the spring and summer, may leave enough residues to jeopardize the growth of a succeeding crop, especially if sown in the following autumn. Therefore, consideration must be given not only to the herbicide to be used in a specific crop but also to what crop follows in the rotation. Advice is given in commercial literature and also in 'Approved Products for Farmers and Growers' (Agricultural Chemicals Approval Scheme, 1976). Commonly used herbicides that require a lengthy time interval to be left between application and the planting of succeeding crops include atrazine, ethofumesate, propyzamide, simazine and trifluralin.

Crops as weeds

The incidence of arable crops appearing as 'volunteers' and acting as weeds is increasing and many might echo the sentiments of King (1974) when considering 'volunteer' crops in the processing industry. He wrote that the difficulties encountered in avoiding or controlling these "...make this probably the most important production problem facing the industry at the present time."

The occurrence of 'volunteers' can cause complications in four general ways: (a) by providing a 'green bridge' for pests and diseases; (b) by adversely affecting growth and yield; (c) by affecting harvesting;(d) by contamination of harvested produce.

(a) 'Green bridge' for pests and diseases

Weeds do not always carry pests and diseases that will attack a crop whereas the 'green bridge' formed by 'volunteers' can, at least, perpetuate those associated specifically with the original crop. Not only can the normal break between harvest and a winter or spring sown species be bridged but the full benefit of a recognised break crop may not be fully realised.

There are many examples of pests and diseases that can be perpetuated in this way. For cereals Hughes (1974) has listed powdery mildew (Erysiphe graminis), rusts (Puccinia striiformis, P.hordei), glume blotch (Leptosphaeria nodorum), leaf blotch

(*Rhynchosporium secalis*) and net blotch (*Pyrenophora teres*). For oil rape Hughes (1976) has listed cabbage seed weevil (*Ceutorrhychus assimilis*), bladder pod midge (*Dasyneura brassicae*), mealy cabbage aphid (*Brevicoryne brassicae*), powdery mildew (*Eryisphe polygoni*). dark leaf spot (*Alternaria brassicae*) and club root (*Plasmodiophora brassicae*). Lutman and Elliott (1973) have indicated that potato 'volunteers' can affect the health of plants grown in seed production areas, can reduce the rate of decline of potato cyst eelworm (*Heterodera rostochiensis* and *H.pallida*), and can transmit tuber borne bacterial and fungal diseases which would be of particular importance where VTSC stocks were grown.

Beet cyst eelworm (*Heterodera schachtii*) can be perpetuated by both sugar beet and oil rape and therefore rape 'volunteers' could cause serious problems in rotations containing sugar beet by encouraging a build up of the population of the pest in the soil.

(b) Effect on husbandry, growth and yield

'Volunteers' act as weeds and therefore cause all the repercussions found normally with weeds. Many modern varieties have been bred for vigour with the result that when occurring as 'volunteers' in other crops their competitive effect is more pronounced. An example of this was suggested by Lutman and Elliott (1973) with groundkeeper potatoes in beet, carrots, onions and brassicas.

'Volunteers' may cause severe difficulties when they arise in their 'own' crop species. Hughes (1974) has suggested that cereal 'volunteers' emerging before sowing can affect seedbed preparation and subsequent drilling. If they occur in the crop the increase in effective plant population may result in a yield loss.

Beet as a weed in sugar beet can have serious consequences because most 'weed beet' are annual in habit and therefore have no real yield potential. These 'weed beet' cannot be controlled within the row during the seedling stages because they cannot be distinguished from the plants sown and therefore are a menace whether the crop is hand singled or drilled to a stand.

(c) Effect on harvesting

The efficiency of harvesting, whether by hand or machine, can be reduced when any weed is present. A greater bulk of material has to be dealt with and this is particularly serious if the 'volunteer' is still green and affects the moisture content or appearance of the produce. Under these circumstances a pre-harvest desiccant may be necessary such as when potatoes occur in dried peas and navy beans (King,1974). The presence of 'volunteer' cereals in cereal crops can lead to a build up of disease which may cause lodging and uneven ripening (Hughes,1974).

(d) Contamination of harvested produce

This is a problem that occurs in many crops as a result of the presence of 'volunteers'.

Harvested seeds can be easily contaminated. If such a crop is self pollinated then the 'volunteers' have to be present within the field, for example the wrong variety being present in cereal crops grown for seed (Hughes,1974). With cross pollinated species, contamination can come in the form of pollen either from within the field or outside. This aspect is important with sugar beet seed crops, particularly if the 'volunteers' are of annual habit. Oil rape can be contaminated by 'volunteer' pollen. This can be important if the 'weeds' are old types with seed of high erucic acid content, or varieties with a high glucosinolate content being present in low glucosinolate types (Hughes,1976).

King (1974) has indicated that produce contamination by 'volunteers' is very important in crops produced for processing and that potatoes are particularly bad in this respect in vining peas, broad beans and dwarf beans. Potato 'apples' are similar in size, shape and density to peas and broad beans and can pass through mechanical cleaning operations and have to be removed during the final inspection. This is not possible with dwarf beans if the contaminants are present when sliced and therefore careful pre-harvest field inspection is necessary.

Control of 'volunteers'

Every opportunity must be taken to control these 'weeds.' When the land is free from crops cultivations can be used to induce germination so that subsequent growth may be controlled by further cultivation or herbicide use. It is important in this context that cultivations are restricted in depth because if the 'volunteer' seeds or groundkeepers are buried too deeply there is a danger of inducing dormancy or protecting them from the various agencies that may reduce their numbers. Direct drilling may be helpful in this respect but unfortunately there are many rotations in eastern England containing crops that cannot be sown in this way.

In row crops, inter-row cultivation or spraying with a non selective contact herbicide can be helpful in containing some of the 'volunteer' problems.

Cereals

Hughes (1974) at the 12th British Weed Control Conference outlined various methods of control. The selection of species and varieties that exhibited 'low shedding' qualities and the employment of shallow stubble cultivations with the subsequent use of paraquat or glyphosate would be helpful. For within crop control Hughes suggested the utilisation of cereal herbicides that had some crop or variety limitations, e.g. benzoylprop-ethyl to control barley in wheat, barban against certain barley varieties in barley, and chlortoluron against certain wheats in wheat. For cereals in other crops Hughes indicated that the following would be helpful: triazine derivatives in field beans and maize; linuron in linseed and sunflower; trifluralin in brassicas and other vegetables; TCA, dalapon, carbetamide or propyzamide in oil rape.

In addition ethofumesate might be helpful in herbage seeds.

Most of the sugar beet seed crops are grown in situ under a cover crop which is usually barley. Once the 'nurse' crop has been harvested 'volunteer' cereals are a common problem and these may be controlled by the use of TCA, propham, or a mixture of the two, or dalapon.

Potatoes

Lutman and Elliott (1973) and Lutman (1974a) have indicated that groundkeepers are less likely to survive if they are left near the soil surface because they are more liable to be killed by low winter temperatures and be attacked by birds, especially rooks.

Working with pot experiments Lutman (1974b) found that chlorpropham delayed sprout emergence and trifluralin, picloram, propyzamide or dichlobenil when applied to the soil prevented sprout growth. Both picloram and dichlobenil killed the parent tuber but if used in the field would pose problems with their persistence. Unfortunately, trifluralin and propyzamide only inhibited sprouting and when the tubers were moved to fresh soil they grew so that in practice these two chemicals might not be fully effective.

The vigour of potatoes and the size of their food reserve made them difficult to control with post-emergence herbicides and from work at the Weed Research Organisation (1976) it appears that most chemicals are ineffective. Glyphosate or aminotriazole will kill the plants if sufficient foliage is present to ensure adequate uptake of the herbicides. If so, then these two herbicides will also kill, or prevent sprouting of the daughter tubers attached to the parent plant at the time of application. It is suggested that these chemicals may be most useful in autumn stubbles.

Pre-harvest desiccants may be helpful in cereals (Lutman and Elliott,1973) and in dried peas and navy beans (King,1974).

A recent innovation which has been developed in Holland is the inclusion of an attachment to the harvester to crush the small tubers that fall through the main web (Crisford and Trow-Smith,1976). Encouraging results have been obtained and trials are to be started in the United Kingdom to assess the potential of this technique on the various soil types in which potatoes are grown.

Oil rape

Various methods of control have been outlined by Hughes (1976) which cover the harvest period, after harvest and control within various crops. It is suggested that the choice of 'low shedding' and strong strawed varieties will reduce seed loss and that hand tidying of swaths, correct setting of combines, cutting and swath lifting under dull and cool conditions, making trailers 'leak proof' and using covers on them will all help against seed loss. For contact kill of germinated seeds a mixture of paraquat and diquat with a wetter appears to be the best.

Hughes suggests that 'volunteer' oil rape behaves like Raphanus raphanistrum in susceptibility to common herbicides and in cereals can be controlled by MCPA, 2,4-D, mecoprop, or methabenzthiazuron. Selective control in other crops by pre-emergence herbicide should be satisfactory providing moisture is available or the application is not too long delayed.

The author of this paper has observed that control of rape in sugar beet by phenmedipham post-emergence is possible providing the oil rape seedlings do not have more than two true leaves. Better contact control can be obtained by the addition of barban or adjuvant oils to the phenmedipham.

Sugar beet

This crop can occur as a 'weed' from previously shed seed or as a groundkeeper. It is those plants developing from seed that appear to be the greatest problem (Longden,1974 and 1975, British Sugar Corporation,1976).

For control in the beet crop the British Sugar Corporation (1976) has made the following recommendations: early working of seedbeds with re-growth killed by subsequent cultivation or herbicide application (stale seedbed), tractor hoe close to the crop row, remove early bolters during second or late hand hoeing, pull and remove early bolters by mid July, mechanically cut bolters by mid July if there are too many to pull and repeat the operation in mid August and harvest infested fields early. For the years between beet crops it is suggested that in stubbles straw is burnt, shallow cultivations are practiced early, and that seedlings are treated with glyphosate or diquat, use growth regulator herbicides in cereals, where possible introduce early harvested crops into the rotation, and ensure good farm hygiene.

From observations in the field it has been found that growth regulator herbicides may not always give satisfactory control of 'weed beet' in cereals. A similar observation was made by Hilton (1976) when evaluating various post-emergence herbicides applied to annual wild beet seedlings with two true leaves in a pot trial in the glasshouses of the Weed Research Organisation. He found that MCPA, MCPB and mecoprop did not control the beet, although extreme distortion was observed. Isoproturon, chlortoluron and metoxuron gave quite good control which was improved by the addition of an adjuvant oil. Ioxynil was very effective but did not match the results from bentazone which completely killed all of the beet.

Chlortoluron and isoproturon can be used in winter wheat and winter barley; metoxuron alone in winter wheat, winter barley and carrot; metoxuron with simazine in winter wheat and winter barley; ioxynil alone in onion and leek; ioxynil with dichlorprop and MCPA and ioxynil with mecoprop in cereals; ioxynil with linuron in onion, leek, spring wheat and spring barley; bentazone alone in french, navy and runner beans; bentazone with dichlorprop in cereals; and bentazone with MCPB in peas.

Individual bolters may be hand rogued by spot treatment with glyphosate (Longden,1974) or with a 'roguing glove' (Breay,1975).

Herbage seeds, particularly ryegrass

Grass 'volunteers' if numerous can be particularly competitive. Many of the grass killers available for use in cereals can control ryegrass and other 'volunteer' herbage grass seeds.

Low doses of TCA (1 kg/ha) as a tank mix with pre-emergence herbicides will give control of crop grasses in sugar beet.

Other 'volunteer' crops

Field beans, peas, bulbs, Russian comfrey, horseradish and clover have all occurred as 'volunteers.'

It is important to start control procedures against 'volunteers' as soon as the crop is harvested. In the majority of cases this will be in the autumn and the use of cultivations designed to keep the seeds or groundkeepers close to the soil surface in order that they are subjected to all possible factors that might reduce their potential to survive. Coupled with this will be the need to induce as many as possible of the 'volunteers' to grow in order that these can be killed by further cultivations or herbicide application. Following crops that have a particularly suppressive growth habit can be helpful in restricting 'volunteer' development and reproduction but the use of such crops may not always be economic. Another means of attack is to re-arrange the rotation in order that the crops following ones where 'volunteers' are likely to be produced are those that would provide the best opportunity for control. For example, good control of cereals can be achieved in field beans, maize, brassicas and oil rape. Cereals provide an opportunity for successful control of emerged 'volunteer' oil rape but seeds of this weed can remain dormant for several years.

CONCLUSIONS

The control of annual broad leaved weeds in eastern England is treated mainly on an individual crop basis. This is not the case with grass weeds which are attacked throughout the rotation. If the infestation of monocotyledonous weeds is severe then crops may be selected which offer the opportunity for a high level of control.

The occurrence of crop plants as weeds is increasing and is having a major impact on many farming systems. The problems caused by the 'volunteers' include:

(a) perpetuation of pest and disease infestations,
(b) competition for environmental resources,
(c) reduction in harvesting efficiency,
(d) contamination of harvested produce.

The control of 'volunteers' is also having to be considered on a rotational basis. Every opportunity must be taken to reduce their population with the ultimate aim of complete control. This may mean some adjustments in the crops grown and their sequence in the rotation. It is imperative that their importance is not underestimated.

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SOIL MANAGEMENT WITH HERBICIDES - THE RESPONSE OF SOILS AND PLANTS

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Summary Most fruit trees are now grown in herbicide treated strips with mown grassed alleyways between the tree rows while a small acreage is under total herbicide management. The effect of herbicide use on soil conditions and the influence of grass competition on tree performance are reviewed in this paper using mainly data from trials at East Malling.

The use of herbicides has consistently resulted in increased bulk densities at the soil surface although effects on pore size distribution have been more variable. Herbicide treated soils are frequently more acid than grassed soils but have higher nitrate and phosphorus contents. These differences begin to develop early in the life of the orchard.

Grass competition reduces the weight of tree roots and root density in the soil but increases the depth of rooting and the root-shoot ratio. Soil moisture deficits are always higher under grassed than under herbicide treated land. Where trees are grown in a herbicide strip with a grassed alley most root growth and mineral nutrient uptake is from the herbicide strip.

Increasing the proportion of herbicide treated land in the orchard has consistently increased growth and cropping.

INTRODUCTION

For many years tree fruits in the U.K. were grown under arable conditions i.e. using cultivations to suppress weed competition. During the 1940s cultivation was replaced by mown grass as a soil management treatment for established trees with considerable advantages in terms of yield and fruit quality (Rogers et al., 1948). The introduction of effective soil-acting herbicides in the late 1950s allowed satisfactory weed control without machinery passing between the trees within a row and most fruit trees are now grown in bare herbicide treated strips (black strips) with mown grass alleyways between the tree rows. A small but increasing area (Robinson, 1974, Atkinson and White, 1977) is under total herbicide management.

When herbicides were first used in fruit crops fears were expressed about the long-term consequences for the tree, its fruit and the soil (Tubbs, 1966). Approximately 15 years experience of the use of herbicides in top fruit orchards is now available. The relative proportions of grassed and herbicide treated land around the tree have usually been based on convenience, rather than on a true assessment of the effects of varying amounts of grass competition. With information from trials at East Malling Research Station as a basis, this paper reviews the effects of herbicide use on soil physical and chemical properties together with the effects of grass competition on fruit tree growth and productivity.

Herbicide Use And Soil Condition

There is little published information on the long-term effects of herbicide use on soil conditions in orchards or under ornamental trees. In recent years the effect of the direct drilling of cereals (zero tillage) on soil condition has been extensively studied (i.e. Baeumer and Bakermans, 1973, Finney and Knight, 1973, Soane et al., 1975). Compared with arable cultivation, direct drilling has resulted in changes in soil physical condition (bulk density, cone resistance, porosity, etc.) particularly at the surface. For herbicide treated soils in raspberry plantations, Bulfin (1967), Bulfin and Gleeson (1967), Soane et al. (1975) and Clay and Davison (1976) obtained results similar to those for direct drilled cereals. Traffic on the soil surface and the dispersing effect of rain water seeping down soil channels have been suggested as the most important factors influencing the compaction of undisturbed soils (Russell, 1966). In fruit orchards there is more machinery movement and the extent of ground shelter by vegetation is less than in either cereals or raspberries and so compaction could be more serious. Available information on soil physical condition in fruit orchards has been reviewed by Robinson (1974) and Atkinson et al. (1977b).

Soil structure

Information on the effect of a number of non-cultivation treatments involving varying amounts of grassed and herbicide treated soil is available from two trials at East Malling, one in a mature orchard and one in a young orchard.

In the established orchard trees of Cox's Orange Pippin/M.26 were planted in spring 1966 at a spacing of 3.7 x 2.4 m. From planting the trees were maintained in a 1.5 m herbicide strip with grass cover in the alley. When the trees were 6 years old (1972) either the original treatment was retained unchanged (herbicide strip) or the grass in the alley was killed to give an area completely under herbicide management (overall herbicide), or the herbicide strip was grassed down, except for a narrow (approximately 0.3 m) band beside the trees (overall grass). This orchard, therefore, provides the comparison of 9-year-old herbicide strips and grass alleys together with the effect of 3 years of herbicide following grass in the alley and grass following herbicide in the strip.

In the young orchard, trees of Cox/MM.106 were planted in December 1972 at a spacing of 4.5 x 4.5 m and maintained from planting either in a wide (1.7 m) herbicide strip with a grassed alley, or under overall herbicide or in a narrow (0.3 m) herbicide strip. Effects were compared after 2 years treatment. These orchards are subsequently referred to as the established and the young orchard.

In both orchards (Table 1) there was a higher bulk density at the surface of herbicide treated soil but little difference below 10 cm depth. In the established orchard bulk density at the surface was lowest under the grassed alley and highest under the herbicided alley. Grassed and herbicided strips were similar and intermediate. In the young orchard bulk density was lower in the grassed alley than in the herbicide strip. Covering the surface of the herbicide strip with straw 1 year after planting had no effect on bulk density. These results suggest that differences quickly became established, and also that the dispersing effect of rain is at least as important to soil compaction as traffic movement. Although none of the values for bulk density are likely to have adverse effects on root penetration they are higher than those recorded by Jelley et al. (1974), who also found higher values for herbicide treated land.

Table 1

The bulk density ($g\ ml^{-1}$) of two orchard soils

Treatment	Position	Depth (mm) 0-50	75-125	150-200
Established orchard				
Herbicide strip	strip	1.48	1.44	1.47
	alley	1.34	1.51	1.55
Overall grass	"strip"	1.43	1.50	1.47
Overall herbicide	alley	1.54	1.57	1.52
Young orchard				
Herbicide strip	strip	1.59	1.57	1.52
	alley	1.45	1.61	1.50
	strip + straw	1.59	-	

SE for Comparisons Established orchard 0.032, Young orchard 0.030

In the established orchard the proportion of soil pore space drained at < 250 mm tension (large pores) was greatest in the herbicide strip, at the surface, 75 and 150 mm depth and was similar in other treatments, (Atkinson et al., 1977b). The porportion of the total soil volume consisting of pores drained at this tension (Table 2) was also greatest in the herbicide strip.

Table 2

Large pores as a % total soil volume

Treatment	Position	Depth (mm) 0-50	75-125	150-200
Herbicide strip	strip	14.6	17.9	15.3
	alley	9.8	10.8	9.9
Overall grass	"strip"	10.2	11.7	12.4
Overall herbicide	alley	10.3	8.6	11.6

These values are higher than those reported by Jelley et al. (1974) who, in contrast, found more pore space under grassed than under herbicide treated soil.

Soil pH and mineral content

Increases in soil acidity have often occurred when herbicides are applied for long periods to uncultivated soil (i.e. Jordan and Bailey, 1968, Atkinson, 1973, White, 1975). The effect of soil management on available nutrients in the established orchard is shown in Table 3.

Table 3

pH and available nutrients

(mg l^{-1}) in the established orchard

Treatment	Position	pH	P	K
		Depth (mm)		
		0-70	0-70	0-70
Herbicide strip	strip	5.1	49	267
	alley	6.2	24	242
Overall grass	"strip"	5.6	42	285
	alley	6.4	24	267
Overall herbicide	"strip"	5.3	49	283
	alley	6.2	30	255
Standard Errors				
Effect of Trt at posn	(>6 df)	0.4	3.0	17
Posn within Trt	(9-36 df)	0.2	3.1	18

At 0-70 mm depth pH was lower in the herbicide strip than the grassed alley but did not differ between grassed and herbicided alleys. P was consistently higher in the strip than the alley, and was slightly higher in herbicided strips or alleys than in corresponding positions when grassed. K was slightly higher in the strip although the difference was not significant. Similar effects were observed in the young orchard (Atkinson et al., 1977b) indicating that these changes could occur within the first few years of orchard life. The removal of grass in the established orchard to produce the overall herbicide plots did not lower the pH in the subsequent 3 years. In the 5 years following planting, no increase in acidity was found in high density apple plantings, under overall herbicide management, by Atkinson et al. (1977b) and analysis of soil from the strips and alleys of a 10-year-old pear orchard on a silt loam soil (Atkinson, unpublished data) also showed no increase in acidity (pH = 5.93 strip, 6.10 alley LSD at P = 0.05, 0.20). Although usual, increased acidity is not an inevitable consequence of herbicide use. Work in Holland (Delver, 1974, Lord, 1976) has shown higher potassium levels in the herbicide strip.

Organic matter

The maintainance of adequate levels of organic matter can be important for good soil structure. Organic matter levels in the established orchard at EMRS were higher in the grassed alley than in the herbicide strip although they did not decrease in the overall herbicide plots in the 3 years following grass removal (Table 4).

Table 4

Soil organic matter (% DW) at

0-70 mm depth in the established orchard

Position	Herbicide strip	Treatment Overall grass	Overall herbicide
Strip	2.14	2.21	2.17
Alley	3.03	2.96	3.05
Standard errors	Treatments at given position (> 6 df) 0.21	Position within treatments (9-36 df) 0.19	

This difference between grassed and herbicide treated land is similar to that described by Jelley et al. (1974).

Erosion

In a survey of commercial growers' experiences with overall herbicide soil management systems Atkinson and White (1977) found that 37% of growers who had used the system had experienced some erosion and of these 11% had serious erosion. Approximately 20% of growers replying to the survey had reverted to grassed management in some orchards and of these 42% gave soil erosion as the reason for the change. Erosion appears less of a problem with herbicide strip management. On overall herbicide areas erosion has been reduced by a straw litter (Atkinson, 1975, Atkinson and Allen, 1976) or by allowing a cover of moss to develop (Atkinson, 1975, Stott, 1976). Synthetic soil conditioners, i.e. polyvinyl alcohols, may reduce erosion. Erosion plus compaction resulted in a fall in soil surface level of >10 mm in 8% of measured positions on plots sprayed with polyvinyl alcohol compared with 25% on unsprayed plots (Atkinson and Farre, 1977). On overall herbicide areas but not on herbicide strips, there is also a redistribution of simazine resulting in accumulation in some areas of the orchard and depletion with corresponding poor weed control elsewhere (Atkinson and Allen, 1976).

Herbicide Use And The Plant

The use of herbicides allows the growth of tree crops in the absence or partial absence of competition from grass and weeds and from the damage caused by cultivation (Coker, 1959).

Root growth

Under both grass and herbicide management root growth can potentially occur throughout the whole soil volume. Interspecific competition may alter the amount, the periodicity, the distribution of root growth and hence the potential exploitation of soil water and nutrients. The effect of soil management on 5-year trees of Cox/M.26, grown in differing treatments from planting, is shown in Table 5.

Table 5

Soil management and root growth

Treatment	No. of roots on 2.4 x 0.3 m soil face		Wt of roots ($g\ tree^{-1}$) in 0.4 m depth of soil		Ratio Root/scion wt
	< 2 mm	> 2 mm	< 2 mm	> 2 mm	
Herbicide strip	68	10	37	142	0.242
Overall grass	45	5	29	127	0.299
Overall herbicide	80	17	42	177	0.217
	Mean of 9 faces		Mean of 6 trees		

The weight of roots and density of rooting decreased with increasing grass competition, and proportionately more of the trees reserves were devoted to root growth. Trees grown at a range of spacings under overall herbicide management were found (Atkinson et al., 1977a) to have lower root/shoot ratios than previously reported for trees grown under either cultivation or grass (Rogers and Vyvian, 1934, Coker, 1959).

Grass competition also induced a deeper root distribution in the 5 year trees of Cox/M.26 (Table 6). A root laboratory study of the same trees (Atkinson, 1977a) showed a similar result.

Table 6

The wt of roots ($g\ tree^{-1}$) on the rootstock at two depths

Treatment	Root wt attached at 0-70 mm	Root wt attached at 70-150 mm	Ratio
Herbicide strip	140	39	3.6
Overall grass	107	49	2.2
Overall herbicide	179	41	4.4

In the herbicide strip and overall grass treatments of the established orchard previously described root activity at 300-900 mm depth was higher under overall grass (Atkinson, 1977a).

When trees are grown in a herbicide strip, in contrast to overall herbicide or overall grass, the tree is presented with two dissimilar soil environments, one (beside the tree) with and the other (further away) without interspecific root competition. The distribution of apple roots and their activity between these zones has been discussed by Atkinson and White (1976), Atkinson (1977b), Atkinson et al. (1977a). With young (2-6-year) trees most new root growth took place near the surface (0-200 mm) of the herbicide strip. Under the grassed alley root growth usually occurred below 200 mm depth and late in the season. Most root activity (uptake of ^{32}P or ^{15}N) was under the herbicide strip although a small amount was found at 25 cm depth under the grassed alley. Similar results have been presented by Atkinson et al. (1977c) for older trees. Root distribution across a herbicide strip and grass alley in the established orchard described is shown in Figure 1a. Most roots were restricted to the herbicide strip from where most absorption of added $^{15}NO_3$ occurred.

Figure 1. Root distribution under herbicide strip (1a) and overall herbicide (1b) soil management.

In contrast root distribution in the overall herbicide treatment (Figure 1b) was more uniform and $^{15}NO_3$ uptake from the alley, particularly in summer, was greater (Atkinson, Mercer and Johnson, unpublished data).

Soil water exploitation

In the more intensive modern orchards light interception by the trees tends to be lower than in older continuous canopy orchards resulting in greater exposure of the ground cover. Due to this competition from grass and weeds for total water use can be substantial. The size and pattern of water deficits in orchards with grass can influence performance (Atkinson, 1973, Jelley, 1973, Atkinson and White, 1976, Atkinson, 1977b, Atkinson et al. 1977c). Soil water deficits in the established orchard measured in early October are shown in Table 7.

Table 7

The soil moisture deficit (mm) around the tree

Treatment	Distance from the tree (m): Between tree rows 0.5	Between tree rows 1.2	In row 1.2
Herbicide strip	28.7 ± 2.2 (bare)	43.7 ± 5.7 (grass)	33.5 ± 4.6 (bare)
Overall grass	40.8 ± 4.0	54.0 ± 2.4	43.1 ± 5.4
Overall herbicide	22.7 ± 1.6	28.6 ± 3.0	29.2 ± 1.8

Total water loss from the surface 750 mm of soil by the tree and ground cover (grass or bare soil) in early October was 0.43 m^3 for overall grass, 0.36 m^3 for herbicide strip and 0.25 m^3 for the overall herbicide treatment. Grass competition can modify the pattern of water depletion. Under overall grass more water was used from deep in the soil profile (Atkinson, 1973, 1977a). Compared with overall herbicide, trees in a herbicide strip (Table 7) used more water from the area of the strip. Deficits under grass were consistently higher than under bare soil. Plant water potential and stomatal resistance increased with increasing amounts of grass cover (Atkinson, and Farre, 1977).

Nutrient requirements

Removal of a grass cover allows the tree to exploit surface soil without competition, thus herbicide strip and overall herbicide orchards need smaller nutrient inputs. This results from the greater volume of soil being exploited, the greater potential nutrient supply and the more extensive and efficient use of added nutrients (Tables 5 and 6). Leaf mineral concentrations in August 1974 in the established orchard described, are shown in Table 8. Leaf nitrogen fell with increasing grass competition while potassium was slightly higher in herbicide strip trees. There was little effect on other elements. Stott (1976) found a similar effect on nitrogen and an increase in phosphorus with increasing grass competition. Higher potassium levels in leaves from herbicide strip trees have been reported by Delver (1974). Measurements of the uptake of mineral nutrients by trees planted at a density of over 100,000 ha^{-1} indicated that under overall herbicide management large amounts of nitrogen (up to 360 kg ha^{-1} yr^{-1}) could be removed without the need for nitrogen fertilizers and with the development of only marginal nitrogen deficiency (2.36% N), (Atkinson, 1977c).

Table 8

The concentration (% DW) of mineral elements

in leaves in August 1974

Treatment	N	P	K	Ca	Mg
Herbicide strip	2.40 ± 0.15	0.22 ± 0.004	1.84 ± 0.12	0.50 ± 0.036	0.15 ± 0.009
Overall grass	2.08 ± 0.06	0.22 ± 0.02	1.66 ± 0.02	0.68 ± 0.019	0.15 ± 0.012
Overall herbicide	2.93 ± 0.09	0.22 ± 0.005	1.62 ± 0.07	0.66 ± 0.065	0.15 ± 0.004

Yield and growth

The effect of grass competition on growth and cropping has been reviewed by Robinson (1974) and Stott (1976b). Reductions in grass competition due to herbicides have usually been associated with increases in cropping. Complete elimination of grass at Ballygagin, Eire, resulted in a 34% increase in cumulative yield (O'Kennedy, 1974), while at Long Ashton the change from a wide herbicide strip to overall herbicide was accompanied by a 41% increase in crop in 1973 (Stott, 1976a) and a 29% increase in 1974 + 1975 (Stott, 1976b). At East Malling (Table 9) the change from a herbicide strip to overall herbicide in the established orchard described produced a 32% increase in crop over the period 1972-1975.

Reducing grass competition appeared to reduce the severity of biennial cropping, while its effects on fruit bud formation and June drop (Atkinson and Farre, 1977) paralleled those on cropping. Similar effects have been produced by weed competition (Atkinson and Holloway, 1976). Gormley et al., (1973ab) found that soil management could affect both fruit quality and yield although the effects of grass and herbicide were not consistent over a number of years. In the East Malling experiments and those of Stott (1976b) reducing grass competition increased wood growth.

Table 9

The total wt of fruit kg $tree^{-1}$ in the established orchard

Treatment	1972	1973	1974	1975
Herbicide strip	7.2	18.2	8.9	15.2
Overall grass	7.4	17.0	4.9	13.9
Overall herbicide	9.4	20.6	14.5	16.6

Conclusions

The development of soil-acting herbicides has made possible both herbicide strip and overall herbicide soil management. Although overall grass management was superior to cultivation (Rogers et al., 1948), competition from even a well mown sward has detrimental effects on growth and cropping of both young and established trees. The adverse effects of grass seem to increase with the area covered.

Overall herbicide management can result in some erosion problems and difficulties with machinery movement in wet conditions (Atkinson and White, 1977). There are fewer problems with herbicide strips. The use of herbicides as an alternative to grass frequently leads to increased acidification and compaction of the surface soil; differences develop rapidly at first and then more slowly. The problems due to residues and damaged soil structure which were envisaged when herbicides were introduced (Tubbs, 1966) seem not to have occurred. Under both grass and herbicide management non-capillary pores are more numerous than under cultivation although the volume of pores under herbicide management can either be higher (Table 2) or lower (Jelley et al., 1974) than with grass. Organic matter levels are normally lower than under grass (Table 3) but can be sustained in the presence of an adequate tree density (Atkinson et al., 1977b). Soil phosphorus concentrations seem usually to be higher with herbicide management. Increased potassium concentrations in soil and leaves, particularly where grass mowings are thrown onto the herbicide strip, are frequently also found (Delver, 1974). These can lead to increased bitter pit.

Grass competition reduces the weight of tree roots present and their density in the soil (Table 5); the root/shoot ratio (Table 5) and the soil depth where root growth and nutrient uptake occurs is increased. Trees under overall herbicide management will make better use of both natural or supplementary nutrients (Atkinson, 1977a) than those with a complete or partial grass cover and can absorb large amounts of major nutrients without fertilizer addition (Atkinson, 1977c). Where trees are planted in herbicided strips with grassed alleys most roots are restricted, even with established trees (Figure 1), to the area of the strip. This limits the amount of nutrients and water available.

Grass competition usually in proportion to the amount present, reduces growth and cropping (Robinson, 1974, Stott, 1976, Table 9) although effects on fruit quality are more variable (Gormley et al., 1973ab).

The widespread use of herbicides for top fruit soil management is likely to continue. Trees will probably be grown in either herbicide strips with grassed alleyways reduced to the minimum needed for tractor passage and possibly killed in dry years or under overall herbicide particularly in intensive orchards where maximum production is needed, on level sites and on light soils with poor water reserves. The effects of herbicide management on ornamental species has been less considered. The subject has been reviewed by Robinson (1975ab, 1976). It is probable, however, that the trees and the soils on which ornamental species are grown will respond in a similar way to fruit trees and their soils.

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A REVIEW OF RESEARCH ON CONTROLLED DROP APPLICATION AT THE ARC WEED RESEARCH ORGANIZATION

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Summary The contribution of the Weed Research Organization to the development of Controlled Drop Application for herbicides is described. Experimental equipment has been developed for laboratory and field studies; rotary atomizers being used to produce drops of differing sizes in the range 150 to 350 µm diameter, and to apply these in volume rates between 5 and 45 l/ha. Four years field and pot experimentation has shown that some systemic herbicides could be used in spray liquid volumes of 20 l/ha without loss of biological efficiency. Most of the major weeds occurring in cereal crops can be controlled with this technique and the implications of this are discussed.

Résumé La contribution de la WRO au développement d'une technique pour la production d'une population de gouttes aux diamètres identiques et connus est décrite. Du matériel a été développé pour expérimentation au laboratoire ainsi qu'aux champs, utilisant un pulvérisateur à disques tournoyants pour la production de gouttelettes aux diamètres entre 150 et 350 µm et pour l'application de celles-ci dans des volumes entre 5 et 45 litres de liquide/ha. Quatre années d'expérimentation en pots et aux champs ont montré qu'il est possible de pulvériser certains herbicides systémiques dans des volumes de 20 litres de liquide/ha, sans qu'ils perdent leur efficacité biologique. On discute la possibilité de contrôler la plupart des principaux adventices des cultures céréalières, et tout ce que cela implique.

INTRODUCTION

The ability to generate uniform size drops of spray solutions by means of a rotary atomizer and thereby to reduce spray volume rates, creates very exciting possibilities for weed control but also creates severe problems of research direction. Strictly speaking a research programme should study the effect on biological performance of a wide range of factors; volume rate, drop size, formulation, herbicide dose and the size and form of crops and weeds. All of these factors, their interactions, and the influence of environment, should really be examined separately for every herbicide type. We have no right to expect that any two herbicides will react in the same way to this new method of application. A further complication is the need to investigate the interaction between the biological effects and the physics or engineering of this new system by studying; methods of generating and distributing drops over the target area, the uniformity of output, the effect of wind and the potential for positive assistance by an artificially created wind to force the drops into the target zone. It can be seen that an ideal research programme, including all of these factors and their interactions, would be a monumental undertaking, probably amounting to nearly as much weed research as has been done already on conventional systems, or indeed more.

Our approach so far at WRO has been to take two broad lines of attack. First, the form of deposit has been included as one factor in some detailed studies of the performance of selected herbicides. Secondly, in a slightly more ad hoc way, we have examined a restricted range of variables to determine the requirements for successful control on the basis of current formulations of some very extensively used compounds. We have attempted to answer two questions; first is this a potential practical weed control system for use in our more widely grown crops; secondly what are the broad design parameters for the eventual design of satisfactory field equipment? We worked on the premise that the logistic advantage of low volume application could be so great as to justify the adoption of a new system of application even if there were no advantage in improved herbicide performance. However, it was necessary to ensure that performance was not impaired by the new techniques.

The WRO field research and indeed much of the more detailed work on pot grown material has been confined within certain limits, drop size has been varied between 150 µm and 350 µm diameter and volume rate between 5 and 45 l/ha. The herbicides used have mostly been applied at doses ranging between about a quarter of the normal field recommended dose and the field recommended dose. This programme has now been running rather more than four years. It has evolved as the equipment has evolved and as experience has been gained. The most appropriate way to review the programme, therefore, is to do so historically rather than in a strictly scientific way.

THE EARLY FIELD EXPERIMENTS

1972

At this time the research team were equipped with spinning discs originally designed for ULV drift spraying. The discs (designed and manufactured by Micron Sprayers Ltd) would only produce drops of uniform size from oil solutions so that only oil soluble herbicides could be tested. In scientific terms this meant that the effects of volume rate and type of diluent were confounded in our experiments. We were comparing a "package treatment" of herbicide dissolved in oil and applied at reduced volumes with the same herbicide applied as an oil in water emulsion at conventional volume rates.

Nonetheless, equipment was made which embodied shrouded spinning discs to provide a satisfactory distribution of drops, 280 µm in diameter. Field experiments with barban and 2,4-D ester were sufficiently encouraging to justify further work.

1973

The same basic equipment was upgraded and field experiments carried out with barban, 2,4-D ester and tri-allate. As in 1972, results were encouraging and all of this early work with oil solutions has been published (Taylor and Merritt, 1974).

1974

The programme of work was extended slightly, still using the same equipment. Volume rates of 10 or, in some cases, 20 l/ha were used with a range of herbicides in oil solution. The performance of a mixture of bromoxynil and ioxynil esters* was poor at these low volumes. Barban and ester formulations of dichlorprop, a mixture of barban, MCPB, dichlorprop and mecoprop**, a dichlorprop MCPA mixture and a mixture of dichlorprop with bromoxynil and ioxynil† were more effective with low volume applications. Performance was reduced, however, compared with conventional applications. We concluded; that 10 l/ha was probably inadequate, that further field work was required and that more versatile equipment was needed for this work.

* formulated by May and Baker as 'Oxytril CM'.
**formulated by Fisons Ltd as 'Dualweed'.
† formulated by May and Baker as 'Oxytril P'.

EXPERIMENTS ON POT-GROWN PLANTS

Although we were restricted to oil solutions for field work, for indoor work it was possible from the early days to use a range of diluents with a spinning disc cabinet of the type described by Byass and Charlton (1968). With this equipment aqueous solutions could be compared with oil solutions, with conventional emulsions or with 'solubilised' solutions. This technique of 'solubilization' has been described by Turner and Loader (1974). By using surfactants it allows water based formulations to be applied in oil. Finally it was also possible to compare ester and amine formulations and to vary surfactant level and type. A very considerable amount of work was conducted on this topic but unfortunately not all the data are available in published form. However, one paper presented to this conference (Caseley et al, 1976) exemplifies much of the work that has been conducted. Table 1 shows the results of an experiment on the effect of glyphosate on *Agropyron repens*. This compared aqueous solutions of this compound applied at conventional volume with controlled drop application of solubilized material. Results from controlled drop application at 20 l/ha were superior to the results of conventional application.

Table 1

Effects of formulation and application of glyphosate (abbreviated and modified from Caseley et al, 1976)

		A. repens % reduction live nodes	
Dose; kg/ha		0.2	0.4
Formulation	l/ha		
Aqueous solution	165	64	74
Solubilised:			
(a) applied as emulsion	165	59	60
(b) applied without dilution	20	82	72

Table 2, also abbreviated from the same paper, shows the results of a comparison of oil and aqueous solutions applied by controlled drop application. Here it can be seen that the oil application had no intrinsic advantage. The aqueous solution was in fact consistently more effective in reducing survival of viable buds but the differences were slight at doses of 0.1 and 0.2 kg/ha.

Table 2

Formulation of glyphosate for CDA (20 l/ha)

	A. repens % reduction live nodes		
Dose; kg/ha	0.05	0.1	0.2
Formulation			
Oil	28	81	85
Aqueous	69	85	88

The third table abstracted from this paper shows a comparison of aqueous solutions of glyphosate applied conventionally at 78 l/ha and by controlled drop application at 20 l/ha. Results were generally superior at the lower volume rate. There was also a suggestion from these data that applications at low volume were less affected by "wash off" by simulated rainfall after application.

Table 3

Application of aqueous solutions of glyphosate, and the effects of "Wash off" after application

		A. repens % reduction in live nodes					
Dose kg/ha		0.1		0.2		0.4	
Wash off		+	-	+	-	+	-
Vol. rate; l/ha	78	-4	25	-2	51	70	87
	20	28	67	72	82	81	91

In other WRO pot experiments during this period 17 other perennial weeds were tested in a number of experiments with generally good results (W.G. Richardson and W.A. Taylor (personal communication)). Other work conducted by Taylor and Merritt (1976) established the efficiency of a range of herbicides used on cereals on typical target species. It was notable that compounds acting mainly by contact or with limited translocation such as ioxynil, bromoxynil and bentazone were less effective at lower CDA volumes.

A major conclusion reached as a result of this work was that the further development of the field research programme and probably the potential commercial development of CDA were dependent on developing rotary atomisers suitable for use with aqueous solutions and oil in water emulsions as well as oil solutions.

A MAJOR DESIGN DEVELOPMENT

In July 1974 Mr E Bals of Micron Sprayers Ltd loaned us a cupped and toothed plastic disc which could produce drops of uniform size from oil or water solutions. The disc produces drops by 'direct drop formation' at flow rates lower than 85 mls per minute. This imposes a restriction on forward speed but, by the use of multiple discs, we can obtain the desired volume rate at normal working speeds. In the equipment developed by Taylor, Merritt and Drinkwater (1976) discs are stacked in groups of five and shrouded to ensure more uniform distribution of drops. This development gave us a tractor-mounted machine with an integral windshield capable of treating plots 3 metres in width at volume rates from 5 l/ha to 100 l/ha. Drop size was also variable between 150 μm and 350 μm in diameter. The development of this machine with the obviously increased range of possibilities led to an expanded field programme in 1975 and 1976. Part of this work is to be described elsewhere in papers being prepared for Weed Research and part is being presented to this conference by Wilson (1976) and Ayres (1976).

RECENT FIELD EXPERIMENTATION

1975

The field programme in 1975 concentrated on weeds in spring barley and on three herbicides, difenzoquat and barban for control of wild-oats and a mixture of dicamba, mecoprop and MCPA* for control of broad-leaved weeds.

Fig. 1

% reduction total weed dry weight with "Banlene plus" - 1975

Mean of 4 field experiments, 2 doses

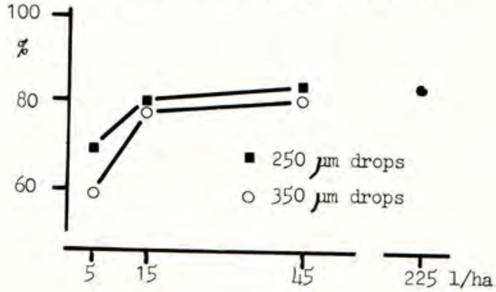


Fig. 2

% reduction of A. fatua seeds with difenzoquat - 1975

Mean of 3 field experiments, 2 doses

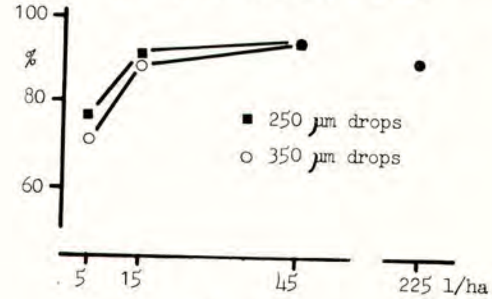
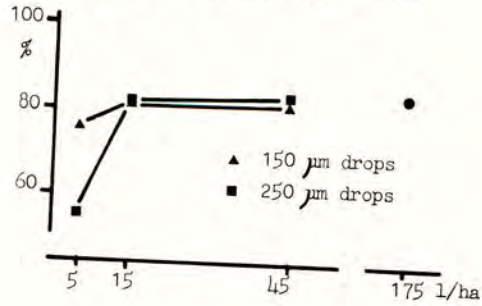


Fig. 3

% reduction of A. fatua seeds with barban - 1975

Mean of 2 field experiments, 2 doses



Figures 1 to 3 show the results in the abbreviated form. Each figure shows the response to volume rate and drop size. The data has been obtained by taking the mean of a number of field experiments and of 2 doses; the normally recommended dose and a reduced dose, 50% of a recommended in the case of barban and 33% of recommended in the case of difenzoquat and the dicamba mixture. The conclusions from these experiments were that controlled drop application of 45 l/ha was entirely satisfactory, results being equal or superior to those obtained from conventional applications. Application at 5 l/ha was clearly unsatisfactory in the case of each of the three compounds. Although application at 15 l/ha was not statistically inferior we felt that the optimum must lie somewhere between 15 and 45 l/ha.

With none of these compounds did we record any major increase in effect although in some cases the decline in performance with decreasing dose was somewhat lower with controlled drop applications than with conventional applications. Barban was applied at drop sizes of 150 or 250 µm diameter and the other compounds 250 or 350 µm. However, the effect of drop size was slight. Indeed, there was virtually no effect at the two higher CDA volume rates but at 5 l/ha, where performance was considerably poorer, there did appear to be an advantage in favour of the smaller drops. It was calculated that at this low volume rate the number of drops per square centimetre must have been inadequate at the higher drop sizes. The calculated number of drops per square centimetre at the relevant volume rates and drop sizes are set out in Table 4.

Table 4

Calculated number of drops/cm^2

Drop size µm	Volume rates l/ha 5	15	45
150	28	85	255
250	6	18	54
350	2	7	20

At the end of the 1975 season we were convinced of the potential for the CDA technique and satisfied with our capability for conducting such experiments. However, the problems of manoeuvring tractor equipment between small plots imposed restrictions on the layout of experiments; large turning areas were needed between relatively small plots. In addition, access on to these experiments was difficult in wet conditions. Thus it was decided that, in addition to retaining the tractor mounted equipment, there was a need for a hand-carried small plot sprayer which could be used more readily for small plot field experiments. To achieve this, units with double shrouded discs were used (kindly loaned by Horstine Farmery Ltd). These were mounted, with appropriate liquid containers and integral windshields, on to a simple aluminium frame by my colleague P. Ayres. Some experiments with chlortoluron and difenzoquat in autumn 1975 and the main field programme in the spring of 1976 were conducted with such equipment.

1976

A limited programme of research was conducted on winter wheat. Promising results were obtained with chlortoluron for control of black-grass, with difenzoquat applied in December and April for wild-oat control, and with a mixture of 2,3,6-TBA, dicamba, MCPA and mecoprop for control of broad-leaved weeds.

The main programme was again concentrated on spring barley and on the same herbicides as those used in 1975 but with the addition of a mixture of ioxynil, bromoxynil and dichlorprop. The volume rates used were 10, 20 and 40 l/ha, with controlled drop application and the recommended conventional volumes. Drop size was not varied in these experiments but was constant at 225 µm diameter.

Figure 4 shows the results obtained from eight field experiments with the dicamba based mixture. There was a reduction in performance of this compound with the lower volume rate of 10 l/ha at the higher doses. Generally, however, performance of this mixture was closely comparable at 20, 40 and 225 l/ha. As in previous years there was little indication of enhanced performance with CDA.

Fig. 4

% reduction total weed dry weight - "Banlene Plus"

Mean of 8 field experiments 1976

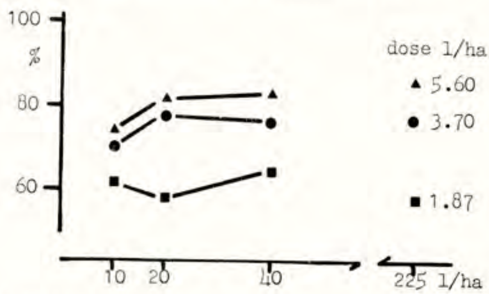


Figure 5 shows the results of five field experiments with a mixture of bromoxynil, ioxynil and dichlorprop ("Oxytril P"). In every case the performance of this mixture with CDA was inferior to performance by conventional application although in many cases acceptable weed control was obtained, particularly of plants presenting a large target area such as Sinapis arvensis. It had been believed that with this mixture, which was known to be marginal for CDA, there might be an increase in performance with the higher CDA volumes. In fact there was a slight tendency for performance to decline with increasing volume rate between 20 and 40 l/ha.

Fig. 5

% reduction total weed dry weight with "Oxytril P"

Mean of 5 field experiments 1976

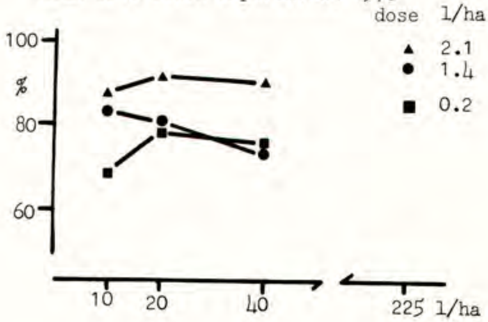


Figure 6 gives results of five field experiments with barban. It can be seen that very good results were obtained with conventional applications, doses of 0.350 and 0.234 kg/ha being equally effective. Control at 20 and 40 l/ha was just as good at the two higher doses but reduced slightly at the lower dose. The performance of barban was reduced by application at 10 l/ha with all doses. These results confirmed earlier work, suggesting that barban was suitable for CDA at volume of around 20 l/ha.

Fig. 6

% reduction A. fatua seeds with barban

Mean of 5 field experiments 1976

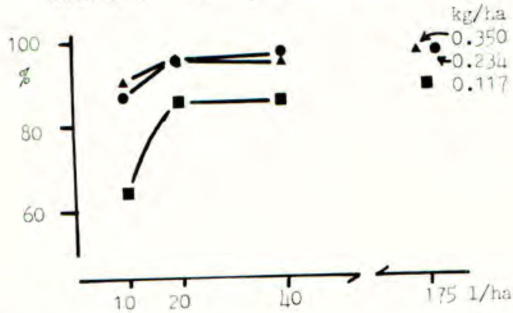
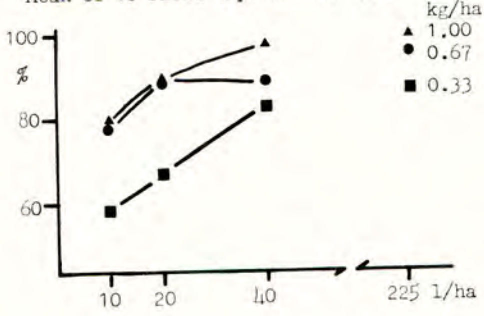


Figure 7 gives the results of ten field experiments with difenzoquat. Conventional applications were extremely successful, the recommended dose of 1 kg/ha reduced production of wild-oat seeds by 99%. There was however, a consistent reduction in performance by CDA. There was also a marked response to volume rate within the CDA applications; in every case 40 l/ha was superior to 20 l/ha and 20 l/ha superior to 10 l/ha. This contrasted markedly with the results on spring barley obtained in 1975 and the more limited results obtained in winter wheat in the winter of 1975/1976. We cannot explain these discrepancies although it seems possible that climatic factors may have influenced the results. In 1975, although the weather was dry following application, it was very wet preceding it so that soil moisture and atmospheric humidity were high and plants were perhaps somewhat softer in their form of growth. In contrast the applications in 1976 were made to plants already suffering from some drought/stress and were followed by further drought. Under these conditions, there would have been little or no opportunity for redistribution of difenzoquat on the leaves of wild oats after CDA application and this could be a significant factor (J.C. Caseley, personal communication).

Fig. 7

% reduction A. fatua seeds with difenzoquat

Mean of 10 field experiments 1976



EXPERIMENTS WITH SURFACTANTS

Looking to the future it would seem that there must be some potential for improving the performance of many compounds by devising formulations better suited to CDA than the formulations in current commercial use. In this respect it must be noted that with most of the proprietary compounds in WRO field experiments we have used the standard formulation. This was not true, however, for difenzoquat. This compound is known to be sensitive to surfactant level and, in all field experiments, we modified the level of surfactant to keep the concentration constant, thus varying the dose per unit area with the spray volume. All our spray solutions contained 0.5% v/v of "Agral". The last paper I have to review is that by Merritt (1976) working on surfactant type and concentration as it affects the performance of MCPA and difenzoquat.

This paper produced two extremely important conclusions. First, the response of difenzoquat to surfactant level was different at the conventional volume of 200 l/ha and CDA at 15 l/ha. Secondly, the response to surfactant continued with increasing concentration up to 5.0% v/v. It appeared that surfactant level could outweigh the effects of varying dose of difenzoquat; 0.2 kg/ha a.i. was equal or slightly superior at 5.0% wetter concentration to 0.8 kg/ha a.i. at 0.05% wetter concentration.

DISCUSSION

The 1976 season has exposed many of the problems of conventional spraying which arise directly from the need to supply water at 150 to 350 l/ha. In the spring, crops and weeds grew very rapidly through the stages recommended for application. The need for rapid application emphasised the problems of supply and transport of water. This was especially so on farms with their own water supply, underground water reserves were failing as early as April. Later in the season the climate reversed itself, September and October were very wet. At the time of writing this review (November 1976) there are thousands of hectares waiting to be drilled to winter wheat. Some of the land which has been drilled now awaits treatment with herbicide. However, it seems unlikely that heavy spraying equipment can be used for many months on some of the land most in need of treatment e.g. with black-grass herbicides. In short, there is an overwhelming case for the use of lower volumes of diluent, without need for improved performance.

We believe that controlled drop, low volume, application has a future. It has proved to be a practicable way of applying some widely used herbicides as they are currently formulated. There are, however, two major challenges outstanding.

The engineers need to produce sensible field equipment which allows rapid work rates consistent accuracy, monitoring of performance, and the ability to handle a wide range of materials with easy decontamination between them. Such design work should also capitalise on the low power requirement and the reduced need to transport liquids to produce a light machine.

The challenge to research workers is just as great; the subject abounds with unanswered questions. How many agricultural chemicals can be applied satisfactorily by this technique? Are we justified in using materials formulated for conventional application and to what extent could performance be improved and made more reliable with novel formulations?

As these questions are answered we believe we may see the evolution of one of the most significant developments so far in the field of weed control.

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CONTROL OF ANNUAL BROAD-LEAVED WEEDS IN SPRING BARLEY BY CONTROLLED DROP APPLICATION: COMPARISONS OF THE ACTIVITY OF TWO HERBICIDE MIXTURES AT THREE DOSES AND FOUR VOLUME RATES

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Summary In thirteen field experiments, herbicide mixtures containing dicamba, mecoprop and MCPA or bromoxynil, ioxynil and dichlorprop were applied to a wide range of dicotyledonous weeds in volume rates of 10, 20 and 40 l/ha using controlled drop application equipment. For comparison conventional applications at 225 l/ha were made with a small plot hydraulic sprayer. At the recommended dose of the dicamba mixture 40 l/ha gave control comparable to the 225 l/ha applications and control at 20 l/ha was as good as 40 l/ha. Control from 10 l/ha was significantly poorer than all other volume rates. Total broad-leaved control from conventional applications of the bromoxynil mixture was significantly better than the controlled drop application treatments, although with some species, control from CDA treatments was better than 90%.

Résumé: Dans 13 expériences de plein champ les associations dicamba + mecoprop + MCPA et bromoxynil + ioxynil + dichlorprop ont été appliqués à un large spectre d'adventices dicotylédones dans des volumes de 10, 20 et 40 litres/ha. Des traitements utilisant des appareils controlled drop application [CDA] (que l'on pourrait traduire approximativement: "production d'une population de gouttelettes aux diametres identiques et connus") ont été comparé aux applications normales dans 225 litres/ha utilisant un pulvérisateur destiné au traitement de petites parcelles. A la dose préconisée l'association à base de dicamba dans 40 litres/ha a effectué un désherbage comparable à celui obtenu avec le volume normal (225 litres/ha); dans 20 litres/ha le désherbage obtenue était égal à celui obtenu dans 40 litres/ha. Dans 10 litres/ha le désherbage était nettement inférieur à celui obtenu avec tous les autres volumes/ha. La destruction de dicotylédones obtenue avec l'association à base de bromoxynil dans 225 litres/ha était nettement supérieur à celle obtenue par la technique CDA, bien que la destruction de certaines espèces au moyen de cette technique dépassât 90%.

INTRODUCTION

Methods of applying herbicides for broad-leaved weed control in cereals in the have remained essentially unchanged over the past 25 years. Many of the mical and practical disadvantages associated with these conventional systems or and Merritt, 1975) arise from the need to carry large quantities of water to the herbicides at the recommended volume rates. Work at the Weed Research ization over the past five years has shown that controlled drop applications of aqueous solutions of some herbicide at 5-45 l/ha is feasible.

Greenhouse trials (Merritt & Taylor, pers. com.) with various broad-leaved weed cides have shown that weed control from contact herbicides might not be as effective when applied by CDA. Preliminary field trials in 1974 (unpublished) with contact herbicides indicated that this was the case for a mixture of bromoxynil and ioxynil esters applied as an oil solution but that the addition of dichlorprop had improved performance. In 1975, following the development of an experimental field machine capable of applying a wide range of formulations at control drop sizes, and in a range of volume rates (Taylor, Merrit and Drinkwater, 1976), a series of field trials with two broad-leaved weed herbicide mixtures were conducted. The experiments in which the translocated herbicide mixture, containing dicamba with mecoprop and MCPA, was applied showed that CDA at 45 l/ha had given levels of control comparable to those achieved by conventional applications. These results suggested that the technique was agronomically feasible and warranted further examination of controlled drop application between 15 and 45 l/ha. Evidence on the performance of the contact herbicide mixture containing bromoxynil and ioxynil was limited and further investigation was required.

This paper describes 13 field experiments in which either a contact or translocated herbicide mixture was used for the control of a range of dicotyledonous weeds growing in a spring barley crop. The two herbicide mixtures used contained either dicamba, mecoprop and MCPA ("Banlene plus"*), or bromoxynil with ioxynil and dichlorprop esters ("Oxytril P"**). These were applied as the formulated commercial products in either a range of spray liquid volume rates between 10 and 40 l/ha by CDA or by conventional application.

METHOD AND MATERIALS

In the spring of 1976, 13 identical experiments were set up in spring barley sites on farms within a radius of 35 miles of the Weed Research Organization. Each experiment was a split plot design and contained two replicates. Within each replicate there were three main plots which measured 8 x 12 m. The main plots consisted of four sub-plots each measuring 2 x 12 m. An unsprayed plot was included between each of the main plots to enable visual comparisons of herbicide effect to be made and to assess the dry weight reduction of treated over untreated weeds. There were two of these plots on each replicate and the size of each was 2 x 12 m. Each replicate measured 12 x 28 m and the total experimental area was 24 x 28 m.

Table 1 shows the herbicide used, application date, crop growth stage and the predominant weed species at each site.

The dicamba mixture was applied at the recommended field rate of 5.60 l. of product/ha and at two-thirds and one-third of this rate. Applications of the bromoxynil mixture were made at the recommended field rate of 1.4 l. of product/ha and also rates both one half above and below this. Both herbicide mixtures were applied using water as diluent.

Conventional applications of the two herbicide mixtures were made using a propane pressurized sprayer fitted to a 2 m boom. The herbicides were sprayed at a total volume rate of 225 l/ha using Spraying Systems 6502 "Tee-jets" at a pressure of 2.07 bars and walking at 1 m/sec.

*Trade mark of Fisons Ltd

**Trade mark of May and Baker Ltd

Table 1

Herbicide, herbicide application date, crop growth stage and predominant weed species, at each site

Sites	Application date	Weed species	Crop growth stage
Bromoxynil, ioxynil and dichlorprop			
1. Dinton	29 April	*Stellaria media* *Aethusa cynapium*	3-4 leaves, tillering
2. Compton Beauchamp	29 April	*Sinapis arvensis*	4 leaves 1-3 tillers
3. Harnhill	30 April	*Stellaria media* *Sinapis arvensis*	4-5 leaves 1-3 tillers
4. Guiting	13 May	*Polygonum convolvulus* *Aethusa cynapium* *Viola arvensis*	7 leaves 4 tillers
5. Didcot	14 May	*Chenopodium album*	3-4 leaves tillering
Dicamba, mecoprop and MCPA			
6. Blewbury	6 May	*Polygonum aviculare* *Viola arvensis*	3-4 tillers
7. Weston-on-the Green	10 May	*Polygonum aviculare* *Chenopodium album* *Fumaria officinalis*	4-5 tillers
8. Harnhill	14 May	*Stellaria media* *Sinapis arvensis*	3-6 tillers
9. Meysey Hampton	17 May	*Polygonum aviculare*	6-8 tillers
10. Aston Tirrold	18 May	*Polygonum aviculare* *Polygonum convolvulus*	4-5 tillers 1 node
11. Didcot	18 May	*Polygonum lapathifolium* *Lamium purpureum*	4-5 tillers
12. Rissington	21 May	*Viola arvensis* *Veronica persica* *Stellaria media*	6 tillers 1 node
13. Guiting	24 May	*Polygonum convolvulus* *Aethusa cynapium* *Viola arvensis*	fully tillered

Sites 3 and 8 in adjacent position in the same field. Sites 5 and 11 in different fields on the same farm.

The controlled drop application treatments were applied using units (Farmery, 1975) embodying spinning discs of the type described by Bals (1975). Each unit was comprised of two discs mounted on a vertical shaft driven by a small 12 volt electric motor. The discs produced uniform drops 225μm in diameter when rotated at 1880 rev/min with the spray liquid used in these trials. Liquid to the discs was supplied through a 6 mm diameter polythene tube from a non-pressurized reservoir positioned 45 cm above the unit. Taylor, Merritt and Drinkwater (1976) had established that flow of spray liquid onto this disc should not exceed 90 ml/min if uniform drop production is to be maintained. Flow control was achieved by passing the spray solution through a small-hole restrictor. Each was identical to ensure the same flow to each unit. An "on-off" tap was positioned above each restrictor to facilitate ease of operation in the field.

The units were attached, 1.2 m apart, on the lower side of a dexion frame, measuring 0.45 x 2.0 m, held by two operators. Hessian screens were mounted at right angles across either side of the spray boom as the overall swath of the two rotary atomisers was slightly wider than the plot width of 2 m. These screens intercepted the spray and prevented adjacent plots from becoming contaminated.

Volume rates to be applied with the machine were calculated by first calibrating the flow rate of the herbicide concentration at each treatment. The forward walking speed was then adjusted to achieve the required volume rate. The walking speeds used in these experiments were 1.2 m/sec (10 l/ha), 0.6 m/sec (20 l/ha) and 0.3 m/sec (40 l/ha).

Assessments

The dry weight of surviving plants were assessed five to six weeks after spraying. At each site, with the exception of Aston Tirrold, three areas each measuring 1 m^2 were selected at irregular intervals along the central 1 x 12 m of each plot. At Aston Tirrold, because of the large number of dicotyledonous weeds present, three smaller areas, 0.25 m^2 each, were selected on each plot. All the dicotyledonous weeds within these areas were removed at ground level and separated into the predominant species and others. Samples were dried for 24 hours at 100°C and weighed.

RESULTS

Dicamba, mecoprop and MCPA

The difference in the effect of volume rate on the dry weight of all surviving broad-leaved weeds varied between doses and between sites. (Table 2). At six of the eight sites there was no significant difference between volume rates, within any single dose rate. At the other two sites either 40 l/ha (Guiting) or 225 l/ha (Meysey Hampton) gave significantly better control at some doses. The mean values from all sites (Table 4) do however, indicate significant trends in volume rate effect. At the recommended rate of the dicamba mixture there was no difference between 40 l/ha and 225 l/ha or between 40 and 20 l/ha, with the control from 10 l/ha being significantly lower. At the intermediate rate, control from 10 l/ha was again lower than the other volume rates, but at this dose level there are no differences between 20, 40 or 225 l/ha. Control from applications of 1.87 l/ha of product show no significant differences between any volume rate. The interaction of dose and volume rate (Table 4) shows no significant difference between the three dose rates at 10 l/ha. At 20 l/ha the difference between 5.60 and 3.70 l. of product/ha is also not significant but at 40 and 225 l/ha all dose levels are significant. Figure 1 illustrates the variation in the degree of control of the individual broad-leaved weed species assessed in respect to both volume rate and susceptibility to the herbicide mixture. Control of susceptible species at the recommended dose for volumes of 20, 40 and 225 l/ha was in most cases better than 85% reduction in dry weight of foliage. With some species, notably *Fumaria officinalis* and *Sinapis arvensis* control was greater than 95%. At 10 l/ha control of some of the individual species, notably *Stellaria media* was not satisfactory. Control of *Viola arvensis*, one of the more resistant species, showed no response to volume rate, whereas control of *Aethusa cynapium*, also more resistant, increased with volume rate.

Table 2

Dicamba, mecoprop and MCPA - Total dry weight (g/ m^2) of all surviving broad-leaved weeds.
Logarithmically transformed data, Log_{10} ([g/m^2 x 10] + 1), in brackets.

Site		6	7	8	9	10	11	12	13
Dose of product 1/ha	Vol. rate								
	10	16.72	3.19	10.59	0.92 (1.006)	27.93	12.73	2.23	6.70 (1.833)
1.87	20	16.62	4.29	19.18	2.36 (1.388)	23.42	9.31	3.06	5.38 (1.733)
	40	13.28	2.81	10.99	1.13 (1.089)	21.85	13.65	2.39	5.92 (1.766)
	225	17.03	4.56	19.60	0.86 (0.965)	29.41	11.87	1.21	4.65 (1.675)
	10	12.28	1.90	12.48	1.42 (1.126)	14.28	7.54	1.76	8.69 (1.789)
3.70	20	9.79	0.99	9.12	0.16 (0.414)	13.12	7.69	1.93	4.28 (1.512)
	40	8.80	2.47	14.12	0.92 (0.902)	13.51	8.20	1.41	2.00 (1.170)
	225	9.03	3.25	9.28	0.05 (0.139)	12.13	8.71	1.92	3.86 (1.505)
	10	9.65	1.12	14.75	1.16 (1.079)	15.66	8.32	1.82	4.54 (1.666)
* 5.60	20	3.99	1.44	7.30	0.45 (0.710)	17.15	6.87	1.39	2.51 (1.360)
	40	3.83	1.55	6.25	0.89 (0.876)	21.19	5.31	0.61	1.86 (1.255)
	225	4.99	1.21	8.07	0.01 (0.046)	9.93	7.29	0.55	2.47 (1.408)
S.E. for volume rates within the same dose rate		0.819	0.609	2.016	(0.1258)	3.49	2.091	0.387	(0.1101)
S.E. for same volume rate between dose rates		3.539	0.629	2.580	(0.1957)	3.48	2.409	0.398	(0.2469)
Untreated plots (data not included in the statistical analysis)		28.44	13.56	80.90	7.98	33.69	34.20	5.60	17.18

* recommended field rate

Table 4

Dicamba, mecoprop and MCPA - Total dry weight (g/m^2) of all surviving broad-leaved weeds (mean of 8 sites) Logarithmically transformed data, Log_{10} (g/m^2 x 10 + 1) in brackets.

(all doses in terms of product)

Dose l/ha	Volume rate 10	20	40	225	Mean	SE(±)
1.87	10.13(1.809)	10.45(1.878)	9.00(1.786)	11.15(1.802)	10.18(1.819)	
3.70	7.54(1.698)	5.89(1.513)	6.43(1.579)	6.03(1.528)	6.47(1.580)	(0.0437)
*5.60	7.13(1.668)	5.14(1.477)	5.19(1.423)	4.32(1.318)	5.44(1.472)	
Mean	8.27(1.725)	7.16(1.623)	6.87(1.596)	7.16(1.550)		
SE(±)	(0.0203)					

SE for comparing volume rates within the same dose rate (0.0351)
SE for comparing the same volume rate between dose rates (0.0532)

* recommended field rate.

Bromoxynil, ioxynil and dichlorprop

Total broad-leaved weed control at each site with the recommended dose applied at 225 l/ha was better than 89% reduction in dry weight of foliage. Although at each site the conventional application at each dose rate was not significantly different from any of the CDA treatments (Table 3) the mean values from the five sites (Table 5) showed that at both the recommended and the higher dose, 225 l/ha was better than either 20 or 40 l/ha and that 10 l/ha gave the poorest control.

Table 5

Bromoxynil, ioxynil and dichlorprop - Total dry weight (g/m^2) of all surviving broad-leaved weeds (mean of 5 sites). Logarithmically transformed data, Log_{10} (g/m^2 x 10 + 1), in brackets

(all doses in terms of product)

Dose l/ha	Volume rate 10	20	40	225	Mean	SE(±)
0.7	8.13(1.733)	6.91(1.556)	7.61(1.707)	4.45(1.462)	6.78(1.614)	
*1.4	6.62(1.610)	7.55(1.415)	13.73(1.788)	1.65(1.009)	7.39(1.456)	(0.0411)
2.1	6.66(1.616)	2.34(1.030)	1.88(1.204)	0.62(0.707)	2.87(1.139)	
Mean	7.13(1.653)	5.60(1.334)	7.74(1.566)	2.24(1.059)		
SE(±)	(0.0501)					

SE for comparing volume rates within the same dose rate (0.0869)
SE for comparing the same volume rate between dose rates (0.0857)

* recommended field rate.

Table 3

Bromoxynil, ioxynil and dichlorprop - Total dry weight (g/m^2) of all surviving broad-leaved weeds. Logarithmically transformed date, Log_{10} ([g/m^2 x 10] + 1), in brackets.

Site		1	2	3	4	5
Dose of product l/ha	Vol. rate					
0.7	10	6.66	3.48 (1.317)	22.54 (2.335)	4.92 (1.689)	3.05 (1.496)
	20	7.62	4.34 (1.304)	19.44 (2.154)	1.83 (1.275)	1.34 (1.157)
	40	6.03	6.58 (1.802)	18.11 (2.201)	6.06 (1.721)	1.24 (1.031)
	225	3.45	1.81 (1.269)	12.90 (2.101)	3.47 (1.543)	0.62 (0.849)
*1.4	10	3.84	14.71 (2.123)	10.98 (1.901)	2.48 (1.412)	1.07 (1.050)
	20	5.96	0.31 (0.603)	28.81 (2.448)	1.61 (1.232)	1.04 (1.018)
	40	6.31	26.13 (2.224)	32.69 (2.513)	2.76 (1.456)	0.77 (0.940)
	225	1.67	0.55 (0.784)	4.99 (1.685)	0.87 (0.984)	0.16 (0.377)
2.1	10	5.84	15.74 (2.065)	8.68 (1.943)	2.27 (1.374)	0.76 (0.923)
	20	3.92	0.24 (0.482)	6.62 (1.735)	0.70 (0.856)	0.21 (0.489)
	40	2.78	1.02 (1.041)	2.93 (1.425)	2.10 (1.312)	0.55 (0.804)
	225	0.84	0.26 (0.557)	1.38 (1.130)	0.50 (0.741)	0.04 (0.149)
S.E. for volume rates within the same dose rate		2.381	(0.331)	(0.2225)	(0.1512)	(0.1613)
S.E. for same volume rate between dose rates		2.141	(0.3231)	(0.2271)	(0.1668)	(0.1933)
Untreated plots (data not included in the statistical analysis)		15.12	138.97	85.54	13.24	7.27

* recommended field rate

Interaction between dose and volume rates showed that non-significant differences between dose levels occurred at the lower volume rates. All of the six individual weed species assessed (Fig. 1) were either susceptible or moderately susceptible to the bromoxynil mixture. All volume rates at the recommended dose gave better than 86% reduction in dry weight of foliage for Chenopodium album, Sinapis arvensis and Polygonum convolvulus. Control of the other three species, in particular Stellaria media, was less good with the CDA treatments.

DISCUSSION

The high level of weed control from controlled drop applications of 20 and 40 l/ha in this series of experiments offers further proof of the agronomic feasibility of this technique. The series was designed to cover a wide range of sites with varying weed populations and numbers. Although with only two replicates the individual sites lost some degree of accuracy, which is reflected in the large standard errors, the combined site analysis proved to be statistically acceptable and, overall, the series presented a clear picture.

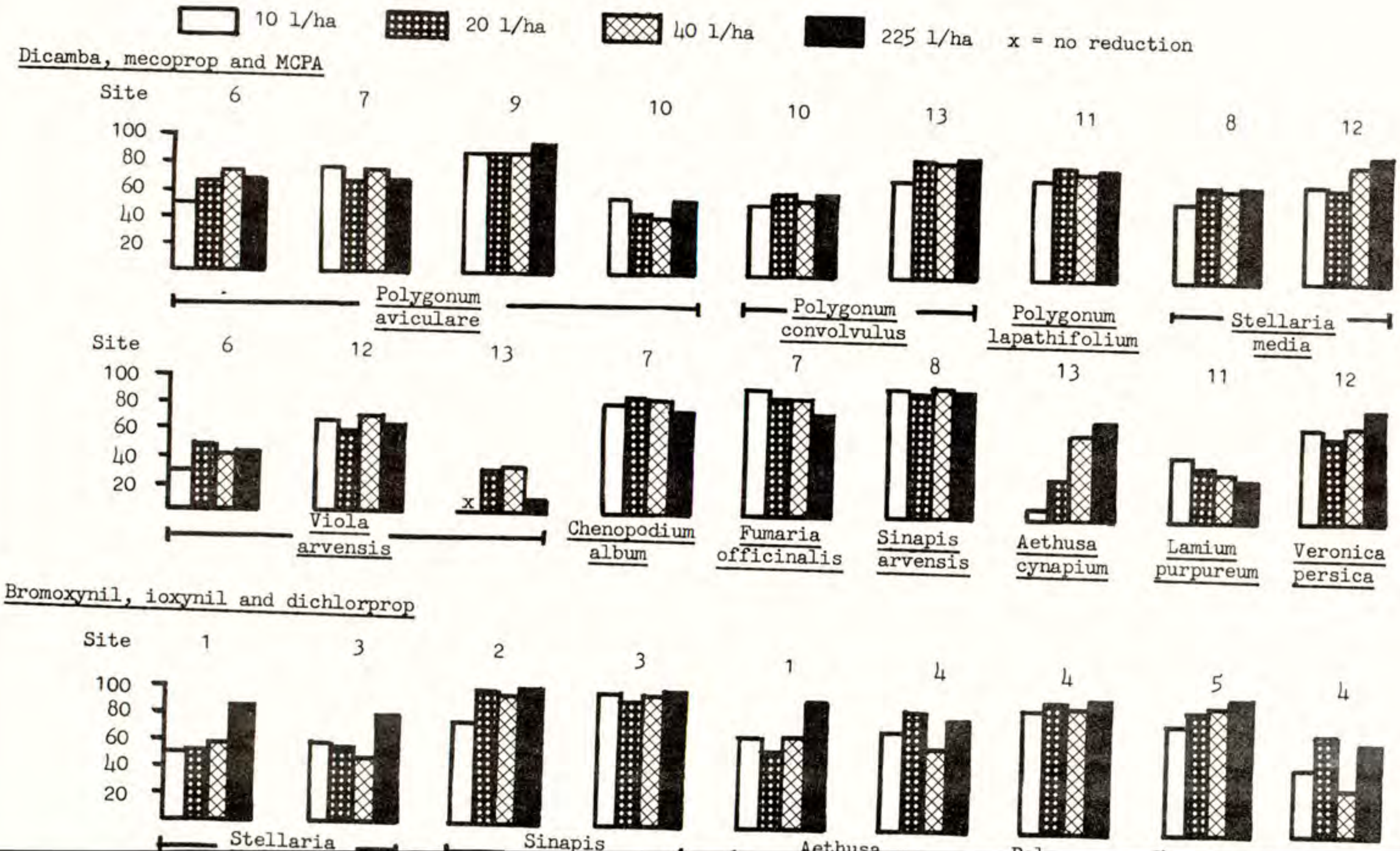
The results with the translocated herbicide mixture are particularly encouraging notably the good control with applications at 20 l/ha. Previous work with controlled drop application with this mixture at 15 l/ha had shown that at this volume rate weed control was less reliable than at 45 l/ha. The evidence from these experiments would therefore indicate that with suitable equipment and use 20-25 l/ha might be the optimum CDA rate for weed control with this particular herbicide mixture.

The total broad-leaved weed control from controlled drop applications of the partially contact herbicide mixtures was not as good as the conventional applications but control of some of the individual species assessed was greater than 90% reduction of dry weight of foliage. Although these species, Chenopodium album Sinapis arvensis and Polygonum convolvulus, were susceptible to both dichlorprop, and ioxynil and bromoxynil they were also the species that presented the largest target area. Drop numbers are important to the performance of controlled drop applications of contact broad-leaved weed herbicides and a reduction in drop size to produce more drops per unit area may improve control, particularly of the smaller leaved species. However, better control with applications at 20 l/ha than at 40 l/ha suggest that herbicide concentration in the drops may also be important, although the poor results at 10 l/ha, where herbicide concentration was even higher, are probably due to the reduced numbers of drops per unit area produced at this volume. Effects of herbicide concentration at lower volume rates were also observed with the translocated herbicide mixture, although these were confined to dose response only. At these lower volume rates it may be that it is not only the amount of active ingredient but also the level of surfactant, as high as 10 or 20 times the level in the recommended conventional application, that could be important in the degree of biological control achieved. Although some evidence to support this exists (Merritt, 1976) further work on herbicide concentration in the drops, and surfactant levels is required.

The success of the CDA technique as demonstrated in these experiments must be balanced against the range of herbicides which have still to be examined with this system under field conditions. At present, herbicides are formulated for use with conventional volume rates but changes in formulation may improve weed control with controlled drop application. Further improvement in equipment may also be possible and if ongoing research continues to be as promising then the prospects for the commercial acceptibility of the technique must be viewed with optimism.

Figure 1

% reductions in dry weight of foliage (Mean of 3 dose rates)



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CONTROL OF AVENA FATUA IN SPRING BARLEY BY CONTROLLED DROP APPLICATION: COMPARISONS OF THE ACTIVITY OF TWO HERBICIDES AT THREE DOSES AND FOUR VOLUME RATES

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Summary Comparisons of controlled drop and conventional applications of barban in five experiments and difenzoquat in eleven experiments were made in spring barley crops infested with A. fatua. In four experiments barban 0.350 kg/ha applied at 10, 20 and 40 l/ha reduced seed production of A. fatua by an average of 91%, 96% and 95% respectively compared with 99% by the conventional application. In the fifth experiment, barban applied conventionally gave poor control (61%) compared with controlled drop applications of 85%, 93% and 90% respectively. Difenzoquat 1.00 kg/ha applied at 10, 20 and 40 l/ha gave an average of 78%, 86% and 95% reduction of seeding compared with 99% by the conventional application. When herbicide dose was reduced by one third the average levels of control were maintained with barban, but were reduced with difenzoquat. It was concluded that 20 l/ha would be an optimum volume rate for barban but that a higher volume rate may be needed for difenzoquat. Reasons for differences in controlled drop application performance between herbicides and between seasons are suggested.

Résumé Dans 5 essais avec barban et 11 avec difenzoquat pour la destruction d'Avena fatua en cultures d'orge d'été "controlled drop applications" (qu'on peut traduire ainsi: technique pour la production d'une population de gouttelettes au diamètre identique et connu) furent comparées aux applications ordinaires. Dans 4 essais, le barban à raison de 0.350 kg/ha, appliqué dans 10, 20 et 40 litres/ha, effectu des baisses de 91%, 96% et 95% respectivement dans la production de semences d'A. fatua; l'application ordinaire donna une baisse de 99%. Dans le cinquième essais, l'application ordinaire du barban donna une baisse de 61% en comparaison avec 'controlled drop applications' de 85%, 93% et 90% respectivement. Le difenzoquat à 1 kg/ha, appliqué également dans 10, 20 et 40 litres/ha effectua des baisses de 78%, 86% et 95% respectivement en comparaison avec 99% suivant des applications ordinaires. Lorsque da dose d'herbicide se réduisit d'un tiers les niveaux de réduction se maintinrent avec le barban mais baissèrent avec le difenzoquat. En fin de compte il parut que 20 litres/ha serait le volume optimum pour des traitements au barban tandis que le difenzoquat pourrait exiger un volume supérieur. On propose des explications pour les différences du comportement des "controlled drop applications" entre les deux herbicides et les saisons différentes.

INTRODUCTION

Controlled drop application (CDA) by rotary atomisers allows herbicides to be applied in much lower volumes of water than with conventional spraying through hydraulic nozzles (Taylor and Merritt, 1975). The logistic advantage of having less water to transport should increase the speed and timeliness of herbicide application. Timeliness of application is particularly relevant to the control of A. fatua where successful control is often limited by critical growth stages or environmental factors.

A programme for the control of A. fatua by controlled drop application has been carried out at the Weed Research Organization for several years. The herbicides examined have been barban and difenzoquat. Experiments carried out during 1974 and 1975 are at present in process of publication. Results of experiments carried out during 1976 are published in this report.

In the earlier work, controlled drop applications of barban and difenzoquat at 15 l/ha and 45 l/ha gave as good a control of A. fatua as applications at conventional volume rates. Variations in drop size had relatively little effect on the level of control. Volume rates at 10 l/ha and less gave poorer control than conventional volume rates, and an optimum volume rate of about 20 l/ha was suggested for the controlled drop application of these herbicides. The series of experiments carried out in 1976 were designed to confirm this and assess the reliability of this method of application.

METHODS AND MATERIALS

Fifteen experiments were set up in spring barley crops during April 1976 in which controlled drop applications of 10, 20 and 40 l/ha were compared with applications at conventional volume rates. Five of these experiments were subsequently sprayed with barban during late April, and ten with difenzoquat during May. Each herbicide was applied at the recommended rate, and also at reduced rates (0.67, and 0.33 of the recommended) to increase the sensitivity of comparisons between volume rates. Experiments were each of a randomised split plot design with main plots of herbicide dose split for volume rate, and replicated twice.

Treatments comprised:-

	Barban	Difenzoquat
Main plots - dose kg/ha a.i.	0.117, 0.234, 0.350	0.33, 0.67, 1.00
	X	X
Sub plots - volume rate l/ha	10, 20, 40, 175	10, 20, 40, 225

Two additional plots were left unsprayed within each replicate, one between each pair of main plots. Plots measured 2m x 12m and each experiment occupied an area of 28m x 24m.

Agricultural Development and Advisory Service, South East Region carried out an experiment (site 16, Table 1) with difenzoquat with treatments similar to those described above, with four replicates. Controlled drop applications were made by staff of the Weed Research Organization with the same equipment as used in the main series of experiments.

Two units supplied by Horstine Farmery Limited were used for the controlled drop applications (Farmery, 1975). Each unit consisted of two discs mounted on a common spindle and driven by a 12 v. electric motor. The discs rotated at 1880 rev/min resulting in drops of 225 µm diameter. Liquid flowed on to the top disc, and was regulated by the use of brass restrictors inserted in the polythene tubing. The two units were mounted on a frame and spaced 1.2 m apart to give uniform distribution of drops over a width of 2 m. The frame was supported on hessian wind shields set 2 m apart to confine drops to the width of the plot. Two operators carried this frame, and after calibrating flow rates of all the CDA spray solutions through the restrictors, walking speeds of 1.2 m/sec, 0.6 m/sec and 0.3 m/sec were established for the volume rates of 10 l/ha, 20 l/ha and 40 l/ha respectively.

Conventional applications were made using a propane pressurised sprayer with a boom held by two operators walking at 1 m/sec. Barban was applied with Spraying Systems Teejets 65015 nozzles at a pressure of 2.8 bars and difenzoquat with 6502 nozzles at a pressure of 2.1 bars.

Differing concentrations of barban (Carbyne B 25, 25% e.c.) and difenzoquat (Avenge 40% e.c. without wetter) were prepared in water for the various combinations of dose and volume rate. With all applications of difenzoquat, a surfactant (Agral) was added to give a standard concentration of 0.5% v/v.

Assessments

In the spring, densities of barley and A.fatua seedlings were determined (Table 1). Barley seedlings were counted on 20 random quadrats of 0.1 m^2 on each replicate. A. fatua seedlings were counted on 10 random quadrats on each plot, quadrat size varying from 0.025 m^2 to 0.1 m^2 according to A. fatua density. The stage of growth of seedlings was recorded at the time of herbicide application.

Table 1

Experiment locations, application dates, and densities and growth stages of barley and A. fatua

Site location	Application date	Seedlings/m^2 Barley	Seedlings/m^2 A.fatua	A. fatua (% of seedlings in 4 groups) Up to $1\frac{1}{2}$lvs	$1\frac{1}{2}$-3 lvs	3-$4\frac{1}{2}$ lvs	Over $4\frac{1}{2}$lvs	Barley lvs/ plant	Barley tillers /plant
Barban experiments									
1. Meysey Hampton	26 April	196	222	20	66	14	1	4	
2. Chippinghurst	27 April	211	31	30	59	11	0	3	
3. Waterstock	27 April	282	44	8	68	24	0	4	
4. Rissington	27 April	148	74	42	58	0	0	4	
5. Guiting	28 April	145	50	71	29	0	0	$3\frac{1}{2}$	
Difenzoquat experiments									
6. Bicester	4 May	299	65	7	45	41	7		2-3
7. Compton Beauchamp	5 May	245	83	8	31	45	16		4-6
8. Down Ampney	6 May	284	424	0	45	46	9		4-6
9. Stonesfield	7 May	237	32	8	12	42	38		2-4
10. Elsfield	7 May	212	33	4	4	75	17		4-5
11. Rissington	10 May	148	127	20	40	18	22		5-7
12. Guiting	13 May	145	44	6	34	52	8		4-6
13. Waterstock	14 May	282	40	3	19	62	16		3-4
14. Streatly	18 May	264	27	2	53	45	0		2-3
15. Preston Bisset	21 May	190	40	3	7	52	38		3-4
16. Benson (ADAS)	13 May		71	4.4 leaves (average stage)					

Note: Experiments 3 and 13, 4 and 11, 5 and 12 were adjacent in the same fields.

The range of stages of A. fatua was recorded by noting the stage of all seedlings present within a total area of 0.8 m^2 (8 quadrats of 0.1 m^2 on the unsprayed plots). The proportions of seedlings in the four groups shown in Table 1 were calculated.

In July the number of A. fatua panicles were recorded. All panicles were counted in the centre 1 m x 8 m of each plot. The number of seeds on each panicle was determined from a random sample of 30 panicles per plot. From this data, the numbers of seeds produced per m^2 were estimated. Results from individual sites were analysed, fortunate that so many vegetable herbicides were cleared at a time when costs were more reasonable. Fortunately most field vegetable crops are still large enough in Great Britain to encourage manufacturers to extend clearance from major arable crops to field vegetable crops. This cannot be guaranteed for the future and the situation may be approaching when all vegetables are minor crops on which only very limited clearance and approval expenditure can be tolerated by manufacturers.

The same problem will also restrict the availability of herbicides on a regional basis. Minor crops can occupy positions of considerable importance locally, for example the growing of leeks in the Lothians. On a national basis this is still a minor crop to a chemical manufacturer. However even with 'major' crops such as peas the Scottish acreage would not pay for the cost of setting up trials in Scotland, and if regional differences are likely to occur and the advisory services cannot do any supporting work this area suffers as much as do the leeks.

Faced with this situation the Agricultural Chemicals Approval Scheme, with the help of the Agricultural Development and Advisory Service and the British Agrochemical Association have established a new category of approval to make it easier for manufacturers to get minor use recommendations on product labels and subsequently obtain full approval. These uses will appear on the label under the heading 'Use Provisionally Accepted under ACAS'. Before a use can appear in this category there must be sufficient evidence to show that there is a high probability that the product is safe to the crop concerned and effective against the weeds mentioned. Upon acceptance the scheme then notifies the advisory and development services, and any relevant research bodies. There is then five years in which data must be accumulated in order that full approval can be granted, failing which the recommendation would be removed from the label.

This it is hoped will partly offset some of the difficulties of getting minor use recommendations on to labels. The next stage of combining recommendations and tailoring products to meet individual crop needs will need an equally combined operation to be fruitful. Much could be done by cooperation between the major sectors of the vegetable industry to produce more herbicide programmes for the mutual benefit of all.

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INVESTIGATIONS INTO THE ADDITION OF MINERAL OIL TO BENTAZONE FOR POST-EMERGENCE WEED CONTROL IN DWARF BEANS

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Summary In experiments carried out over two seasons the addition of mineral oil to bentazone considerably improved the control of *Chenopodium album* and it would appear that such a mixture overcomes those problems of lack of control of this weed using bentazone alone, which occur when it develops and is treated under very dry conditions. Control of other species is also improved by the addition of oil, but their control with bentazone does not appear to be such a problem under dry conditions. The addition of 2 l/ha of soil to 1.5 kg a.i./ha of bentazone did not significantly reduce selectivity under dry conditions, but further work wouldbe desirable under wetter and more humid conditions.

Applications of bentazone and bentazone plus oil made at 224 l/ha gave significantly better weed control than those made at 560 l/ha, without increased crop effects being recorded.

INTRODUCTION

Dwarf green beans (*Phaseolus vulgaris*) used for freezing, canning or dehydration are still mostly grown in wide rows, usually approximately 46-50 cm apart. Until recently these were the only row widths suited to the harvesters available, but there are now machines which are capable of harvesting crops grown in rows as close as 13 cm. Before more intensive systems can be fully exploited, it is essential that reliable chemical weed control systems are available, since cultivations or shielded sprays are precluded and the crop offers little competition to weed development. Previous work with pre-sowing applications of trifluralin and post-emergence bentazone (Farrant & Bryant, 1974; Handley & King, 1972, 1974, May, 1974; Roberts, Bond & Ricketts, 1974) has shown that 'programmes' based on these two herbicides are capable of giving more effective and reliable weed control than pre-emergence herbicides alone. In 1975 herbicide programmes involving the pre-sowing incorporation of trifluralin, followed by either dinoseb-acetate plus monolinuron pre-emergence, or bentazone post-emergence were widely used commercially and in general worked well. However, under very dry conditions, in commercial and experimental usage, *Chenopodium album* was found to be completely resistant to bentazone, irrespective of growth stage. Control of other weed species did not appear to be affected to the same degree. In 1974, preliminary tests in dwarf beans by the Processors & Growers Research Organisation (Unpublished) showed that the addition of mineral oil to bentazone increased control, particularly of *C. album* without seriously reducing selectivity. A series of replicated experiments testing such mixtures has been carried out during 1975 and 1976, two exceptionally dry summers in eastern England, and the results are presented in this paper.

METHOD AND MATERIALS

The experiments were carried out either in commercial dwarf bean crops or on areas sown for this purpose on the Thornhaugh trial ground. Plots were 10 sq m, treatments being replicated four times. The materials were applied with a van der Weij plot sprayer, fitted with Birchmeier cone nozzles, at volumes of 224 or 560 l/ha and a pressure of 2.1 kg/cm^2. The standard formulation of Basagran containing 48% bentazone in aqueous solution was used and the mineral oil was the commercial product Actipron. Assessments were carried out during the season for effects on the crop and for weed control. At harvest the pods were removed by hand and weighed or, in the case of the dried beans, the plants were pulled by hand, threshed with a plot viner and the produce dried to 16% m.c. The green bean experiments were harvested at the commercial freezing or canning stages of maturity and samples of produce from each plot were used to determine the relative maturity, by measurement of seed length. The largest seed was removed from the most mature pod on each of ten plants taken at random from each plot. The total length of the ten seeds was then measured in mm. In 1976, an attempt was made to determine whether or not the addition of oil made bentazone more 'rain fast' and 6.8 litres of water per plot was applied to some treatments one hour after the application of bentazone and oil, using a watering can with a fine rose. This amount of water was equivalent to approximately 1 mm of rain.

The site details are as follows:-

No.	Location	Variety (date sown)	Stage of crop & weed at time of post-em application: Crop	Stage of crop & weed at time of post-em application: Weeds	Weather: Temp. (C)	Weather: Humidity
1	Thornhaugh	Cascade (23/5)	2 trifol.	Seed.to est.	24	Mod.
2	Gedney	" (19/6)	" "	" " "	16	"
3	Fosdyke	" (26/6)	2-3 trifol.	None	20	High
4	Writtle	Purley King (15/5)	" "	Seed.to est	18	Low-mod.
5	Coggeshall	" " (16/5)	1-3 trifol.	" " "	18	" "
6	Thornhaugh	Cascade (24/5)	Cot.-1½ trifol.	" " "	30	Low
7	Holbeach	Chicobel(17/6)	2-2½ trifol.	None	13	Low-mod.
8	Thornhaugh	Cascade (3/6)	" "	Seed.to est.	18	Low
9	Sutton Bridge	Cascade	1½-2 trifol.	Advanced	13	Low
10	Thornhaugh	Cascade (23/7)	1½-2 trifol.	Seed. to young plant	17	Low

Samples of produce taken from plots treated with bentazone and oil were canned and frozen in 1975 and submitted to Campden Food Preservation Research Association for taint assessments.

RESULTS

1975

The results of assessments for weed control and effects on the crop appear in Table 1. At the three green bean sites, bentazone alone caused quite marked marginal chlorosis and necrosis shortly after application and the addition of 1 l/ha of oil increased the effects on the crop at two sites. At site 1 the addition of 1 or 2 l/ha did not apparently increase the effects. At the two dried bean sites, no noticeable increases in effect on the crop were recorded from the addition of oil and the general effects of the bentazone were very slight.

In most cases the crop soon outgrew the effects and by harvest little difference in vigour could be detected between the treated and untreated plots, but at sites 2 and 3 vigour was reduced even at harvest.

At site 1, Chenopodium album was the predominant weed and was present in large numbers, and the plants had developed under very dry conditions. Bentazone alone had very little effect on the majority of plants, but the addition of 1 l/ha of oil improved control to an almost acceptable level and the addition of 2 l/ha gave good control. At site 2, where C. album and Polygonum convolvulus were the main weeds, bentazone alone gave excellent control of both species and the addition of 1 l/ha of oil produced only a marginal improvement. At site 4, in dried beans, C. album and P. convolvulus were again the main weed species present, together with Solanum nigrum, Polygonum aviculare and Sinapis arvensis. Bentazone alone gave only partial weed control, the majority of weeds being at an advanced growth stage when treated and the addition of 1 l/ha of oil only improved control slightly and there was little improvement from the high rate of bentazone and oil. At site 5 the weeds were again at an advanced stage of maturity by the time the crop had reached a suitable stage of development for treatment and included two species, P. aviculare and Veronica spp., both resistant to bentazone, together with P. convolvulus and Stellaria media. Control from bentazone alone was very poor and the addition of 1 l/ha of oil gave only slight improvement while control from bentazone at 2.8 kg a.i./ha plus 2 l/ha of oil was also unacceptable.

Table 1

Crop and weed assessments - green and dried beans 1975

Material	Rate kg a.i./ha	Site: / Date:	Crop effects§ 1 10/7	2 7/8	3 10/8	4 17/7	5 16/7	Weed control§ 1 10/7	2 7/8	4 17/7	5 16/7
bentazone	1.4		6.5	7.0	7.0	9.3	9.5	3.5	8.8	4.5	2.8
" + oil	1.4+1 l.		6.4	6.0	6.4	9.3	9.3	6.5	9.0	5.5	3.3
" "	1.4+2 l.		7.0	-	-	-	-	8.5	-	-	-
" "	2.8+2 l.		6.0	5.0	5.4	9.0	9.0	9.2	9.5	5.8	4.3
Untreated			10.0	10.0	10.0	10.0	10.0	10.0	0.0	0.0	0.0

Key: § Crop effects 10 = no visible effects.
0 = crop killed
Weed control 10 = complete control
0 = no control

Yield and maturity data appear in Table 2.

Table 2

Yield and maturity data - green and dried beans 1975

Material	Rate kg a.i./ha	Site:	Yield % of untreated 1	2	3	4	5	Relative maturity (seed length mm) 1	2	3
bentazone	1.4		203	106	100	110	129	111**	94	86
" + oil	1.4+ 1 l.		238	108	108	110	81	123**	97	90
" "	1.4+ 2 l.		245	-	-	-	-	132**	-	-
" "	2.8+ 2 l.		276	80*	91	128	108	124**	92	95
Herbicide mean			241*	98	100	116	106	123***	94	90
Untreated			100	100	100	100	100	83	95	97
Yield of untreated (tonnes/ha)			2.3	12.7	10.8	0.8	0.8	-	-	-
S.E.Dmean ±			80	10	30	22	25	9	5	7
S.E.Dherbicide mean & untreated±			56	8		13	21	7	3	-

* significantly different from untreated at the 5% level
** " " " " " " 1% "
*** " " " " " " 0.1% "

At site 1 where severe weed competition seriously affected crop growth on the untreated control plots, all bentazone treatments gave higher yields and the herbicide mean was significantlygreater than the untreated. At site 2 where weed competition was less severe yields from the normal rates were not significantly higher than the untreated, but the twice normal rate was significantly lower. At site 3, where no weeds were present, there were no significant differences between any of the treatments, while again at sites 4 & 5 the bentazone treatments did not significantly increase yield of dried beans compared to the untreated control. The only major effects on maturity of produce were at site 1, where the seeds from pods taken from the untreated plots were significantly smaller than on any of the treated ones. This could have been an effect of the severe weed competition at this site.

1976

The results of crop and weed assessments appear in Tables 3 and 4. Bentazone alone had little effect on the crop at site 6 and the addition of ammonium sulphate and mineral oil increased the effects, but not to an unacceptable degree except where bentazone @ 3.0 kg a.i./ha plus 4 l. of oil had been used. At site 7, all bentazone treatments caused marked crop effects when assessed eight days after application, but the effects from bentazone and oil mixtures were only marginally worse than bentazone alone. Where the rate of bentazone had been reduced to 1.0 kg a.i./ha plus 2 l/ha of oil the effects were less than with 1.5 kg a.i./ha of bentazone alone. The addition of ammonium sulphate made no difference to the crop effects at this site.

At site 6, bentazone gave very poor control of the predominant weed C. album and of Fumaria officinalis, but control of Capsella bursa-pastoris was almost acceptable. The addition of ammonium sulphate reduced the control of C. album, but appeared to improve slightly the control of C. bursa pastoris and F. officinalis. The addition of 1 l/ha of oil considerably improved the control of C. album and marginally improved the control of C. bursa pastoris while 2 l/ha gave an even greater improvement in control of C. album. The addition of oil did not materially improve control of F. officinalis. There were insufficient weeds at site 7 to enable weed assessments to be carried out.

Table 3

Assessments and yield data - green beans 1976

Material	Rate kg a.i./ha	Site: Date:	Crop 6 24/7	Crop 7 28/7	Weed 6 24/7	Yield % of untreated 7	Relative maturity seed length 7
bentazone	1.5		9.3	5.9	3.7	92	63
bentazone + Ammon. sulphate	1.5 + 4 kg		8.0	6.0	2.7	92	62
bentazone + oil	1.5 + 1 1.		7.3	5.6	6.0	99	61
" "	1.5 + 2 1.		8.3	5.6	6.0	94	68
" "	1.0 + 2 1.		8.0	7.0	6.3	94	67
" "	3.0 + 4 1.		6.7	5.0	9.0	88*	57
Untreated			10.0	10.0	0.0	100	62
Yield of untreated (tonnes/ha)			-	-	-	4.8	-
S.E.D mean ±			-	-	-	6	5

Key: Weed control 10 = complete control
0 = no control

$ Crop effects 10 = no visible effects
0 = crop killed

* significantly different from the untreated at the 5% level.

At site 7, the double rate of bentazone and oil was significantly lower yielding than the untreated control and the bentazone at 1.5 kg a.i./ha plus 1 litre of oil treatment but there were no differences in yield between other treatments. No significant effects on maturity of produce were recorded.

Table 4

Crop and weed assessments - green beans 1976

Material	Rate kg a.i./ha	Volume	Site: Date:	Crop $ 8 13/7	Crop $ 9 19/7	Crop $ 10 10/8	Weeds $ 8 10/8	Weeds $ 9 19/7	Weeds $ 10 10/8
bentazone	1.5	Low		7.0	8.0	8.1	4.3	5.1	6.5
" + oil	1.5 + 2 1.	"		7.0	8.1	8.2	8.5	6.0	9.0
" "	1.0 + 2 1.	"		8.0	8.6	8.4	6.3	5.0	8.0
" "	3.0 + 4 1.	"		6.0	8.1	8.0	9.8	6.8	10.0
bentazone	1.5	Medium		7.0	8.1	8.8	1.0	4.3	4.5
" + oil	1.5 + 2 1.	"		7.5	8.3	8.3	5.8	4.5	8.0
" "	1.0 + 2 1.	"		8.0	8.1	8.3	4.3	4.4	5.5
" "	1.0 + 2 1.ƒ	"		8.5	8.3	8.6	2.0	6.4	5.3
Untreated				10.0	10.0	10.0	0.0	0.0	0.0

Key: ƒ Plots watered one hour after treatment applied.
$ Crop effects 10 = no visible effects.
0 = crop killed

Weed control 10 = complete control
0 = no control

In the second series of experiments carried out in 1976, (Table 4), slightly more effects on the crop were recorded when the treatments were applied at low volume than when applied in medium volume. The addition of oil at 2 l/ha to 1.5 kg a.i./ha of bentazone did not increase the effects on the crop compared to bentazone alone. The mixture of 2 l/ha of oil and 1.0 kg a.i./ha of bentazone gave fewer crop effects than either bentazone at 1.5 kg a.i./ha or the mixture of this rate with oil. The twice normal rate of bentazone at 3.0 kg a.i./ha plus 4 l/ha of oil gave quite marked effects at site 8, but not at the other two sites. Where the plots were watered one hour after treatment the effects on the crop were less marked.

All treatments applied at low volume gave much better weed control than when applied at medium volume. Bentazone alone gave generally poor control, particularly of C. album, which was the predominant weed at each of the three sites, and the addition of oil considerably improved the control of this weed and also C. bursa pastoris, which occurred at site 9. Although the mixture of 1.0 kg a.i./ha of bentazone and 2 l/ha of oil gave better control than 1.5 kg a.i./ha of bentazone alone it was noticeably less effective than where the oil was mixed with the higher rate of bentazone. These same trends appeared when low and medium volume treatments were compared. The effect of watering the plots after treatment was to reduce the control at one site and noticeably improved it at another, while at the third site there was no difference between the watered and unwatered plots.

Table 5

Yield & maturity data - green beans 1976

Material	Rate kg a.i./ha	Volume	Site:	Yield % of untreated 8	10	Relative maturity (seed length) 8	10
bentazone	1.5	Low		174**	139*	112	72
" + oil	1.5 + 2 l	"		198***	153*	115	63
" "	1.0 + 2 l	"		195***	141*	105	63
" "	3.0 + 4 l	"		188***	142*	98	70
bentazone	1.5	Medium		137	124	109	68
" + oil	1.5 + 2 l	"		186***	150*	123	69
" "	1.0 + 2 l	"		187***	122	122	67
" "	1.0 + 2 l †	"		139	137*	112	67
Untreated				100	100	104	64
Yield of untreated (tonnes/ha)				4.0	6.8	-	-
S.E.D. mean ±				20	14	8	4

* Significantly different from untreated at the 5% level
** " " " " " " 1% level
*** " " " " " " 0.1% level

At site 8 all treatments, with the exception of the medium volume applications of bentazone at 1.5 kg a.i./ha and bentazone at 1.0 kg a.i./ha plus 2 l/ha of oil which was subjected to artificial watering, significantly outyielded the untreated control. The low volume applications of bentazone plus oil at 1.5 kg a.i./ha + 2 l/ha, 1.0 kg a.i./ha + 2 l/ha and 3.0 kg a.i./ha + 4 l/ha and the medium volume applications of bentazone plus oil at 1.5 kg a.i./ha + 2 l/ha and 1.0 kg a.i./ha + 2 l/ha, significantly outyielded the medium volume applications of bentazone at 1.5 kg a.i./ha and the bentazone at 1.0 kg a.i./ha + 2 l/ha of oil followed by artificial watering.

At site 10 all treatments, with the exception of bentazone at 1.5 kg a.i./ha and bentazone at 1.0 kg a.i./ha plus 2 l/ha of oil applied at medium volume, significantly outyielded the untreated control. Bentazone at 1.5 kg a.i./ha plus 2 l/ha of oil applied at low and medium volume gave significantly higher yields than bentazone at 1.0 kg a.i./ha plus 2 l/ha of oil applied at medium volume, while bentazone at 1.5 kg a.i./ha plus 2 l/ha of oil applied at low volume gave a significantly higher yield than bentazone at 1.5 kg a.i./ha applied at medium volume.

The differences in seed length recorded at the two sites were not statistically significant.

Produce quality No taints were found in the canned and frozen samples taken from plots treated with the twice normal rate of bentazone plus oil in 1975.

DISCUSSION

Throughout the series of experiments carried out in 1975 and 1976 bentazone has given poor control of *Chenopodium album* growing under dry conditions and results against this weed have been inferior to those obtained in previous, wetter seasons. In all the experiments the addition of oil improved general weed control and particularly control of *C. album*.

In 1976 there was considerable difference in weed control between treatments applied in low or medium volume, particularly those containing oil, and there seems little doubt than bentazone plus oil treatments are more effective when applied at low volume. Although the rate of 1.0 kg a.i./ha of bentazone with 2 l/ha of oil caused slightly fewer crop effects than 1.5 kg a.i./ha with 2 l/ha of oil, results suggest that it is preferable to use 1.5 kg a.i./ha of bentazone with 2 l/ha of oil due to the improved effectiveness of this mixture against weeds.

On occasions, the addition of oil slightly increased the visual effects on the crop, but at harvest there were no indications that it reduced yield or affected maturity and where increased visual effects occurred they were more than compensated for by improved weed control. It is interesting to note that in 1976 the site where most crop effects were recorded was sprayed at mid-day, while the other sites were treated either in the morning or late afternoon. Also the temperature at this site when spraying took place was not particularly high, whereas several of the crops at other sites were treated at much higher temperatures. There is therefore the possibility that the crop is more susceptible to herbicide uptake at that time of the day. Although the addition of ammonium sulphate to herbicides has been claimed to increase effectiveness, in these experiments it had no beneficial effect. At two sites there were indications that the effect of bentazone at 1.0 kg a.i./ha plus oil at 2 l/ha on weeds was unaffected by watering shortly after treatment, but at a third site control was noticeably reduced.

The use of a bentazone/mineral oil tank mix shows promise for improving the control of difficult weeds such as *C. album* particularly when they develop under dry conditions, any slight increase in crop effect from the use of such a mixture being more than compensated for by improved weed control. The use of such a mixture is particularly attractive in dwarf beans where bentazone cannot be used with safety until at least one or two expanded trifoliate leaves have developed, by which time the weeds are often at an advanced stage.

These experiments have established the safety of bentazone plus oil mixtures in seasons where conditions were dry and humidity low, but where applications were sometimes made at higher temperatures than those recommended for the material (21°C). Further work is therefore desirable in more humid weather, to confirm the safety of this mixture over a wider range of conditions.

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THE IMPACT OF HERBICIDES ON PLANT BREEDING

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Summary Comparisons are made between the evolution of resistance to fungicides and pesticides by pathogens and pests, and to herbicides by weeds. Attention is drawn to the complex competitive forces that operate on weed populations which restrict the establishment of ecologically successful, resistant forms. Metabolic interferences at biochemical and cytological levels, which characterise many of the newer herbicides are examined in relation to damage to growth processes and to the range of variation in resistance among cultivars. It is suggested that gene mutations which increase the rates and alter the timing of detoxication of herbicides can make a valuable contribution towards minimising possible detrimental effects of herbicides on apparently tolerant genotypes and provide the genetic mechanism for breeding fully resistant cultivars.

It is a striking feature of developments in crop protection that the genetical component of our thinking and understanding, while dominating developments and disappointments in the control of microbial diseases and animal pests, has played such a minor role in weed science. One reason for this arises from the fact that genetical implications and consequences are more clearly in focus where the double act of the interacting genetic systems of hosts and parasites are involved, as in the dynamics of resistant cultivars and virulent races of pests and pathogens. In contrast, crop protection by the use of herbicides is at a very much more indirect level, usually not involving parasitism but providing a defense of a more general kind against diversion of light energy and nutrients to competing weed populations. Also the reaction of crops to herbicides has not hitherto been at issue because it has been assumed that treatment effects due to herbicides are neutral. Whether this is justifiable in the light of current knowledge on the action of the biologically active, organo-herbicides, is one of the issues I would like to examine in this paper.

As might well have been expected, a range of genetical variation in the level of tolerance to herbicides is found among both weeds and crops (WRO 1972), and also as expected, the mechanisms of resistance span the entire spectrum of protective systems from failure of uptake, and of translocation, to complex biological systems of molecular degradation and detoxication. All these forms of resistance are of interest to geneticists and plant breeders, but as the current range of herbicides rely for their effects to an increasing extent on the interruption of metabolic pathways rather than acting as general cell poisons, it is mechanisms of detoxication inherent in plant metabolism and their rate of function, that have added the new dimension to the relation between weed science and plant breeding programmes. Unfortunately, several, if not most, of the mechanisms of detoxication within the plant, are still imperfectly understood and very few of the enzymes involved have been identified. When eventually the processes are understood in detail, it should come as no surprise that most detoxication systems, and therefore species selectivity, will be shown to be under direct genetical control and capable of modification at all quantitative levels, ranging from minor alterations in reaction rate to complete suppression, dependent on the magnitude of the effects of mutations in structural and rate-controlling genes.

Evolution of resistant races of weeds

In the light of basic assumptions of this kind on the direct implication of genetic controls of herbicide tolerance, one must question why the evolution of resistant mutations within weed species has not progressed along lines similar to the numerous resistances that have negatived the effects of fungicides, and insecticides? It must be conceded as somewhat contrary to the expected order of things that only a few resistant strains have so far evolved in response to the very heavy, world-wide selection pressures imposed by numerous herbicides over the past twenty-five years. The scale of the evolutionary potential may be highlighted by the fact that currently a crop area of about 150 million acres, roughly 3 times the acreage of the U.K., is treated annually with herbicides in the U.S.A.. Yet the number of resistant strains within weed species is impressively few: and most of those reported have precious little direct relation to evolution in the field but are the products of selection among experimental laboratory populations developed to study resistance potential. The list of resistant species includes: scentless mayweed, resistant to M.C.P.A., Amaranthus spp. and Chenopodium album, to atrazine, and groundsel, scentless mayweed and Chenopodium album, resistant to simazine. Even the alternative ecological response, the preferential multiplication of resistant weed species and the appearance of new weed problems have been far less troublesome than might have been expected, although it may be that the dramatic spread of wild oat in recent years in England may be due, in part at least, to the absence of competition from the common broad-leaved weeds which have long yielded to control by selective herbicides.

A commonly accepted explanation for the absence of resistant weed strains centres on the huge populations of unselected buried viable seeds of the species being controlled that are ever-ready to fill the ecological vacuum created by the eradication of the established, susceptible population. Although this factor clearly must have operated during the early years of use of selective herbicides, it might, however, be expected that after continual application over the years, this counter-selection effect would have sufficiently weakened to allow the multiplication of many resistant populations in several weed species and on a wide scale.

Further consideration suggests that other more subtle factors may be operating. Comparisons of the evolution of insects and microbial pathogens in response to insecticides and fungicides with the interactions between weeds and herbicides reveal clear ecological differences. Pests and pathogens compete at sub-specific and inter-specific levels for sites on host plants, so that when susceptible, genotypes are eliminated, pressure on the substrate sites is eliminated and they become available for colonisation by resistant strains or by other resistant species. Resistant weeds don't have things so easy: they are in competition for ecological sites in the soil, not only with susceptible reserve soil populations of their own and of other species, but they must also compete with the crop, which, invariably is in a position of decided agronomic advantage in its claims on the essentials of the environment, especially light and soil nutrients.

Thus, to have any chance of successful establishment, resistant weed genotypes must be at least as fit as, if not fitter than, the susceptible members of the population at the crucial business of establishment and survival. There is no information available on the relative fitness of resistant strains of weeds, and it is possible, in common with many mutational changes that most mutant phenotypes are less efficient ecologically, at least initially, than the susceptible forms from which they arose. If this is true, it not only serves to explain the unexpectedly low frequency of resistant forms of weeds, but also has serious implications for the breeding of resistant crop cultivars. The question of the fitness of resistant weeds becomes critically relevant especially since it is directly related to the far more significant question of whether resistant crop cultivars are as agronomically fit as the newer high-yielding, susceptible counterparts to which British agriculture has now become thoroughly accustomed.

Herbicide damage to crops

The issue of which genotype of crop species has the most competent protective mechanism against modern herbicides, without loss of agronomic fitness, is a direct result of the success and sophistication of herbicide chemistry. Present-day formulations do not use sledge-hammer techniques of contact-killing, or of general poisoning of metabolic systems but rely on subtle, biochemical meddling in the vital processes of respiration, or photosynthesis, or of protein or lipid metabolism, leading to a cut-off of energy supplies and ultimately to metabolic exhaustion. Much of this meddling is achieved through interference with the many enzymes involved in glycolosis, in the Krebs cycle and in photosynthesis. Surprisingly few of these critical metabolic inhibitions in which modern herbicides take part have been elucidated in detail. It has taken 25 years to establish the role of the phenoxy herbicides in R.N.A. synthesis and therefore in the direct control of protain translation, so that understanding in this area cannot be said to come easy.

Geneticists have a particular interest in the biochemical fate of herbicides in plants since as has been indicated it is almost certain that most will prove to be directly mediated by gene-controlled systems which are amenable to selection. The plant breeder has a further more practical interest since he needs to know whether the herbicide effects, and the genetical solution he proposes, are neutral vis a vis agronomic performance.

The release of highly susceptible, prime cultivars of crop plants such as Maris Huntsman wheat, which is damaged by widely used herbicides, may well prove to be a blessing, especially if it acts as a stimulus to further understanding of the biochemical and genetical interactions between plants and herbicides. The problem is not whether the current range of organo-herbicides and their successors have a large and readily visible effect on growth and agricultural yield of crops, but whether at the biochemical, at the cell level, there is a more insidious reduction, if only temporary, in metabolic efficiency such as might eliminate the genetical advantages that have contributed to the superior performance of cultivars.

Genetic control of herbicide selectivity

In the same way as the herbicidal effects of the current range of chemicals are linked to metabolic pathways, so also are the patterns of their detoxication and degradation, on which it is becoming increasingly apparent the selectivity they possess largely depends. Furthermore, the molecular mechanisms, many of which are well-known and highly specific, such as oxidation, hydroxylation, dechlorination, de-alkylation and conjugation, are almost certainly enzymatically determined and therefore directly gene-mediated, although some, including the best known example, the de-chlorination and hydroxylation of simazine, is based on direct interaction between non-enzymatic chemicals and is therefore a few synthetic steps away from direct gene control.

The fact that selectivity rests so often on molecular degradation underlines the importance of rate of detoxication, as distinct from the specific pathway, in relation to the ability of the crop plant to attain maximal rates of growth, and to recover the metabolic losses suffered while the herbicide is present at toxic levels. The known interactions between plants and the organo-herbicides are so basic to growth and development that it cannot be assumed that even a temporary inhibiting effect is completely trivial.

Maleic hydrazide has been identified for a long time as a powerful inducer of chromosome breakage and of other effects on mitotic processes. The carbamates, propham and chlorpropham, are also known to affect cell division in plants, including barley and peas (Ennis 1948, Scott and Struckmeyer 1955, and Canvin and Friesen 1959), while the dinitroanilines, nitralin and trifluralin, have recently been shown to produce severe inhibiting effects on root development and on mitosis in cotton, Johnson grass (Sorghum halepense) maize and sugar beet (Hacskaylo and Amato 1969, Gentner and Burk 1968 and Schweizer 1970). Among the abnormalities noted were: inhibition of cell-wall formation resulting in repeated endomitosis, chromosome fragmentation and aggregation, inhibition of spindle formation and of the development of lateral roots. Somewhat similar abnormalities have been found by Bingham (1968) resulting from the effect of the phthallate, DCPA, on Bermuda grass (Cynodon dactylon). None of these effects need necessarily be visibly detectable at moderate dosages, but the effects on growth of the crop during critical stages of development could be quite significant. The important point is that we are not completely sure what is happening, and further investigations are necessary to remove the uncertainties.

At a different biological level, many compounds, including the widely used phenoxy acids, interfere with biochemical syntheses including the production of ATP which has a primary role in the synthesis of R.N.A. and protein. Additionally 2,4-D appears to have a direct regulatory action on R.N.Aase synthesis. Mann et al (1965) presented good evidence which established a strong inhibiting effect by several important herbicides drawn from among amides, chlorocarbamates, nitriles, carboxylic acids and the phenols, on the incorporation of amino acids into protein. Among some other important anti-metabolic functions reported was a 75 per cent level of inhibition of phosphorus uptake into nucleic acids by Barban.

In a comprehensive study of the effects of 22 herbicides on R.N.A. and protein synthesis in maize and soyabean, Moreland et al (1969) showed that no less than two-thirds of those tested, were active anti-metabolites. The most active in relation to inhibition of protein synthesis were ioxynil, dinoseb, propanil, chlorpropham and pyriclor, with diuron, propachlor, dicamba and fenac giving intermediate but still significant inhibiting levels. Three of the chemicals, isocil, CDAA and picloram, while being neutral in respect of R.N.A. and general protein synthesis, had a significant effect on gibberellic-acid induced production of α-amylase and therefore could have severely adverse effects on germination and establishment. Similar results have been obtained by Jones and Foy (1971) in respect of α-amylase production in barley seeds: the most pronounced inhibitors in these experiments were fenac, bromoxynil, endothall, paraquat and dalapon.

Probably the most clear-cut effect that has been established for the organo-herbicides however, is the widespread inhibitory effect of urea and triazine formulations on reactions associated with the dissociation of water, the first step in electron transport during photosynthesis (see Ashton and Crafts, 1973, for full summary). Although it is suggested by several workers that this block for photosynthesis involving the Hill reaction does not directly account for the death of the plant through being starved of photosynthate, a large and rapid decrease in sugar content occurs in the tissues when the reaction is inhibited which must lead to sub-optimal levels of energy substrates for growth.

Implications for plant breeding

It follows from the close inter-dependence between selectivity and detoxication that both the crop and weed species may be damaged to some extent by metabolically active herbicides, and that selection for greater or lesser damage rests on identifying gene mutations which change the amount, or the activity, or alter the timing of the detoxicating enzyme proteins. The timing of enzyme activity, which is known to be precisely controlled during morphogenesis, clearly has special relevance to problems of herbicidal selectivity and plant breeding, since genetic segregation for differences in repression and de-repression of genes at particular stages of development could form the basis for breeding resistant or tolerant genotypes within a crop species.

Thus the plant breeder can no longer take merely a superficial interest in the effect of herbicides on cultivars. The absence of visible effects cannot with certainty be assumed to indicate economically neutral effects on yield. If the application of herbicides resulting in the elimination of say a 10 per cent yield loss due to weeds is associated with a direct reduction of harvest yield of only 5 per cent, which in most cases is very difficult to establish at farm level, plus the equivalent of a 10 per cent economic loss in the form of recurring herbicide application costs, the benefits of plant breeding quickly disappear. It is very unlikely that cultivars can be safely divided into two discontinuous groups, those on which a given herbicide can be considered safe and those on which it is unsafe. The groups will almost certainly respectively represent a range of quantitative effects from near zero or maximal effects, to within the fiducial limits of the unsafe category. At the very least, it must therefore be recognised that the validity or otherwise of this supposition should be critically substantiated. Once this is done and the biochemical and the agronomic consequences of herbicide application on crops has been more precisely determined the genetical and plant breeding solution will become clearer.

The evolutionary difficulties in respect of the evolution of resistant weeds should however warn against too optimistic an assessment of easy success in applying the genetical solution. There is no prima facie reason for supposing that mutations which modify the anti-metabolic functions of herbicides are in all instances as efficient as cultivars as susceptible forms. Indeed, natural selection over time will probably ensure that few of them are, at least initially. It is unlikely, however, that the entire interacting system of action and detoxication will give rise to problems that are incapable of solution in future, through intelligent hybridisation and selection by the plant breeders.

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THE EVOLUTION OF HERBICIDE RESISTANCE IN WEEDS AND ITS IMPLICATIONS FOR THE FARMER

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Summary The present status of herbicide resistance in weed species and its potential implications for the farmer is reviewed. Definitions of herbicide resistance and screening tests for detecting resistance have been outlined. The paper evaluates factors determining the intensity of selection and the rate of evolution of resistance. Mechanisms of herbicide resistance are discussed. Practical methods have been emphasised by which evolution of herbicide resistant weed populations can be prevented.

INTRODUCTION

Evolution of insecticide resistance was the inevitable result of widespread use of insecticides. A parallel increase in the use of herbicides led to predictions (Blackman, 1950; Abel, 1954; Harper, 1956) that evolution of genetically resistant weed populations would occur. There are few indications that these predictions have been fulfilled despite considerable evidence of intraspecific variation in susceptibility to herbicides (e.g. Hammerton, 1967; Ryan, 1970) and more than twenty years of regular herbicide application to many species of weeds, since the original predictions were made. There are however, a few well substantiated cases of evolution of resistant strains of weed species. For example, Senecio vulgaris (Ryan, 1970), Amaranthus retroflexus (Peabody, 1973) and Chenopodium album (Bandeen, 1975), have evolved resistance to atrazine and some other triazine herbicides in several localities in North America. These cases of resistance occurred in environments which particularly favoured rapid evolution because the herbicide treatment was maintained over many consecutive years of cropping a particular area.

The presence of genetic variation for resistance in cultivars of some crop plants has lead to attempts to select herbicide resistant crop strains (e.g. Warwick, 1973; Faulkner, 1975) which may in the future provide scope for enhanced efficiency of weed control. However, there is an inherent danger in this plant breeding approach, since where a crop is dependent on one particular herbicide for effective weed control, conditions may occur favouring parallel evolution of resistance in weed populations (c.f. evolution of atrazine resistance by populations of Chenopodium album [Bandeen, 1975] and Amaranthus retroflexus [Peabody, 1973] in maize crops).

RECOGNITION OF HERBICIDE RESISTANCE

Definition of resistance

The term "resistance" is applied to a weed population within a species which is normally susceptible to a particular herbicide but which is no longer controlled by that herbicide in a particular area. The term is not applied to weed species which are normally resistant in the first place but characterises populations which have received repeated applications of the herbicide.

The relative resistance of a weed population to any particular herbicide may be measured as a mean ED_{50} value, derived from regressions of probit mortality plotted against log herbicide dosage. The ED_{50} may not be measurable if the weed population exhibits such a high degree of resistance that there is no mortality, even at very high application rates, for example, resistance to simazine and atrazine by *Senecio vulgaris* (Ryan, 1970).

A concept of resistance which may be of more practical use to the grower or chemical manufacturer is one based on the relative increase in application rate of the herbicide necessary to provide satisfactory weed control comparable to control of normal susceptible weed populations.

Recognition of resistant populations in the field

The detection of resistant populations in the field is likely to be extremely difficult for growers or advisory officers, since failure to control weeds may occur for a considerable number of reasons. It would be difficult to determine whether failure of control was due to use of an inferior grade or formulation of a herbicide, to incorrect dosage, patchy application, unsatisfactory environmental conditions, or to a real change in the susceptibility of a weed population. Timing is important since weather conditions may determine herbicidal activity and the growth stage of a weed population may determine its relative susceptibility. Rate of application and climatic conditions during and immediately following application are often critical factors determining the success or failure of herbicidal control. Herbicide application may be uneven resulting in incomplete cover and untreated patches or areas receiving low concentrations of herbicides. Surviving individuals in these areas may appear to be resistant. Often unsprayed zones are obvious to an observer in the field but sometimes the reasons why certain individual plants survive treatment are obscure.

Failures are inevitable through one or more of the factors mentioned previously and in the field it will usually be difficult to differentiate between them and genuine resistance. Thus the grower should try and exclude all possible operator errors and environmental conditions as reasons for failure of weed control before considering the possibility that a herbicide resistant weed population has developed.

If failure of weed control occurs in the same area, in the same crop, using the same herbicide in successive years, or if the density of survivors in a weed population appears to increase over several successive years despite consistent herbicide management, then development of a resistant population may be suspected and quantitative screening tests carried out to expose any resistance. Obviously a resistant population should be detected and destroyed as early as possible in its development before a large pool of dormant seed of the resistant genotype has built up and before seed is inadvertently spread to other areas of the farm.

Screening tests for detecting resistance

There are no published tests for detection and measurement of herbicide resistance equivalent to the World Health Organisation standard tests for the detection of insecticide resistance. Nevertheless, standard screening techniques are used by herbicide manufacturers to test the thousands of new chemicals produced each year for selective herbicidal activity. Many of these tests provide models of the type of approach which may be used for the detection of herbicide resistance. Tests for measurement of resistance to triazine herbicides in crop cultivars have been recently outlined in detail by Warwick (1973) whilst Fisher and Faulkner (1975) have described screening techniques for measuring resistance of grass cultivars to seven mainly foliar-absorbed herbicides. Clearly tests will differ according to type of herbicide (soil or foliar applied) and the plant species being tested. Whatever the herbicide or weed species, the screening test must be relevant to field conditions. However, the test must also be repeatable, relatively simple and sufficiently flexible to be applicable to a group of species and herbicides. A controlled environment is essential for such tests although a glasshouse with adequate light and temperature control should normally be adequate.

Difficulties may be encountered in sampling the "resistant" population. Where possible, seed should be collected from as many individual plants as possible (growing in situ), the objective being to obtain a reasonably representative sample of the genotypes present in the population. If a foliar applied herbicide is to be tested and no seed is available it may be possible to sample very young seedlings or sections of rhizome from vegetatively reproducing perennial weeds. A disadvantage of using vegetative offshoots is that if resistance is detected, there is no indication that it is heritable if seed is not used. Two or three control populations which have never experienced herbicide application should also be sampled for comparison with the "resistant" population. Control populations should not be sampled too close to the "resistant" population since input of genes for resistance is possible due to pollen flow.

Four alternative approaches are possible for screening with most pre-emergence applied herbicides. These are field screening, water culture, sand culture and soil culture. Warwick (1973) has critically reviewed the advantages and disadvantages of the different methods. Although field screening is relevant to the real situation for both soil and foliar applied herbicides, repeatability may be very poor due to seasonal and daily fluctuations in climate and soil heterogeneity. Water and sand culture tests both have serious disadvantages as practical tests since herbicidal activity and uptake into the plant can be very different to that in the field. It is difficult to relate concentration of herbicide used in the water or sand culture to that applied in the field. However, uptake of herbicide by imbibing seed in sand may provide an efficient technique for screening large numbers for resistance to some herbicides normally applied post-emergence. Soil culture using a standard seed or potting compost in pots or seed boxes is more relevant to the field situation particularly for soil applied herbicides. The technique is repeatable under controlled environments (soil, temperature and light) and herbicide uptake and persistence are more appropriate to behaviour in the field.

Tests using foliar applied sprays have additonal requirements. Samples of even aged seedlings should be treated at the growth stage appropriate to normal field practice for the species/herbicide combination. Seed dormancy or intermittent germination can also be a problem. Appropriate untreated controls and the elimination of all individuals which germinate after a particular date can alleviate but not cure this problem.

EVOLUTION OF RESISTANCE

Presence of variation

The evolution of a character depends on the presence of genetic variation for that character and the evolution of herbicide resistance is no exception. Although the presence of variation in herbicide resistance within weed species has been well documented (e.g. Jacobsohn and Andersen, 1968; Hammerton, 1966), there is considerably less evidence that this has a genetic basis (Schooler, et al, 1972; Ellis and Kay, 1975; Holliday and Putwain, in press).

Table 2

Numbers of panicles and seeds produced in the barban experiments

Means of 2 replicates. Logarithmically transformed data ($\log_{10}$ (10 x + 1.0)) in brackets

Site		Panicles/m² 1	2	3	4	5	Mean	Seeds/m² 1	2	3	4	5	Mean
Dose kg/ha	Vol l/ha												
0.117	10	8.0	0.8	17.4	23.5	2.2	10.38	251(3.37)	28(2.39)	467(3.44)	1366(4.08)*	38(2.58)	430
	20	12.4	1.8	7.1	6.6	2.4	6.06	387(3.49)	115(2.93)	14●(3.00)	171(3.23)	45(2.55)	172
	40	7.4	0.5	12.9	8.1	2.6	6.30	253(3.38)	16(2.21)	218(3.26)	345(3.49)*	45(2.61)	175
	175	6.7	0.6	8.1	9.1	13.8	7.66	190(3.06)	16(2.20)	174(3.12)	102(2.96)	513(3.69)	199
0.234	10	6.9	0.5	7.4	6.5	4.4	5.14	162(3.17)	14([illegible].22)	133(3.08)	185(3.26)*	85(2.91)	166
	20	2.2	0.4	6.4	3.0	1.8	2.76	43(2.35)	23(2.33)	114(3.06)	83(2.90)*	22(2.28)	57
	40	2.8	0.0	4.8	4.4	2.4	2.88	81(2.24)	0(0.00)	49(2.69)	96(2.98)*	36(2.38)	52
	175	1.3	0.1	4.4	1.4	3.6	2.16	45(2.02)	2(0.82)	75(2.82)	20(2.29)	76(2.73)	44
0.350	10	6.2	0.7	5.6	5.8	3.8	4.42	202(3.26)*	20(2.30)	115(3.06)*	175(2.94)*	65(2.80)	115
	20	2.0	0.2	4.8	3.9	2.2	2.62	64(2.71)	14(1.91)	78(2.86)*	86(2.86)	33(2.34)	55
	40	3.9	0.0	4.1	6.9	2.6	3.50	85(2.51)	0(0.00)	49(2.69)*	192(3.10)*	44(2.63)	74
	175	0.5	0.1	1.8	1.6	8.2	2.44	12(1.72)	3(0.91)	16(2.19)	34(2.40)	175(3.13)	48
unsprayed		27.2	15.5	26.0	35.5	12.0	23.24	1212	799	1217	2225	449	1180
S.E. for comparisons between volume rates within a dose ±								(0.404)	(0.491)	(0.128)	(0.145)	(0.231)	

*control significantly poorer (p = 0.05) than conventional volume rates and combined analyses carried out for the barban series and for the difenzoquat series of experiments.

RESULTS

In experiments treated with barban in late April (Table 1), barley had between 3 and 4 leaves, and A. fatua seedlings ranged up to 4½ leaves but were mostly 3 leaves or less. In the experiments treated later with difenzoquat in May the barley was well tillered and the A. fatua showed a wider range of stages, many exceeding 4½ leaves and tillering.

Barban experiments

Controlled drop applications of barban at 20 l/ha and 40 l/ha gave good control of A. fatua panicles and seed production when applied at 0.234 kg/ha and at 0.350 kg/ha (Table 2); over 90% control of seed production was achieved at all sites at these volume rates and doses. At 10 l/ha the level of control in most cases was inferior. Conventional applications gave good control at sites 1-4, but the poor control with the conventional application at site 5 is difficult to explain; it was noted that at this site the crop population was low, and the date of application early relative to growth stage, with over half of the A. fatua seedlings less than one full leaf at application.

Mean values for controlled drop applications of barban (Table 8) show little difference in numbers of seeds produced between 20 l/ha and 40 l/ha applied at 0.350 or 0.224 kg/ha. The presence of zero values at site 2 made statistical analysis difficult and introduced some anomalies between the raw data and the logarithmically transformed data. A modified Tukey test for significance (Snedecor, 1956) showed no significant difference in numbers of seeds produced between 20 l/ha, 40 l/ha and 175 l/ha for each dose. Applications at 10 l/ha resulted in significantly more seeds.

Controlled drop applications of 20 l/ha and 40 l/ha reduced seed numbers by 94-96% at the two higher doses (Table 9). Conventional applications gave very good control on sites 1-4 reaching an average of 99% with 0.350 kg/ha; mean levels of control with conventional applications were reduced when site 5 was included.

Difenzoquat experiments

Conventional applications of difenzoquat applied at 1.0 kg/ha gave a high degree of control of panicles and seeds (Tables 3, 4 and 5) with over 97% reduction of seeds produced at all sites.

Table 4

Numbers of seeds produced in the difenzoquat experiments. Means of 2 replicates.
Logarithmically transformed data ($Log_{10}(10x + 1.0)$) in brackets

Seeds/m^2

Site		7	8	9	10	11	12	13	14	15
Dose kg/ha	Vol. l/ha									
0.33	10	541(3.70)*	1114(3.91)	1047(4.02)*	68(2.83)	502(3.69)*	768(3.85)	113(3.04)	1209(4.06)	14(2.08)	530(3.72)
	20	561(3.90)*	1146(3.63)	740(3.87)*	85(2.92)	157(3.11)	674(3.81)	189(3.24)	727(3.70)	37(2.38)	309(3.35)
	40	232(3.13)	385(3.26)	299(3.47)*	12(2.05)	175(3.24)	110(3.02)	59(2.72)	1000(3.95)	18(1.91)	221(3.31)
	225	149(3.13)	451(2.86)	52(2.72)	36(2.55)	85(2.90)	271(3.39)	157(3.03)	587(3.72)	24(1.34)	102(2.73)
0.67	10	832(3.90)*	456(3.53)*	480(3.64)*	31(2.49)	210(3.32)*	467(3.62)*	247(3.31)	540(3.64)	4(1.62)	44(2.64)
	20	402(3.59)*	160(3.18)*	156(3.07)*	10(1.86)	67(2.83)*	111(3.00)	376(3.52)	105(3.01)	3(1.41)	59(2.77)
	40	269(3.37)*	56(2.55)*	206(3.21)*	6(1.73)	85(2.88)*	59(2.72)	56(2.59)	924(3.74)	5(1.62)	73(2.82)
	225	59(2.77)	4(0.94)	8(1.90)	6(1.02)	0(0.00)	52(2.67)	36(2.53)	292(3.02)	1(0.52)	33(1.41)
1.00	10	487(3.78)*	289(3.07)*	513(3.71)*	30(2.46)*	164(2.80)*	320(3.49)*	341(3.53)*	650(3.74)*	13(2.12)*	69(2.59)*
	20	291(3.46)*	243(3.19)*	102(3.00)*	9(1.96)*	27(2.38)*	78(2.73)*	82(2.89)	614(3.64)*	14(1.23)	36(1.86)*
	40	50(2.63)*	33(1.41)	61(2.73)*	2(1.22)*	86(1.62)	25(2.36)*	65(2.75)	60(2.54)	8(1.88)	62(2.51)*
	225	9(1.95)	3(1.32)	4(1.55)	0(0.00)	0(0.00)	3(1.30)	20(2.15)	5(1.61)	1(0.58)	3(0.85)
unsprayed		1562	2128	2302	586	1774	2824	960	1199	39	835
S.E. ±		(0.131)	(0.380)	(0.088)	(0.369)	(0.543)	(0.150)	(0.243)	(0.291)	(0.431)	(0.450)

S.E. for comparisons between volume rates within a dose

* control significantly poorer (p = 0.05) than conventional volume rates

Table 3

Numbers of A. fatua panicles produced in the difenzoquat experiments

	Site	Panicles/m²											
		6	7	8	9	10	11	12	13	14	15	16	Mean
Dose kg/ha	Volume l/ha												
0.33	10	18.2	24.4	34.1	3.8	10.2	16.3	8.9	32.8	1.5	8.4	5.7	14.94
	20	20.1	22.4	25.3	5.1	2.9	15.9	9.6	19.1	3.6	5.9	2.2	12.01
	40	9.6	10.3	13.0	1.0	3.9	4.3	3.8	30.8	2.6	4.6	1.0	7.72
	225	8.3	8.9	2.9	3.6	2.5	8.8	7.1	20.2	2.8	3.2	2.5	6.21
0.67	10	26.6	9.8	19.6	1.9	4.9	12.8	9.8	14.2	0.8	1.4	5.7	9.77
	20	19.5	3.9	7.1	0.6	1.8	3.9	13.3	4.4	0.7	1.4	5.2	5.62
	40	13.4	1.6	8.7	0.8	2.1	3.4	3.1	31.6	0.8	1.7	1.6	6.25
	225	5.1	0.2	0.4	0.7	0.0	2.9	2.8	15.8	0.1	0.6	0.6	2.65
1.00	10	22.2	9.4	17.8	1.7	4.1	8.2	13.6	20.6	1.2	1.7	4.6	9.55
	20	14.2	6.5	4.1	1.0	0.9	3.2	5.1	19.2	1.7	0.9	1.2	5.27
	40	4.1	0.8	4.1	0.2	2.3	1.1	3.7	2.8	1.0	1.6	1.6	2.12
	225	1.4	0.2	0.3	0.0	0.0	0.2	2.6	0.4	0.1	0.1	0.6	0.54
Unsprayed		34.5	33.1	59.2	18.6	21.8	36.4	25.3	25.3	3.4	11.7	14.4	25.78

Table 5

Numbers of spikelets produced in ADAS experiment (difenzoquat site 16)

Dose kg/ha	Volume l/ha	Spikelets/m²				
		10	20	40	225	Mean
0.33		105.5	44.7	14.4	12.5	44.3
0.67		104.3	70.2	24.0	9.4	52.0
1.00		90.6	21.6	25.6	5.2	35.8
Mean		100.1	45.5	21.3	9.0	
S.E. of treatments ± 13.24						

There was a trend at all sites towards slightly poorer control with the controlled drop applications. The number of sites where for a given dose controlled drop applications gave significantly poorer control than the conventional are shown in Table 6.

Table 6

Number of sites where control by controlled drop applications of difenzoquat was significantly poorer than conventional applications

Dose kg/ha	10	20	40 l/ha
0.33	4	2	1
0.67	6	5	4
1.00	11	7	5

These differences, although statistically significant were often small in terms of % control of seeding. In five experiments controlled drop applications of 1.0 kg /ha at 40 l/ha resulted in significantly poorer control than conventional applications, but nonetheless gave 97%, 97%, 99%, 99% and 93% reduction of seeding. Table 7 shows the number of sites where over 90% control of seeding was achieved.

Table 7

Number of sites where 90% or better control of seeding was achieved with difenzoquat

Dose kg/ha	10	20	40	225 l/ha
0.33	0	1	5	6
0.67	2	8	8	10
1.00	3	7	10	11

The combined values for experiments 6-15 are shown in Table 8. Average values for the three doses show that controlled drop applications gave significantly poorer control than conventional applications; each change in volume rate from 225 l/ha resulted in significantly ($p = 0.05$) more seeds. At 1.0 kg/ha there was a similar significant trend for progressively more seeds as the volume rate was reduced from 225 l/ha; however, controlled drop applications of 1.0 kg/ha at 40 l/ha gave good control, reducing seed production by an average of 95% (Table 9)

Table 8

Mean values for the control of *A. fatua*.
Logarithmically transformed data (Log_{10} (10x + 1.0)) in brackets

Seeds/m^2

Barban (mean of sites 1-5)			Volume l/ha		
Dose kg/ha	10	20	40	175	Mean ± (0.109)
0.117	430(3.17)	172(3.04)	175(2.99)	199(2.82)	244(3.01)
0.234	116(2.73)	57(2.58)	52(2.06)	44(2.33)	67(2.43)
0.350	115(2.87)	55(2.54)	74(2.19)	48(2.08)	73(2.42)
Mean ±(0.081)	220(2.92)	94(2.72)	101(2.41)	97(2.41)	
S.E. Body of Table ± (0.163)					
Difenzoquat (mean of sites 6-15)					
Dose kg/ha	10	20	40	225	Mean ± (0.069)
0.33	591(3.49)	464(3.38)	251(3.01)	191(2.84)	374(3.18)
0.67	331(3.17)	145(2.82)	174(2.72)	49(1.68)	175(2.60)
1.00	287(3.17)	150(2.63)	45(2.17)	5(1.14)	122(2.28)
Mean ±(0.063)	403(3.28)	253(2.94)	157(2.63)	82(1.88)	
S.E. Body of Table ± (0.117)					

Table 9

Mean values for the control of A. fatua, % reduction of A. fatua seeds

Barban (sites 1-5)

kg/ha	10 l/ha	20 l/ha	40 l/ha	175 l/ha
0.117	74	85	87	73
0.234	89	95	95	94
0.350	90	95	94	92

Barban (sites 1-4)

kg/ha	10 l/ha	20 l/ha	40 l/ha	175 l/ha
0.117	69	84	86	91
0.234	91	95	96	97
0.350	91	96	95	99

Difenzoquat (sites 6-15)

kg/ha	10 l/ha	20 l/ha	40 l/ha	225 l/ha
0.33	59	62	77	78
0.67	79	89	86	96
1.00	78	86	95	99

DISCUSSION

These results add further support to the possibility of reducing spray volumes by controlled drop application techniques. Results with barban at 20 l/ha and at 40 l/ha were comparable with conventional applications; this agrees with experiments in 1975 and suggests that 20 l/ha is an optimum volume rate for the controlled drop application of barban.

Controlled drop applications of difenzoquat gave slightly poorer results than conventional applications. There was a greater response to increasing volume rate with difenzoquat than with barban, with better control from 40 l/ha than from 20 l/ha. When the difenzoquat was applied the barley was well tillered often giving complete ground cover, and it is possible that drop penetration to the A. fatua seedlings was inpeded by the crop to a greater extent than with the earlier applications of barban. In a concurrent series of experiments (Ayres, 1976) with a mixture of dicamba with mecoprop and MCPA (Banlene Plus), there was no reduction in the level of control of dicotyledonous weeds with controlled drop applications of 20 l/ha and 40 l/ha. These applications were made to barley during the same period as the difenzoquat applications. It seems likely that individual herbicides will respond differently in their performance to reducing volume and increasing drop concentration. In 1975 it was noted that where similar numbers of drops/unit area of difenzoquat were applied, poorer control resulted from the more concentrated drops at 5 l/ha (250 µm drops) than at 15 l/ha (350 µm drops), suggesting that too high a concentration of this herbicide may reduce efficiency.

The slightly reduced performance of controlled drop applications of difenzoquat in 1976 was in contrast to the equal or slightly better control, compared with conventional applications obtained in 1975 (Wilson and Taylor, in preparation). The equipment used for application differed between the two years, but in each case calibrations before, during and at the end of the spring application period showed a satisfactory output and distribution of drops. It is possible that this seasonal difference is related to environmental differences modifying plant growth, and so affecting the performance of difenzoquat when applied in concentrated drops. The spring of 1976 was dry and seedlings were under some drought stress when the herbicide was applied. In contrast, in 1975 conditions were more normal; 31 mm of rain fell at Begbroke in the week prior to applications.

In these experiments all controlled drop applications were made with formulations designed for conventional use. It may be that if formulations of herbicides are developed specifically for controlled drop applications, improved and more consistent results would follow.

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THE DEVELOPMENT OF HERBICIDE PROGRAMMES FOR FIELD VEGETABLE CROPS

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THE INTRODUCTION OF HERBICIDES

When herbicides were first introduced into vegetable growing they were regarded very much as an aid to traditional methods of weed control. The early herbicides were either non-selective or selective only in very few crops. They also only controlled a limited number of weeds. However they were of considerable benefit and allowed the grower to reduce the amount of soil cultivations required for weed control.

The first vegetable herbicides were inorganic compounds or soluble salts, eg sulphuric acid, cresylic acid, mineral oils, dinoseb and sodium monochloroacetate. In the late fifties and early sixties the first soil-acting compounds appeared - propham, chlorpropham, monuron and pentachlorophenol. As well as reducing labour input, the use of these herbicides contributed to better crop establishment and greater flexibility in the timing of crop sowing.

As herbicides became integrated into crop management during the 60's many new herbicides were discovered and recommendations were developed for their use in vegetables until some form of herbicide treatment was available for most vegetable crops. Compounds introduced in this time included paraquat, fenuron, dimexan, desmetryne, linuron, monolinuron, pyrazone, prometryne, nitrofen, propachlor, pentanochlor, ametryne, lenacil and trifluralin.

Herbicides were still however considered as single treatments to supplement traditional methods of weed control. Hand labour or mechanical hoeing were used to remove any surviving weeds. These materials freed the grower from most of the labour burden of weed control; his flexibility was increased and on this basis he was able to employ more efficient production systems and to consider new ways of growing vegetable crops. In the 70's the numbers of new herbicides developed for use in vegetables have been much fewer. Increasing development costs and more stringent safety requirements are acting to restrict or delay new introductions very severely.

THE LIMITATIONS OF HERBICIDES

The limitations of herbicides were at first far outweighed by the benefits obtained, but as labour became scarce and crop growing systems became more dependent on herbicides problems arose. These were due to three main factors associated with herbicides:

1 - No single herbicide controls all weed species.

2 - Herbicides, especially soil-acting herbicides, are very dependent on favourable weather and soil conditions for effective control of normally susceptible species.

3 - Restrictions imposed by soil type, stage of growth of the crop, varietal tolerance, persistent soil residues etc. limit the choice of herbicides for particular situations, regardless of the desired weed control spectrum. Without the safety net of supplementary cultivations, therefore, situations often arise when weeds escaping control from herbicides compete with the crop, interfere with harvesting opportunities and shed seed to cause problems in succeeding crops.

Modern systems of production are also making greater demands on herbicide performance, namely:

1 - Closer drilling of crops in order to maximise land use and to control crop size in specific markets such as carrots, Brussels sprouts, cauliflowers and red beet. This severely restricts or eliminates opportunities for supplementary cultivations to control resistant weeds.

2 - The mechanisation of crop production, especially that of harvesting and with it the need to prevent any interference in the operation by weeds demands 100% weed control in many crops.

3 - Frequent mono-cropping on the same land with similar crops has become common practice in certain areas. Cabbage and cauliflowers, for example, can be grown continuously on the same ground throughout the year. This tends to increase the selection of weed species closely related to the crop and this associated with the repeated use of the same herbicide can lead to the dominance of resistant weed species in the weed population; of particular note are such weed species as Polygonum aviculare, Chenopodium album, Solanum nigrum and Veronica persica.

4 - Sequential drilling of herbicides, such as calabrese, leeks, peas and dwarf beans, for continuous harvesting makes heavy demands of herbicides. Soil and weather conditions vary and the major weed species encountered change as the season progresses. A range of treatments is therefore necessary to ensure adequate weed control.

5 - Vegetables are increasingly being grown in arable crop rotations and are therefore exposed to a different range of weed species from those traditionally encountered. Perennial weeds such as Agropyron repens, Cirsium arvense, and Tussilago farfara survive in arable rotations and although not widespread in field vegetables are very competitive and are serious local weed problems. Annual arable weeds such as Avena fatua, Alopecurous myosuroides, Galium aparine and Galeopsis tetrahit can be a major nuisance in vegetables.

6 - The recent emergence of volunteer crops as weeds of both arable and vegetable rotations has created important weed control problems in all major vegetable crops. Potatoes are the most common example but there are also local problems with sugar beet remains, annual beet, oil seed rape and volunteer barley. In the absence of cultivations there are almost no satisfactory herbicides that can satisfactorily deal with these 'crop' weeds.

THE NEED FOR IMPROVED WEED MANAGEMENT

Faced with the above problems the grower can do a great deal to assist herbicide efficacy by intelligent weed control management. One of the essentials in this is forward planning, based on a knowledge of projected rotations and on correct identification of weeds that are likely to occur in particular crops and fields. This in itself is a complex undertaking as weed populations tend to fluctuate with environmental conditions. However with experience a grower can examine the rotation to see at which point a known troublesome weed is most vulnerable, rather than wait until it assumes major importance in a vegetable crop where suitable herbicides may not be available. Cereals for example can be looked at as cleaning crops in a mixed rotation. Stubble treatment is by far the best way of controlling perennial weeds, while with the many broad spectrum herbicides now available, particularly those based on dicamba, there are few annual broad-leaved weeds that cannot be controlled in cereals and their seeding prevented in that year. Full use must be made of the non-vegetable break crops for the control of basically arable weeds. Although there are recommendations for the control of Avena fatua and Alopecurous myosuroides in several vegetable crops it is wise to use the arable crop to control these weeds in order to reduce the weed management problem in succeeding vegetable crops.

There is also the possibility that different growing techniques could be used in one part of the rotation to alleviate weed problems that could not be tackled in a vegetable crop. The reduction in weed seed return to the soil following minimal cultivations or direct drilling in cereals could be of benefit to succeeding vegetable crops. Timely supplementary cultivation is still an essential part of weed control management in widely drilled crops. It can, however, be replaced by contact herbicides, such as paraquat, which kill weeds without stimulating further weed germination. These herbicides have other useful parts to play in weed management. It is surprising how often fields from which vegetable crops have been harvested, especially brassica crops, are left to become weedy until such time as cultivations begin for the next crop. The timely use of contact herbicides would do much to prevent weed seed returning to the soil, to make ploughing easier and to help control any perennial weeds present.

The use of the stale seed bed technique using contact herbicides enables a grower to clean up drilled land immediately prior to crop emergence. This is of considerable assistance to purely soil-acting herbicides applied pre- or shortly post-emergence of the crop. Not all residual and contact herbicides can be tank mixed but this technique can help overcome one of the major problems of recent years, that is the very dry soil conditions at drilling time.

A recent method of extending the use of residual herbicides has been the incorporation of normally surface applied herbicides into the soil before drilling. There is considerable evidence to show that this technique does give some weed control under dry conditions where a surface applied spray would have failed.

While better weed control management can reduce the intensity of the demands made on single herbicides, there is no doubt that the major method of achieving improved and more comprehensive weed control in individual vegetable crops will be by the use of several herbicides, either in tank mixes or as sequential applications. This requires an understanding of the benefits and limitations of different materials and the ways in which they can be most usefully combined.

Herbicide Programmes and the Major Weed Problems in Individual Crops

Perennial weeds are an increasing problem in field vegetables as mechanisation increases and the number of cultivations diminish. The vegetables most commonly associated with arable crops are those most commonly troubled by perennial weeds, namely peas and carrots. The weeds of greatest concern are Agropyron repens, Cirsium arvense and Tussilago farfara. There are no selective herbicides for their control which must be confined to other crops or summer and autumn treatment after harvest. Aminotriazole, dalapon, TCA and glyphosate can be used when crop, clearance and safety intervals allow but this is poor consolation to the grower faced with a crop disappearing under a canopy of grass. The pre-crop recommendations, such as those of TCA, are seldom of use as conditions at the time of application are not suitable to growth and kill off perennial weeds. The approach to perennial weeds must therefore consist of tackling them over a period of years in other crops, in the autumn and by using the spring pre-crop treatments as back up measures.

The problems posed by wild oats in field vegetables are those of direct competition with the crop and interference with mechanical harvesting machinery, especially in peas and beans. There are a number of herbicides recommended for the control of wild oats in vegetables including TCA, propham, di-allate, tri-allate, cycloate and barban, with the prospect of more materials such as benzoylprop-ethyl and 2-[4-(2',4'-dichlorophenoxy)-phenoxy]-methyl-propionate (Hoe 23408). The most commonly used wild oat herbicides are di-allate and tri-allate. With the greater need for good seed beds on vegetable crops these compounds can be readily incorporated into the husbandry of the crop. Due to their complete absence of effect on survivors it is sometimes necessary to back up both compounds with barban, when recommended. There is great need for the new compounds in the post emergence situation.

The overriding problem in field vegetables is that of annual weeds. On paper there appear to be numerous selective herbicides available for vegetables but for the reasons stated above they are prone to failure due to weather, soil, incorrect timing and resistant weeds. In these circumstances the use of herbicide programmes helps the grower to avoid the worst herbicide failures if a planned sequence of herbicides can be employed. Besides being of direct benefit a programme has the asset of utilising the minor benefits of a herbicide that would otherwise be wasted. When a soil acting herbicide fails, for example, it will often check the subsequent weed growth which can be enough to make a secondary treatment more effective.

Onions This crop is beset with weed problems as it gives no competition to the weeds and is therefore slow to emerge and stays in the ground for long periods. It is therefore necessary to maintain complete weed control. Without supplementary cultivations there must therefore be complete reliance on herbicides. There are a number of pre-emergence and post-emergence herbicides in the onion crop although they leave some difficult gaps such as the period between the crook stage and the 2-4 leaf stage when weed growth can be most rapid. Herbicide programmes normally used on this crop based on propachlor, chlorpropham and pyrazone/chlorpropham pre-emergence and methazole, linuron/ioxynil, ioxynil and dinoseb acetate post-emergence. On spring sown onions either a mixture of propachlor and chlorpropham or pyrazone/chlorbufam are applied pre-emergence and followed up with paraquat if necessary. This can be followed up with pyrazone/chlorbufam at the crook stage. In overwintering onions emergence is relatively rapid and the use of paraquat not therefore of value. After emergence growth slows down and the winter is generally passed in the 2-3 leaf stage. There is therefore greater need for post-emergence herbicide use. Of all the materials recommended methazole appears preferable as it does not damage the crop foliage which in the winter situation let in secondary problems from botrytis etc. There is a considerable case for a split dose to carry weed control over the winter.

Timing of herbicides in the onion crop is critical as mayweed is poorly controlled by all the herbicides except propachlor and once established makes enormous growth. Fumaria officinalis is also poorly controlled by most of these materials.

Leeks These reflect most of the situations outlined in onions. Their most critical stage for weed control is between the crook stage and the 3 leaf stage. Most of the leek crops are grown in Scotland and the North of England which means that this gap can be as long as 5-6 weeks. Leeks do however have additional herbicide recommendations namely monolinuron, prometryne and in some transplant situations even simazine.

Red Beet This crop benefits greatly from having the same response to herbicides as sugar beet. The latter has the most complex spectrum of herbicides recommendations of any crop in Europe. It is interesting to note however that sugar beet herbicides are so closely tailored to the needs of this crop that the slight variation in husbandry between sugar beet and red beet is sufficient to render some recommendations impracticable. This is reflected in the poor results obtained from soil-acting herbicides due to the later drilling of red beet, the effect of higher soil organic matter of horticultural soils and the greater likelihood of damage from phenmedipham from application in very hot weather.

Programmes of herbicides are now being used based on cycloate/lenacil, pre-drilling, lenacil pre-emergence and phenmedipham post-emergence. The use of cycloate/lenacil not only gives control of Avena fatua but by being incorporated ameliorates the effect of dry soil conditions.

Peas Peas suffer many weed problems due to their being grown in arable rotations. The crop is drilled at an early time of the year and on some very difficult land. It suffers more than most vegetable crops from perennial weeds and Avena fatua. The complexity of the weed problems in peas in aggravated by added problems of contamination of the crop at harvest by weed parts such as seed heads of mayweed spp., Cirsium arvense, Papaver rhoeas and Solanum nigrum. Weed control programmes are based on a number of selective pre-emergence herbicides with an increasing number of post-emergence materials. Early weed control is required as the crop is very open for most of its life, and access to the crop is impossible shortly after emergence. It is fortunately a relatively short lived crop although peas for harvesting dry are in the ground longer and any weeds that escape early treatments can grow and compete with the crop.

Most annual weeds can be controlled. Polygonum aviculare, Solanum nigrum and Galium aparine are difficult to control under adverse conditions unless a programme of herbicides is followed. This situation has been improved by the recent development of bentazone/MCPB and cyanazine/MCPB. Avena fatua can be a serious problem in the pea crop. It is generally controlled with tri-allate pre-drilling and barban used post-emergence as a follow up treatment.

Dwarf Beans This crop offers little competition to weeds. There is a need to keep the crop clean as weeds can cause serious interference with the harvesting machinery and as in peas cause contamination on the produce. It is a late drilled crop and not tolerant of many soil-acting herbicides. It is dependent on herbicide programmes based on reduced doses of trifluralin followed by bentazone. Some growers also use a programme of trifluralin followed by monolinuron/dinoseb acetate. There is also reported in these proceedings results of a mixture of bentazone and an emulsifiable oil in this crop.

Brassicas All brassica crops suffer from a general shortage of selective herbicides. There is wide acceptance of a programme of trifluralin pre-drilling followed by propachlor pre-emergence. There are restrictions on the use of trifluralin on some soil types and in these circumstances growers have used reduced doses of the herbicide. If used correctly the two materials offer a wide spectrum of weed activity which will persist well into the life of the crop. This is particularly necessary as in cauliflower, broccoli and calabrese there is no herbicide that can be safely used post-emergence. Cabbage and Brussels sprouts will tolerate aziprotryne, desmetryne and sodium monochloroacetate, and in winter crops carbetamide. They are all however relatively restricted in weed control and their conditions of use are narrow. Some benefits can be obtained by mixing these compounds but without adequate pre-emergence weed control they are not good enough to sustain the full weed control needs of these crops.

Carrots Like the pea crop carrots are grown as arable crops in mixed rotations with other row crops and cereals. Both perennial grass weeds and Avena fatua are troublesome. Dalapon can be used for post-emergence control of these weeds but the treatment is essentially a crop saving one and results are seldom adequate. There are ample herbicides for annual weed control. The main herbicides, linuron and chlorbromuron are selective both pre- and post-emergence and have always been recommended as combined programmes. They are particularly suited to this role as they have good contact kill on susceptible weeds. Difficulties can arise due to annual grass weeds and mayweeds but this has been overcome to a large extent by the tank mix of either linuron or chlorbromuron with metoxuron.

THE STATUS OF HERBICIDE PROGRAMMES

Growers and advisers are not in an enviable position when faced with weed problems that can only be overcome by sequential or combined use of herbicides. Clearance of a herbicide through the Pesticides Safety Precautions Scheme does not preclude the use of other pesticides on the same crop. However, label recommendations for the use of other compounds or tank mixtures must be cleared by the Safety Scheme. We are therefore faced with an ambiguous situation. Related compounds may be applied at different times in the life of the crop and be both cleared and approved. The same materials to do the same job cannot be mixed in the same sprayer unless recommended by the manufacturer in agreement with the Safety Scheme.

The approval of herbicides by the Agricultural Chemicals Approval Scheme is likewise given with respect to individual use of compounds and therefore unless there is known to be interaction between compounds, no account is taken of other materials used in the same crop. Before there can be a label recommendation referring to a tank mix or a linked recommendation, full information must be provided to the Scheme on crop safety, physical compatibility and efficacy.

The manufacturer when faced with combined recommendations is also in a difficult situation in that he cannot support the use of multiple recommendations unless he has sufficient information to get clearance, approval and in most cases the agreement of the manufacturer of the associated materials. He is concerned that liability in the case of either crop failure or failure to achieve weed control may be implied simply by his product being recommended with another compound which may be the one at fault. These problems are particularly acute when it comes to tailoring herbicide recommendations to achieve optimum crop safety and weed control. For example by a reduction in one or both rates of application of different herbicides in order to control a specified combination of weed species. The alteration of rates of use of herbicides by the grower, be they only reductions, are strictly in contravention of approval and clearance.

This circumstance places the research worker, the adviser and the grower at a considerable disadvantage when it comes to finding sequential or programmed uses of herbicides that may need to deviate from the label recommendations. For example sequential programmes combining the use of trifluralin and propachlor in brassicas have been taken up by growers as a result of advisory and research findings and have been a major feature in brassica growing for at least 5 years. The combined recommendations are still without the support of the manufacturer of either product. Other examples of this problem are readily available, since the development of programmes in recent years has been mainly by official organisations and by leading growers rather than by the chemical companies. Manufacturers have of course been quick to develop programme recommendations for compatible herbicides within their own product range, but the potential for this is relatively restricted. They are now beginning to accept that combinations of herbicides are required in modern vegetable growing and that cooperation with other manufacturers may be mutually advantageous. For example the approved label for trifluralin carries recommendations for its use in dwarf beans at three quarters dose to be followed by bentazone. It is also recommended in lettuce at half dose to be followed by propham/diuron. Other examples on labels are the combined use of metoxuron and linuron for post-emergence weed control in carrot, with special use to control volunteer potato shoots and a tank mix recommendation for cycloate and lenacil in red beet.

There is also an indication that certain manufacturers are prepared to accept liability for another manufacturer's product when used under their recommendations. We hope soon to have a label recommendation for an adjuvant oil plus phenmedipham for red beet. This will be recommended by the manufacturers of the oil product who will accept liability for the use of phenmedipham although the label will bear the recommendations of another, different manufacturer. There is also a label recommendation for propachlor to be applied with paraquat, without the support of the Approved label for paraquat.

The acceptance by a manufacturer on his label, of the need for other herbicides, without mentioning individual compounds, has existed for some time eg the use of ioxynil in onions as a contact post-emergence herbicide is recommended on the basis that an appropriate Approved pre-emergence herbicide has been previously applied. No other herbicide is specified, but the grower is given clear instruction that a programme must be carried out in order to obtain optimum weed control.

Another factor that may advance the use of programmes in vegetable growing is the collapse of patents and the subsequent greater availability of active ingredients to distributors. This is very much in the early stages, but one can envisage that when manufacturers can obtain supplies of a number of compounds, they will be able to test new combinations and new rates of use and within their product range be able to make more use of programme recommendations.

THE MINOR USE SITUATION

Most vegetables come within the category of crops in which the cost of clearance and approval is high and the return is likely to be relatively small. In the early days of crop protection profitability from pesticides was high and the actual detail required for clearance and approval were of a lower order. General overheads were smaller and profits could be made from limited usage recommendations. In addition there was the situation, which applies today with lesser effect, that a manufacturer should carry the cost of these minor uses in order to give a complete service to the grower and therefore gain all the customers pesticide business. The emergence of the large modern agricultural merchant carrying a representative range of all speciality products has changed this situation and removed the need of the manufacturer to supply a merchant with all the products he might need in his range. This still does not remove the moral obligation that he has to subsidise to some degree minor use clearance and approval if he is allowed the privilege of making a profit from major use recommendations.

The definition of what constitutes a minor crop is dependent on a number of factors not least being the initial cost of carrying out the necessary toxicological studies to get clearance. At present this is in the order of 2 to 4 million pounds and increasing. Thus in order to succeed a herbicide must have world wide use on a major crop. It is sobering to think that this cost is sufficient to preclude the development of a herbicide for use in cereals only in Europe. Once the use is established then costs become relatively lower in terms of extending the use of a herbicide to other crops.

In this situation the small crop is at a considerable disadvantage. It is

Holliday and Putwain (1974) demonstrated that variability in resistance to simazine existed in the common annual weeds, Senecio vulgaris, Chenopodium album and Capsella bursa-pastoris. Susceptibility to simazine was related to the number of years of field selection, suggesting a possible genetic basis for simazine resistance. The existence of highly resistant genotypes of S.vulgaris was later confirmed by Holliday and Putwain (in press). Thus genetic variation for herbicide resistance has been shown to exist in natural populations of some weeds and there is a potential for evolution of resistance. Whether this potential will be realized so that it becomes a practical problem for growers, depends on the factors which influence the intensity of selection and the rate of evolution.

Genetic inheritance

The rate of evolution of resistance to herbicides depends partly upon the mode of inheritance of the resistance gene(s). There can be no doubt that the frequently extremely rapid development of insecticide resistance was in part determined by the simple mode of inheritance common to the majority of cases of insect/insecticide interactions (Brown, 1964). The vast majority of examples of resistance by insects to DDT, dieldrin and organophosphorous compounds are due to monofactorial (one principal gene) inheritance. Moreover, differences in rate of evolution of resistance between the chemical groups is closely related to the level of dominance of the resistance genes. Resistance to organophosphorous compounds has developed surprisingly quickly in comparison with DDT and dieldrin resistance. The difference may be related to the fact that resistance to organophosphorous tends to be dominant or nearly so, whilst resistance to dieldrin regularly reaches intermediate levels in heterozygotes (Milani, 1963). The situation in insects is clear but what is our knowledge of herbicide resistance in weed populations?

There have been few genetic studies of herbicide resistance in weeds probably due to the comparative rarity of natural evolution of resistance. Studies of the genetics of resistance have been confined mainly to crop plants, for example, resistance to triazine herbicides has been examined in maize (Grogan et al, 1963) and in flax (Comstock and Andersen, 1968). In maize, resistance to simazine and atrazine is controlled by a single dominant gene. Resistance to atrazine in flax, however, is controlled polygenically and heritability is low. Tolerance of barley to barban is controlled by a single recessive gene (Hayes et al, 1965) whilst resistance of Lolium perenne to paraquat is quantitatively inherited but has relatively high heritability.

In weed species there is evidence that several major genes with high dominance are involved in the resistance of Hordeum jubatum to siduron (Schooler et al, 1972) whilst resistance of Avena fatua to diallate is quantitatively inherited (Jacobsohn and Andersen, 1968). Resistance of S.vulgaris to simazine appears to be controlled by two or more major genes with a high degree of dominance (Holliday, unpublished). There is clearly a wide diversity in the mode of inheritance of herbicide resistance in both crops and weeds. Thus predictions of rates of evolution of resistance will depend on a precise knowledge of the genetics of resistance for any particular species/herbicide combination.

Breeding system

The breeding system of a weed species may also determine the rate of evolution of resistance. Harper (1956) suggested that a rapid build-up of resistance is more likely to occur in a sexually reproducing species with an efficient outbreeding system. Does this idea stand up to the evidence of evolution of resistance in weed populations? Resistance to triazine herbicides has been demonstrated in field populations of Senecio vulgaris, Chenopodium album, Amaranthus retroflexus and Capsella bursa-pastoris. Of these species only S.vulgaris is predominantly an inbreeder. Resistance to urea herbicides has been reported in Poa annua and Hordeum jubatum. Both species are predominantly inbreeders (Bishai, 1969; Schooler et al, 1972). On the basis of these few examples Harper's theory has not been confirmed. If a herbicide resistant genotype is already present in an inbreeding species then response to selection could be very rapid (Bishai, 1969).

Inbreeding would also help to maintain resistant genes in a population in several ways. If, for example, the resistant gene was both rare and recessive, only homozygous resistant genotypes would survive selection by the herbicide. Homozygosity is a feature of inbreeding populations although it is by no means complete with respect to herbicide resistance (Schooler et al, 1972). Furthermore, inbreeding would maintain resistant genes in a population in the absence of selection, an important feature of the temporal selection pressure imposed by even the most persistent herbicides. Even in the presence of selection pressure there remains the possibility of gene flow between treated and untreated areas. Gene flow from untreated field margins and adjacent areas onto a treated field would tend to slow down the development of resistance. Conversely gene flow from a treated area provides an important means of spreading resistance and thereby introducing resistant genotypes into unsprayed areas (Holliday and Putwain, 1974).

Ecology and biology of resistant populations

A knowledge of the ecology and biology of weeds is a necessary prerequisite for determining the method of control. One of the most important factors in deciding the timing of herbicide applications is the germination pattern of weeds. Natural populations of annual weeds possess characteristic patterns of germination and dormancy (Roberts and Feast, 1970). Some species which produce an autumn flush of seedlings (e.g. Stellaria media), will escape the herbicidal activity of an early spring application of even the most persistent chemicals. In the fruit growing industry only a minority of growers control annual weeds with a spring and autumn application, thus there may be strong selection for later germination. Several authors have stressed that changes in phenology of weeds are a likely outcome of a systematic herbicide programme. (Harper, 1956; King, 1966 and Hammerton, 1968).

Evidences of changes in phenology have been reported in several annual weed species as a result of herbicide application. Cohen (1975) found that some populations of summer annuals (Mollucela laevis, Solanum hirsutum, Sonchus oleraceus, and Chenopodium spp.) became winter annuals due to applications of herbicides during the summer months. In our own studies on the population dynamics of Senecio vulgaris growing on a site where simazine is applied annually in the spring the pattern of germination is quite different from normal populations, which exhibit two or three germination peaks in spring, summer and autumn. Populations growing on untreated soil usually show maximum germination during the spring (Roberts and Feast, 1970) but on a simazine treated field maximum germination occurs in early summer with a second peak in August or September (Holliday and Putwain, unpublished). It has been found by the same authors that only the later germinating seedlings actually survive to produce seed. It is not known whether this change in phenology of Senecio vulgaris is genetically controlled but there is evidence of such intraspecific variations in germination behaviour of several weed species (Hammerton, 1968). It is therefore surprising that more examples of selection for phenological changes have not been reported in the literature.

Preventing the evolution of herbicide resistance in weed populations

There are various ways by which the grower may reduce the selection pressures on weed populations for evolution of herbicide resistance. Several of the following suggestions were made originally by Harper (1956) and Hammerton (1968), and they have been substantiated by recent evidence.

Continuous treatment with a single herbicide or group of chemically related herbicides should be avoided. The advantage of rotation of herbicides (or of crop rotation) in preventing the selection of resistant weed populations is quite clear (Abel, 1954). It is important that a total kill should be achieved since a partial kill or a stunting of the weeds will create a high selection pressure for resistance. An increase in application rate of a herbicide or use of an alternative chemical to achieve a total kill may be more expensive financially but will ensure zero selection pressure.

The use of chemically related herbicides or chemicals with a similar mode of action should be avoided, since cross resistance is known to occur (Radosevich and Appleby, 1973), where a single defence mechanism confers resistance to several chemically related herbicides. No instances have been reported where resistance to one herbicide confers resistance to other chemically unrelated herbicides. It is unlikely that resistance would develop simultaneously to two chemically unrelated herbicides applied to a crop as a mixture, or during the same growing season.

Spraying of hedgerows and headlands should be carefully avoided since repeated applications of sublethal doses to these areas may result in a slow build up of a resistant population from which resistant genotypes may spread by seed or pollen flow. If a steadily increasing application rate is required to provide adequate control of a weed species during several consecutive years, evolution of resistance might be suspected. Such gradual increments in application rates should be avoided. If possible, weed control should be attempted with an alternative chemically unrelated herbicide.

The only well substantiated instances of natural evolution of herbicide resistance (e.g. Ryan, 1970; Peabody, 1973; Bandeen, 1975), have occurred where a single group of chemically related, persistent herbicides (triazines) have been used continuously in the same field area for several years. Clearly rotation of herbicide or crop is the most practical way of ensuring that resistance does not develop in weed populations, since selection pressures for resistance are maintained at a low level.

MECHANISMS OF HERBICIDE RESISTANCE

Physiological and biochemical processes

Mechanisms of physiological or biochemical resistance may be grouped into, (a) differential absorption or uptake, (b) differential translocation of herbicides to active sites, and (c) metabolic conversion or detoxification of herbicides. A summary of published information concerning physiological mechanisms of herbicide resistance is given in Table 1 and resistance mechanisms are classified according to the three types cited above. The presence or absence of differences between resistant and susceptible genotypes within a weed species for each mechanism of resistance is indicated by a plus or minus sign respectively.

Given the present lack of evidence, reduction in uptake or translocation of herbicide would appear to be of relatively minor importance in conferring herbicide resistance. In contrast, the presence of metabolic conversion or a detoxification system has been established in many of the instances cited in Table 1.

Table 1

Summary of physiological mechanisms of resistance to herbicides in weeds[1]

HERBICIDE	SPECIES	RESISTANCE MECHANISM		
		Uptake	Translocation	Detoxification
Atrazine	- Amaranthus retroflexus	-		+
	Setaria viridis			+
Propazine	- Setaria viridis			+
Simazine	- Senecio vulgaris	-	-	-
2,4-D	- Daucus carota			+
	Convolvulus arvensis	-	-	
	Convolvulus arvensis			+
Amitrole	- Cirsium arvense			+
	Cirsium arvense		-	-
	Cirsium arvense			-
Barban	- Avena fatua	-		+
	Hordeum vulgare	-		+

\+ Indicates either a reduction in uptake, absorption or translocation or an increase in metabolic detoxification in a resistant biotype compared with a susceptible biotype.

\- Indicates that there were no differences between susceptible and resistant biotypes in uptake, translocation or detoxification.

1 Limited space prevents inclusion of authorities in the table. References may be obtained from the authors on request.

Hammerton, (1968) stressed that resistance to soil applied herbicides is likely to depend upon the ability of plants to detoxify or metabolise them and this has been confirmed by recently published evidence.

There is evidence of several other intraspecific physiological differences between resistant and susceptible genotypes which do not fit in with the three main types of physiological resistance outlined previously. For example, genotypes of Cirsium arvense (Hodgson, 1970) and Tripleurospermum inodorum (Ellis and Kay, 1975) resistant to phenoxy herbicides, were more vigorous under chemical stress than susceptible genotypes, with no apparent specific physiological differences between genotypes. The resistance to triazine herbicides by Amaranthus retroflexus (West et al, 1976) and Senecio vulgaris (Radosevich and Devilliers, 1976) is due to a reduction of phytotoxicity on the photosynthetic apparatus of resistant genotypes compared to susceptible ones. A weakly bonded and inactive conjugate associated with the chloroplast may be involved or alternatively the herbicide may be excluded by a triazine-impermeable membrane.

Morphological and anatomical resistance

The toxicity of foliar applied herbicides is closely correlated with leaf surface characteristics, in particular the efficiency of surface retention and cuticular penetration and degree of pubescence (Martin and Juniper, 1970). Leaf stage and growth habit are also important factors which determine spray retention and intraspecific variation in these characters may produce a parallel variation in resistance to herbicides (Hammerton, 1968). Nevertheless, there is little evidence that field resistance to a herbicide has arisen as a result of natural selection for morphological or anatomical characters, although cuticle thickness is involved in resistance to 2,4-D in certain populations of Cirsium arvense (Hodgson, 1973).

CONCLUDING DISCUSSION

The evolution of herbicide resistance, despite 20 to 30 years of intensive use of herbicides, remains a potential threat rather than a reality except for a few isolated instances. However, we must not become complacent since any long term reliance on a particular crop/herbicide combination within a crop management system may provide the appropriate, stable, high selection pressure environment suitable for rapid evolution of resistance. It is important that if a resistant weed population does evolve, it is detected as rapidly as possible so that it can be eliminated by alternative chemical or cultural control methods.

The initial recognition of a resistant weed population in the field must be the responsibility of the grower and his local ADAS advisor If failure of weed control occurs, particularly in successive years, the development of herbicide resistance must be considered as at least one possible explanation of failure of chemical control measures. The responsibility for undertaking simple screening tests for the detection of resistance should rest initially with the manufacturer of the chemical involved, although the Weed Research Organization and many Horticultural Research Stations and University Departments are well equipped to undertake screening tests in suitable controlled environments.

A combined knowledge of the properties of a herbicide, the management of a particular crop and the population biology of a weed species is an essential part of determining ways in which evolution of resistance can be avoided. We have suggested a number of approaches to minimise the possible evolution of resistant weeds. Perhaps the most important of these suggestions is that a sequence of rotation of herbicides be maintained wherever possible. A comment made by Day (1975) is most relevant "Indeed if there is a single unifying principle in all of weed control, it might be rotation: rotation of crops, rotation of cultural practices, and rotation of herbicides" .

It appears that herbicide resistance is not likely to become a serious problem except in a few special situations. A classic example is the continuous use of atrazine for weed control in maize which has resulted in the development of resistance to atrazine by annual weeds in several localities in Canada and the

U.S.A. In the United Kingdom the continuous use of a herbicide or chemically related group of herbicides in a crop is not a common occurrence even in perennial crops such as soft or top fruits.

There is little published evidence concerning the relationship between herbicide resistance in weed species and the physiological, morphological or anatomical characteristics of the plants. Some evidence has been presented of mechanisms of resistance which depend on a reduction in absorption, translocation or metabolic breakdown of a herbicide, but there is only one known case where resistance was related to an anatomical character. In this instance, resistance to 2,4-D by some populations of Cirsium arvense were directly related to cuticle thickness (Hodgson, 1973). Resistant genotypes have a thicker cuticle than the corresponding susceptible genotypes. Other studies which attempted to relate intraspecific variation in herbicide resistance with morphological characters found little correlation (Martin and Juniper, 1970). Thus not much can be added to Harper's (1956) statement that, "little is known of the role played by morphological differences in determining the susceptibility of different weeds to herbicides".

The development of herbicide resistance is most likely therefore to result from selection for changes in physiological or biochemical processes rather than changes in morphological or anatomical characteristics of the plant. Metabolic conversion or detoxification mechanisms appear to be the most frequent mechanisms of herbicide resistance (Table 1). The practical importance of these facts to the farmer is that such mechanisms are often the result of simple biochemical conversion. For example, the inactivation of atrazine by conversion to hydroxyatrazine which confers resistance to this chemical in Zea mays (Grogan et al, 1963). Such simple biochemical processes are often controlled by a single major gene or a few genes and the evolution of resistance is likely to be considerably more rapid when it is a simply inherited character.

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THE POTENTIAL OF MINOR FIELD CROPS IN BRITISH AGRICULTURE

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Summary The current situation of forage maize, oilseed rape, linseed, sunflower and lupin is reviewed, and assessments made of their future prospects in British agriculture. Though the areas in 1976 of forage maize (29 kha) and oilseed rape (47 kha) show an increase recently each is still substantially below the levels elsewhere in Northern Europe and continued expansion of both crops, to 80-100 kha at least seems justified. The economic outlook for linseed is especially favourable at present, and should encourage increased production. Slowly declining industrial demand will set an upper limit to the area grown, but it could attain 20-40 kha. There is little recent commercial experience with sunflower or lupins and future predictions are necessarily speculative. Satisfactory yields of sunflower were harvested from farm trials this year, and if bird damage to ripening grain can be restricted to tolerable levels the crop has distinct possibilities for S.E.England. Similarly *Lupinus sp*, especially *L. albus*, seem much better adapted than soya bean for commercial production in Britain and could make a useful contribution to grain legume production.

INTRODUCTION

In theory, if not in practice, the field of minor crops in Britain is extensive, and no attempt will be made to cover all the ground. There is a considerable literature (see Bunting, 1974) and this review will be restricted to brief considerations of the present position, and possible future, of forage maize, oilseed rape, linseed, sunflower and lupins, taken in the order listed.

FORAGE MAIZE

There has been a spectacular increase in the forage maize area in N.W.Europe over the past decade (see Table 1). In Eastern Europe also, the crop is becoming much more important; in U.S.S.R., for example, 18 million ha of forage maize, representing over 70% of the total maize area, were grown in 1975.

Improvements in varieties and in methods of crop production, conservation and feeding have all made important contributions to this expansion. (Bunting & Gunn 1974, Wilkinson & Kilkenny 1974). Under favourable conditions the maize crop provides a high yield (10-15 t/ha d.m.) of easily conserved, palatable and very digestible forage from a single cut in September or early in October. Crop production and utilisation can be fully mechanised; special machines for precision drilling and harvesting, which are desirable, are now more common and contractor services for these operations are available if required. The digestibility of forage maize is little affected by variations in date of harvest or seasonal conditions, but crops for conservation should be harvested when fairly mature, with a dry matter content exceeding 20%, to maximise yield and minimise ensiling losses. Maize silage is deficient in protein and minerals, and supplementary feeds are necessary, but the high energy content, consistency in quality and ease of mechanical handling make it a valuable component in ruminant rations, especially in intensive systems of beef and milk production.

The distribution of the forage maize crop is largely determined by expected summer temperature - 95% is grown south of the Wash. Earlier ripening varieties, or varieties better adapted to the relatively cool temperatures normally prevailing during the early stages of crop development, would enhance prospects for forage maize in northern areas and also for grain maize production in SE England. The modest but steady expansion of grain maize production was halted by the abnormally cool summer temperatures of 1972 and reversed almost to extinction after the equally adverse conditions of 1974. Conditions, and effects, in continental areas of Northern Europe were only slightly less severe in these years, and stimulated breeding work on adaptation to cooler climates. Improved varieties can be expected when these programmes come to fruition. The area grown is still so much below the levels prevailing in Northern France, W.Germany, Netherlands and Belgium (see Table 1) that even if the most optimistic hopes are not realised, continued expansion, to 80,000 ha at least, is predictable.

Table 1

Area (in 1,000 ha.) of forage maize in north western Europe

	1965	1970	1975
France	360	403	800
W.Germany	100	190	430
Netherlands	3	6	78
Belgium	5	18	50
U.K.	1	2	26

OILSEED RAPE

Rapeseed (Brassica napus, B.campestris) is the traditional oilseed crop of Northern Europe. Other Brassica species (B.juncea, B.hirta = Sinapis alba) well adapted to U.K. conditions are grown for oil in many parts of the world but are used here almost exclusively in the preparation of mustard condiment.

Oilseed rape was quite widely grown in England until the 1830s, disappearing from the agricultural scene in the face of competition from imported tropical oils. A reviving interest in the 1950s was extinguished by the dramatic rise in Canadian production and exportable surplus, and oilseed rape was not re-established on a significant scale until Britain joined EEC. The area grown has increased steadily to the present, 1976, level of 47,000 ha. In France and W. Germany, members of EEC from its inception in 1958, economic incentives led to a rapid increase in rapeseed production throughout the 1960s. Elsewhere in Europe, similar official support encouraged significant expansion in Sweden and Poland. From 1960 to 1974 world production of rapeseed doubled and European production nearly quadrupled.

The major outlet for rapeseed oil is in edible products, and the residual meal after oil extraction is used as a protein concentrate incorporated into livestock feeds. The quality of both oil and meal has caused concern, the main anti-nutritional factors being the high erucic acid content of the oil and cleavage products of glucosinolates in the meal (Appelqvist & Ohlson, 1972). Removal of these factors has been the main breeding objective in oilseed rape in recent years. The work has been remarkably successful. Varieties with a very low content (0-5%) of erucic acid in the oil first became available in Canada in 1968 (Downey et al 1975), and subsequently were developed in Sweden, Germany, France and the U.K. In these countries the older varieties have been largely superseded, and a limit has been set on the erucic acid content of rapeseed oil used for non-industrial purposes. B. napus genotypes combining a low content of erucic acid in the oil and of glucosinolates in the meal have recently been developed, and there is little doubt that within a few years such varieties will dominate oilseed rape production. A further improvement in the quality of rapeseed meal can be expected in the near future by a reduction in fibre content; additional improvements in oil quality are also being sought by increasing the content of linoleic acid and reducing the content of linolenic acid, but progress in these directions is likely to be slower.

Prospects for expansion of the oilseed rape acreage in the U.K. are extremely favourable. World production and utilisation of edible vegetable oils have approximately doubled since 1950, but per capita consumption has increased only 30% and in developing countries is less than one-third the level in North America and Western Europe. The expected, and desirable, increase in consumption in developing countries will limit future exports of edible tropical oils, and in Europe and North America the nutritional preference now being shown for vegetable oils as opposed to animal fats will also necessitate increased production of the temperate oil seed crops, soya beans, sunflower and rapeseed. The improvements effected in oil quality should ensure that the competitive position of rapeseed in this expanding market is at least maintained. Moreover, rapeseed meal is the most concentrated protein feed produced in the U.K. The protein deficit in the agricultural economies of the U.K., and EEC, is stark. In 1973/74 more than 50% of the protein supplied in concentrated form to farm livestock in the U.K. was provided by oilseed meals, imported directly or home produced from imported seeds, while in EEC indigenous oilseed production provides less than 5% of oilseed meal requirements, at present exceeding 10 million t/annum. (Le Quellec, 1975). Direct imports of soya bean meal to EEC countries, negligible in 1950, were more than 3 million t. in 1974 (Schmidt 1975).

Rapeseed meal has a satisfactory amino acid balance but at present the glucosinolate content limits its use in feeds for pigs and poultry, and the relatively high fibre content reduces the metabolisable energy value below that associated with soya bean meal. The glucosinolate content of recently developed rapeseed genotypes is less than one-tenth of the level in varieties previously grown, and the reduction in fibre content when yellow seeded varieties become available will make rapeseed meal a much more valuable commodity than it is at present (see Table 2). Finally, on a slightly longer term view, improvements in yield should follow the release of breeding effort from its present concentration on quality components. Confidence in the future of the oilseed rape crop in the U.K. seems soundly based. In 1975, 39 kha of rapeseed were grown, compared with 300 kha in France, 100 kha in W.Germany and 190 kha in Sweden. Such differences cannot be accounted for in terms of yield, either in absolute figures or in relation to competing arable crops, and a substantial increase in the rapeseed area in the U.K. is justified even in present circumstances. Given the need for a planned reduction in protein imports, and rapeseed production becomes even more significant. One recent report (Joint Consultative Organisation Report No. 2. 1976) indicates a requirement for 140 kha of oilseed rape in a cropping programme designed to save 50% of protein feed imports, and a second report, considering the possibilities for complete self sufficiency in food production, suggests that 800 kha of oilseed rape would be needed to help achieve this aim (Blaxter, 1975). It seems extremely unlikely, therefore, that oilseed rape will come within the purview of any subsequent commentator on minor crops in the U.K.

LINSEED

Linseed (Linum usitatissimum) has a long history of cultivation in the U.K., although until comparatively recently the main objective of cultivation was probably the flax fibre from the stems rather than oil from the seeds. Apart from war-time increases, linseed production was of minor importance until the late 1940s, when plans were made for a progressive expansion in crop area to 160,000 ha to help alleviate the expected world shortage of vegetable oils. The plans floundered almost immediately. The area sown (35,000 ha) in the initial year, 1948, though much below the target figure, remains the highest recorded in the U.K. and by the mid 1950s the linseed crop was of negligible importance here, or elsewhere in Europe. A major problem was the susceptibility of the crop to weed infestation, which in turn exacerbated harvesting difficulties. More effective herbicides are now available, and with the high price of linseed on world markets since 1973 (Table 2) supplemented by grants to producers in EEC, commercial interest is being renewed. About 3,000 ha were grown in Britain in 1976.

Linseed contains about 40% oil and 20% protein. The high content of linolenic acid in the oil precludes its use for edible products, but enhances drying rate and makes it especially useful in the production of paints and varnishes. Despite severe competition from synthetic resins for these traditional outlets, which has led to a continuing decline in world production of linseed over the past twenty years, linseed oil remains the most important of all vegetable oils for industrial purposes. Linseed cake, or the ground meal, has long been established as a satisfactory high protein supplement in cattle feeds.

Any proposed reduction in protein feed-imports would, therefore, also encourage linseed production and the J.C.O. report previously mentioned suggests a figure for the U.K. of 50 kha, to provide sufficient seed to meet current industrial demands for linseed oil. Average annual seed and oil imports early in the 1970s, expressed in terms of seed, were more than 100,000 tonnes for the U.K. and 600,000 tonnes for EEC; in 1975 restricted availability and high prices reduced these figures to around 75,000 and 500,000 respectively. Indigenous production is very small, less than 5,000 tonnes in U.K. and about 50,000 tonnes in EEC. The main exporting countries are Canada and U.S.A., for seed, and Argentina, for oil. Production in these countries has been declining steadily since the 1950s. In 1973-75, their combined annual production averaged 1.1 million t., only half that of 1961-65. Significantly, in none of the major exporting countries has there been any response in production to the high price of linseed in world markets since 1973, probably because linseed is a relatively minor component of their oilseed cropping programmes. The major commitments to rapeseed in Canada, soya beans in U.S.A. and sunflowers in Argentina may well preclude any permanent expansion in available supplies of linseed. In that event linseed prices will remain high in relation to the various edible oilseed crops, where more possibilities exist for competition and substitution, and the present economically favourable outlook for linseed production, if not permanent, is likely to recur. In the light of world trends in linseed oil utilisation it is difficult to imagine that the linseed crop will ever become as important in the U.K. as was once thought possible, but a return to the historically high acreage levels of the 1940s seems quite feasible.

SUNFLOWER

The sunflower is of North American origin, but it was first developed as an agricultural crop plant in Russia in the latter half of the 19th century. Until recently commercial cultivation was effectively confined to Eastern Europe and South America, but over the past decade the crop has been much more widely grown. World production of sunflower oil has fully kept pace with the increase in other edible oils, and only soya bean oil is produced in significantly greater amounts. The increase is a testimony to the achievements effected by plant breeders; it also reflects the growing awareness of the high nutritional quality of sunflower seed oil.

In the late 1940s some of the leading Russian varieties were grown experimentally on farms in SE England. The oil content in the "seed" of these varieties was around 30%; by the end of the 1950s this had been raised to more than 40%, largely by reducing the proportion of husk. This major advance was followed in the 1960s by the development of hybrid varieties. The basis of the first hybrid varieties, developed in France, was the discovery of nuclear genes inducing male sterility and linked with genes controlling seedling colour. More recently suitable sources have been found of cytoplasmic male sterility, and of the necessary fertility restoring genes, and current breeding methods in sunflower are similar to those previously adopted in maize. The commercial impact of hybrid maize is well known, and if precedent is followed the increased yield and much more uniform development associated with hybrid varieties will encourage further expansion in area and geographical distribution of the sunflower crop.

Moderate temperatures during ripening favours development of linoleic acid in sunflower oil (see Table 3), and it is the combination of a high content of linoleic acid (18.2) and complete absence of linolenic acid (18.3) that makes sunflower oil nutritionally superior to oil from other temperate crops, soya bean and rapeseed. In addition to the high content and quality of the oil, trial sowings suggest that the yield of seed from sunflower in SE England is potentially as high as from oilseed rape. With minor modifications, standard cereal combines are used to harvest modern hybrid varieties, which are shorter in height and much more uniform in ripening than the older open pollinated varieties. The fleshy heads of sunflowers dry out slowly and infection by Botrytis cinerea can be severe in cool, damp seasons, but some resistance to Botrytis is claimed for recently introduced hybrid varieties and the major hazard to commercial production in England is bird damage to ripening grain. If this can be minimised, possibly by co-operation within farming groups to enable crop production to be concentrated in localised areas, sunflower seed production could become economically viable in SE England. Results from the few crops grown in 1976 were encouraging and the proposed extension of this enquiry will provide information for a more informed assessment of commercial possibilities.

Table 2

Average annual prices of seed, oil and meal from temperate oil seed crops

		'70-'72	'73	'74	'75
		$/t. CIF Europe			
Seed:	Soya	128	290	277	220
	Rapeseed	139	254	374	293
	Sunflower		309	482	374
	Linseed	129	340	486	338
Oil:	Soya	277	436	832	563
	Rapeseed	269	395	745	551
	Sunflower	343	481	977	739
	Linseed	200	544	1095	701
Meal:	Soya	111	302	184	155
	Rapeseed	82	178	143	129
	Sunflower	91	217	150	135
	Linseed	111	231	190	181

Table 3

Environmental effects on fatty acid composition in sunflower oil (Data as % of total fatty acid content. Mean of vars. Inra 47-01, Inra 65-01)

Fatty acid -	Oleic (18:1)	Linoleic (18:2)
	%	
Site:		
U.K. (Cambridge)	16.1	74.2
Canada (Morden)	20.0	73.4
W.Germany (G.Gerau)	20.3	73.1
Yugoslavia (Novi Sad)	25.3	69.0
India (Hayatnagav)	54.6	40.0

LUPINS

The cultivation of lupins in Europe was largely restricted to use as a green manure crop until varieties with seed essentially free of alkaloids were developed in Germany in the 1930s. "Sweet" varieties exist of the three main species of agricultural interest, Lupinus luteus (yellow lupin), L.angustifolius (blue lupin) and L.albus (white lupin). L.mutabilis (pearl lupin) has recently been suggested as a possible crop for this country, but as yet no low alkaloid strains are available.

The early work on sweet lupins was concentrated chiefly on L.luteus, which is traditionally associated with infertile, acid, sandy soils, and trials beginning in the 1920s were conducted over a long period in Suffolk. Increasing interest is now being taken in L.angustifolius and L.albus. Recent improvements in varieties have led to the establishment of L.angustifolius on a significant scale in W. Australia (Gladstone 1970) and the expansion of L.albus cultivation in U.S.S.R. and Poland. A major problem with L.angustifolius in Europe is its susceptibility to Fusariam wilt disease, and the doubt about L.albus here is whether the available varieties, with large seeds enclosed in fleshy pods, would ripen satisfactorily in cool seasons. There are, however, many encouraging features about the lupin crop. It is frost tolerant and can be sown very early in spring; no special machinery is required for crop production and the seed has a high content of protein (30-40%) suitable for incorporation in animal feedstuffs. Also, varieties of L.albus contain 10-12% oil, of edible quality, and a moderate improvement in this level would make commercial extraction economically feasible and bring the crop into even closer alignment with soya bean. Little progress has been made towards the development of soya bean varieties suitable for commercial production in the U.K. There are special problems associated with soya bean breeding, and lupins, peas (see Snoad, 1975) and navy beans (Innes & Hardwick, 1974) may be more viable alternatives, to supplement, on lighter soils, the field bean crop - essentially the only indigenous source of grain legumes in the U.K. at present.

CONCLUSIONS

Maize silage, a high energy feed produced with relatively low energy inputs, should become more popular as a basic component in ruminant rations, and ensure a permanent and steadily increasing role for the forage maize crop in British agriculture.

Possibilities for the introduction of new arable cash crops have been improved by changes in agricultural policy, following entry into EEC, and recognition of the economic risks involved when dependent on a few major suppliers of basic commodities, as exemplified by recent energy and protein crises. For these reasons, oilseeds and grain legume crops, in particular, will attract increasing attention in the future in the U.K., and other countries of the EEC. In the U.K. the oilseed rape crop will certainly be the main beneficiary, but the special merits of sunflower seed oil may encourage commercial production in SE England, and lupins have considerable promise for grain legume production.

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WEED MANAGEMENT IN GRASSLAND

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Summary Weed management in grassland is complicated by the perennial nature of the crop and other factors. Tools for controlling weeds are grassland management, mechanical treatment and herbicides.

During establishment the type of control adopted depends on whether annual or perennial weeds are present.

On intensively used established grassland broad-leaved weeds are seldom a problem but gramineous weeds are. Selective control of weed grasses is possible but not easy to apply successfully in practice. Broad-leaved weeds remain a problem in extensively used grassland although most of them can be controlled with herbicides. Chemicals in conjunction with seeding can be used to change the botanical composition of pastures.

Legumes and herbage seed crops have special weed management problems most of which are soluble. Bracken can be controlled by herbicides but the justification for their use is dependent on land utilization considerations.

INTRODUCTION

Weed management in grassland is a complex matter. It can vary at one extreme from being part of an attempt to produce and maintain a monoculture of a single species by using all the available techniques to, at the other, controlling a specific weed with the simplest of mechanical or chemical treatments. There are many reasons why weed management in grassland is complicated.

On most farms grass is a perennial crop and offers little opportunity to clean up and start again.

Grass is not a marketable commodity. Normally it has to be utilised through the grazing animal and the presence of weeds does not necessarily reduce the output of animal products. On the other hand, poisonous weeds, even in very small numbers, are extremely dangerous to livestock and can cause reduced output out of all proportion to the degree of infestation.

Most grassland swards consist of a constantly changing community of plants so that what may be an obvious weed at one stage or at one season may be insignificant at another.

Many weeds of grass are also gramineous so that problems of definition and recognition are greater than in other crops.

The weed flora of a grass field is often determined by repeated management practices or by physical characteristics such as altitude, aspect, steepness, wetness, liability to flooding or rockiness. The field may be retained in grass precisely because of these imposed limitations. It is by no means always possible to change the underlying cause of the weed's presence so that the effect of herbicides or other control methods is often transient.

Grassland can be farmed profitably at all levels of intensity so that a plant which is considered a weed at one level of farming can be tolerated at another.

This complexity leads to grassland farmers adopting different attitudes to weed control from arable farmers. These attitudes were discussed at the Eighth British Weed Control Conference by Ormrod (1966) and Harpur (1966).

THE TOOLS FOR WEED MANAGMENT IN GRASSLAND

The grass farmer has three main tools in weed control - grassland management, mechanical treatment and chemicals.

Grassland management for controlling weeds consists of manipulating the timing, period and intensity of mowing or grazing to change the composition of swards. The possibilities were demonstrated by Jones (1933) and Milton (1938). Unfortunately the type of management is often imposed by outside factors and desirable changes are not possible.

Mechanical treatment can consist of drainage, mowing, crushing and ploughing.

Chemical treatment with fertilisers is aimed at encouraging the grasses to become more competitive towards weeds. Davies (1968) at the 9th BWCC presented a paper detailing changes in the weed flora on plots at Trawsgoed Experimental Husbandry Farm resulting from the use of different fertilisers and farmyard manure. It is a common experience of advisers that on many fields 'the best herbicide is another bag of fertiliser'.

Herbicides for weed management in grassland are available in great variety. They fall into 3 main groups - selective broad leaved weed killers, grass killers and those which kill both.

WEED CONTROL DURING ESTABLISHMENT

Newly sown direct seedings are almost always infested with broad leaved weeds. These may be seedlings of annuals, seedlings of biennials and perennials or regenerating portions of perennial weeds. Seedlings of annuals are best controlled by grazing and mowing. Stellaria media, though technically an annual, is particularly troublesome in autumn reseeds and normally has to be sprayed with a herbicide as it readily recovers from grazing or mowing and overwinters in most years. Perennials whether present as seedlings or regrowths must be dealt with by herbicides. The choice of herbicide is often limited however by the need to avoid damage to seedling clovers.

New reseeds are often infested with weed grasses also. Since, as will be shown later, unsown grasses are quick to invade even established grassland it is clearly undesirable to allow them entry at such an early stage. Herbicides are available selectively to control seedling weed grasses but little is known about the long term value of their use.

Nothing can be done about weeds in undersown seeds until the cereal crop is harvested. Then, theoretically either broad leaved or grass weed killers can be used but normally it is far more important to encourage quick establishment with fertilisers.

WEED CONTROL IN ESTABLISHED GRASSLAND

The intensity with which grassland is used primarily determines the type of weed control problem encountered.

Intensively used grass is fertilised heavily especially with nitrogen, stocked densely and usually cut for silage. This treatment eliminates most broad leaved weeds. An exception are docks (Rumex spp) which seems to find in this type of management, especially where slurry is also returned to grassland, their ideal environment. Up to a point docks are mainly an unsightly nuisance but above a certain level they reduce yield of grass. Current herbicides for docks are not wholly satisfactory. Regeneration and reinvasion frequently occur and in some instances grass dry matter output is reduced during the year of application. It is likely at present to be more economical to use one of the cheaper chemicals frequently, possibly annually, than one of the specialist dock herbicides.

The position regarding grass weeds on intensive grassland farms is opposite to that of broadleaved weeds. Heavy use of nitrogen and slurry leads to open swards. Open swards are susceptible to invasion by indigenous grasses and this tendency is exacerbated by heavy stocking. If the colonising grasses are palatable like, say, meadow grasses (Poa spp) this is at least preferable to bare ground or broad leaved weeds. If unpalatable grasses such as Yorkshire fog (Holcus lanatus) encroach the position is more serious.

A technique has been developed at the Weed Research Organisation for reducing the proportion of weed grasses in established swards of perennial ryegrass using low doses of dalapon in July. This has not been adopted widely mainly because there is a temporary decline in dry matter production after spraying. Farmers are reluctant deliberately to lower present performance for the promise of nebulous gains in the future. There is also the likelihood that the weed grasses which have already demonstrated their ability to establish on ground vacated by ryegrasses will also be the first to colonise the areas where their own kind have been killed out.

The technique is likely to be of greatest value as a means of discouraging the entry of weed grasses into young stands of ryegrass. In older swards the distribution of ryegrass plants is often not sufficiently uniform to take over after the weed grasses have been killed out. Under these conditions a more promising technique is to drill ryegrass seed direct into the old sward. This aspect is dealt with later.

In extensively used grassland broad leaved weeds remain a problem. Apart from docks the major ones are Ranunculus spp, Cirsium spp, Juncus spp, Urtica dioica and Senecio spp. The last is a special problem as it is poisonous. All these weeds can be dealt with more effectively by herbicides than by mechanical treatment. However, by definition there is no great pressure on extensively used grassland to increase production so there is little pressure either to control weeds. A further deterrent is that white clover is a desirable constituent of extensively used grassland and farmers are loath to use chemicals which may depress it.

Most pastures on extensively managed farms are composed of indigenous grasses such as Agrostis spp, Poa spp and Yorkshire fog (Holcus lanatus) with a small but varying amount of perennial ryegrass (Lolium perene). Since they already consist mainly of what are normally considered 'weed' grasses the problem is not one of 'maintenance' of better species as on intensive farms but of 'improvement'. The low dose of dalapon technique is seldom applicable due to a low and badly distributed content of ryegrass. Often an acceptable level of improved production can be obtained merely by greater use of fertilisers on the original sward. If further improvement is required seed of perennial ryegrass and possibly white clover needs to be introduced. Early efforts consisting of drilling seed into a slit following overall sward destruction have been disappointing due to slow establishment of the sown species and abundant colonisation by Poa spp - especially between the rows. The 'One-pass' technique developed at WRO where a narrow band only, ahead of the coulter, is sprayed with grass killing chemical and the seed dropped into a trash-free trench is promising but as yet largely untried outside WRO.

WEED CONTROL IN LEGUMES

Lucerne and red clover often suffer severe competition from annual weeds, especially Stellaria media, during establishment and from stoloniferous grasses later. Little can be done with mechanical treatment to counteract this so herbicides have to be used.

Due to the increased cost of nitrogen fertilisers in recent years there is greater interest in improving the proportion of white clover in swards. It is extremely doubtful whether it would pay an intensive livestock farmer to abandon or even decrease nitrogen applications in order to depend on white clover. The extensive farmer would benefit from increased white clover in his swards and this can be obtained by better manuring, especially with phosphates, and grazing management. Herbicides can also be used to increase the proportion of white clover in swards but as this is done by surpressing grass growth in spring it is unlikely to appeal to any farmer.

WEED CONTROL IN HERBAGE SEED CROPS

Herbage seed crops are managed virtually as arable crops. The approach to weed management in them is therefore similar to arable crops and simpler than in other grassland situations. Nevertheless there is still the complication that stands often remain for several harvest years.

Broad leaved weeds can be controlled adequately in herbage seed crops with herbicides. Avena fatua, Alopecurus myosuroides and Poa spp however pose serious problems especially in view of strict mandatory EEC standards. Promising chemicals for their control are being investigated and there are approved recommendations for use in seed crops of some grasses and clovers but results so far have been variable and often accompanied by crop damage.

BRACKEN

Large tracts of hill and marginal land are made virtually useless by bracken (Pteridium aquilinum). Aerial spraying with herbicides has caused spectacular initial reduction of the weed in recent years. Little is known as yet about the permanancy of this control. It obviously will vary from site to site and with degree of follow-up treatment. The decision as to whether or not to spray in any situation can only be made after careful summing up of the use to which the land can be put following control of the bracken.

CONCLUSION

Means are available to control most weeds in grassland and chemicals can also help in the maintenance and improvement of swards. Weed management, however, is only one of the factors which interact to produce economic output of animal products from grassland. The contribution it can make must be assessed in relation to the others and will be greatest when it is integrated with them for optimum productivity.

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Proceedings 1976 British Crop Protection Conference - Weeds

THE EFFECTS OF SEASONAL APPLICATIONS OF GLYPHOSATE ON A MIXED SWARD

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Summary Four rates of glyphosate, varying from 0 to 3.75 kg/ha, were applied on 4 occasions to a permanent pasture containing a number of indigenous species. August applications were the most effective, as judged by reductions in sward growth; spraying in April and June was less effective, while December treatments, at less than 2 kg/ha, were least satisfactory. Sward recovery was very slow in August compared with the other three dates.

Reactions of the individual species in the sward to the August application varied: Holcus lanatus was controlled completely by all rates as was Agrostis stolonifera by 2.0 and 3.0 kg a.i./ha. There was short-term control of Poa trivialis, Alopecurus pratensis and to a lesser extent, Festuca rubra. Lolium perenne, although severely checked, recovered well whereas Trifolium repens recovery took several months.

Résumé Quatre traitements utilisant le glyphosate à 4 doses différentes de 0 à 3.75 kg/ha ont été réalisés a 4 époques différentes dans une prairie permanente où se trouvaient plusieurs espèces indigènes. Les traitements réalisés en août se sont montrés les plus efficaces du point de vue ralentissement de la croissance du gazon; les pulvérisations d'avril et de juin se sont avérées moins efficaces, tandis que les traitements de décembre à moins de 2 kg/ha étaient les moins satisfaisants. Le rétablissement du gazon en août etait très lent par rapport aux trois autres époques d'application.

Le comportement des différentes espèces vis-à-vis des traitements d'août était divers: la destruction du Holcus lanatus a été totale à toutes les doses. et de l'Agrostis stolonifera aux doses de 2 et 3 kg/ha. Il y a eu un freinage à courte durée de la végétation de Poa trivialis, Alopecurus pratensis et, en moindre mesure, Festuca rubra. Le Lolium perenne, bien que fortement freiné, s'est rétabli bien tandis qu'el a fallu plusieurs mois pour le rétablissement du Trifolium repens.

INTRODUCTION

Work at the Weed Research Organization suggested that glyphosate might be a useful addition to the limited number of chemicals used for sward destruction prior to re-seeding (Oswald, 1972). It had already been reported from initial studies that the chemical could give good control of a wide range of annual and perennial weeds (Monsanto Europe S A 1971). However, more detailed information was required on the effects of glyphosate on the various species present in an old grass sward. The effects of spraying at different times of year had also to be measured before confirming the promise of this herbicide.

METHOD AND MATERIALS

The experiment was located at Begbroke Hill, Oxford on a poorly drained, silt clay loam soil. The total rainfall for 1973 was 490 mm compared with the ten year average of 600 mm. The pasture, which had not been ploughed for at least 40 years, contained a large number of grass and broadleaved species (Table 3). These species are characteristically associated with a minimal use of herbicides and fertilizers, plus annual hay cuts taken in June followed by aftermath grazing by beef cattle.

Treatments

Four rates of glyphosate were applied on 4 dates (Table 1). The rates chosen were suggested by the earlier work as being appropriate for each application date. The 16 treatment combinations were laid out in a randomised block design with 3 replications. Plot size was 7.5 m x 2.5 m.

Table 1

Rates of glyphosate sprayed on 4 dates in 1973 (kg a.i./ha)

11 April	29 June	17 August	7 December
3.75	3.5	3.0	1.75
3.25	2.75	2.0	1.0
2.75	2.0	1.0	0.25
0	0	0	0

On all occasions the chemical was applied in 225 l/ha aqueous spray solution containing 0.25 Agral 90 surfactant. The solutions were sprayed at 2.07 bars pressure through Tee jets No 6502 fitted to a 2.5 m boom on an Oxford Precision Sprayer.

At spraying the weather and sward conditions were recorded (Table 2).

Table 2

Conditions at spraying

	Temperature (°C)	Relative humidity (%)	Cloud cover (%)	Herbage height (cm)	Herbage condition
11 April	7.0	94	80	2.5-7.5	Damp, grazed 4 weeks previously
29 June	18.5	83	70	7.5-10.0	Damp, cut 7 days previously
17 August	20.0	96	100	5.0-10.0	Damp, grazed up to spraying
7 December	10.8	86	100	5.0-7.5	Wet, grazed up to spraying

An inclined point quadrat was used to measure the botanical composition of the sward immediately before each spraying. All contacts to ground level were recorded at 250 points.

The visible effects on the sward were recorded 7 days after each spraying and then periodically thereafter until complete or near complete recovery was noted.

Treated plots were scored for the amount of green material present compared to unsprayed control. A mean of two independent scores was obtained for each plot.

After each spraying, when visible effects were severe, treatment effects on the main species were recorded by counting the number of grass tillers and clover petioles on ten 10.8 cm diameter turf cores randomly located and removed from each treated and control plot. This assessment was repeated after sward recovery.

RESULTS

Pre-spraying botanical composition

Table 3

Main species	Percentage composition 11 April	29 June	17 August	7 December
Festuca rubra	47	43	38	38
Holcus lanatus	9	14	16	21
Agrostis stolonifera	7	11	9	11
Lolium perenne	7	3	6	6
Poa trivialis	1	Trace	0	Trace
Alopecurus pratensis	3	2	4	3
Trifolium repens	4	4	8	2

A total of 20 species were recorded. (All those not shown represented less than 5% presence).

The effects on the sward as a whole

(a) Green material reduction. The visible effect on vegetation treated in April appeared as a red coloured chlorosis, changing gradually to a straw colour as the effect increased. Chlorosis on vegetation treated in June, August and December was immediately straw coloured.

The time taken to reach maximum effect is given in Fig. 1. Maximum effects were reached 5 to 6 weeks after spraying in April, 3 to 6 weeks after spraying in June and 4 to 6 weeks after spraying in August. It was 10 weeks before maximum effects were reached after spraying in December.

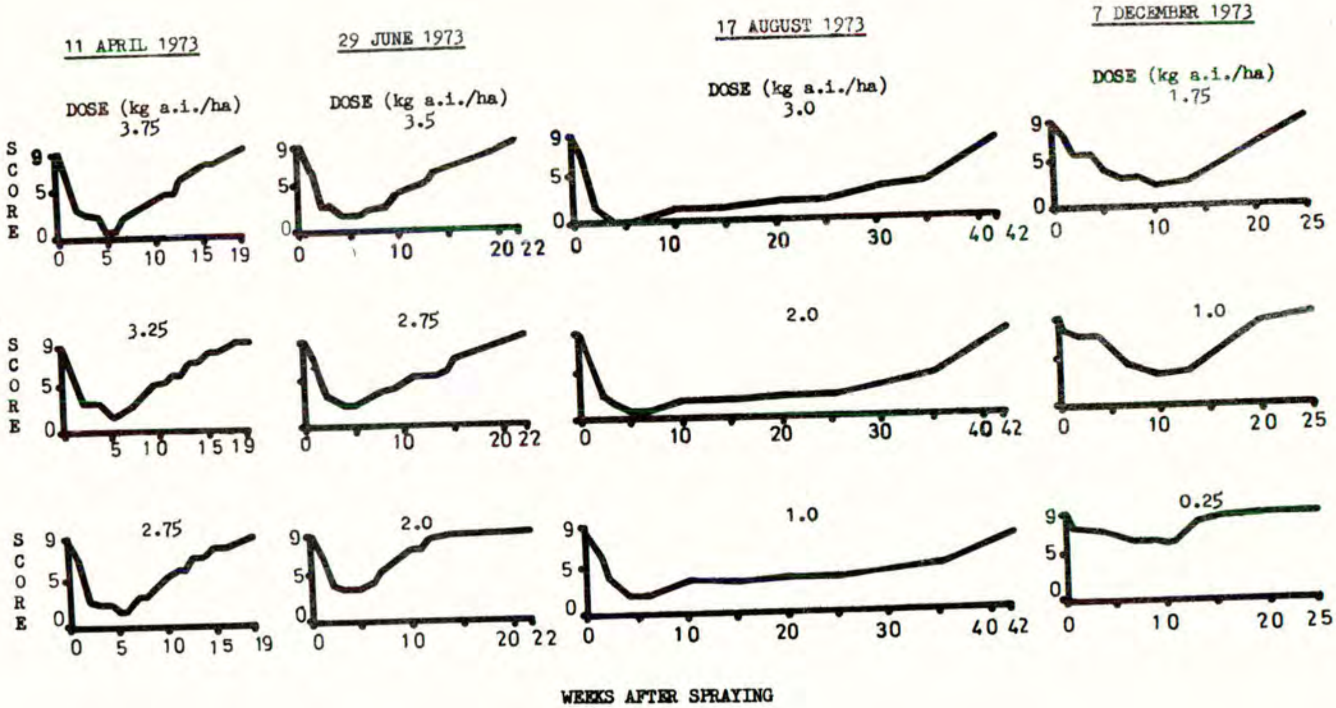
Total elimination of green material was achieved only by the rate of 3.0 kg/ha applied in August. For April, June and December, maximum reductions of 90, 70 and 60% were achieved by 3.75, 3.5 and 1.75 kg/ha respectively.

Maximum reductions in green material were maintained for 7 to 14 days after spraying in June and August. In April and December the maximum effects remained for up to 7 days.

Vegetation treated in April had recovered by 19 weeks. In June it took 20-22 weeks and in December up to 25 weeks for complete sward recovery. The August treatment was so effective that full recovery was not achieved 42 weeks after spraying.

(b) Tiller and petiole reductions. There were significant reductions after all

Fig. 1. Reductions in green material after spraying glyphosate onto a mixed sward at 4 dates scored 0 (absence) to 9 (equal to unsprayed control).



rates in April when assessed 6 weeks after spraying (Fig. 2a). There was no significant difference between the number of tillers and petioles from April treated and untreated plots when assessed 19 weeks after spraying (Fig. 2b).

In June, all treatments significantly reduced vegetation 6 weeks after spraying. Reductions were still recorded 24 weeks after spraying except on plots treated with 2.0 kg/ha.

All doses applied in August caused significant reductions even when assessed 42 weeks after spraying.

Significant reductions were achieved by all doses sprayed in December. The sward completely recovered when assessed 27 weeks after spraying.

The effects on individual species

Festuca rubra. The best control was achieved in August with little recovery even 9 months after treatment (Table 4). There was less effect in April and June, although full recovery had not taken place 6 months after spraying in June at the higher rates. In December, a 50% control was achieved by 1.75 kg/ha.

Holcus lanatus. All doses sprayed in August caused complete kill with no recovery 9 months later. Doses of 2.75 to 3.75 kg/ha sprayed in April and June gave good reductions but some recovery had taken place 4 to 5 months after treatment. The dose of 1.75 kg/ha in December gave 100% control after 6 months. Lower rates were only moderately effective.

Agrostis stolonifera. Doses of 3.0 and 2.0 kg/ha in August gave total kill. The 1.0 kg/ha dose was also very effective but some recovery from this treatment had taken place 9 months after spraying. Treatment in April was less effective followed by June and December.

Lolium perenne. Amounts were too small for analysis of the August treatment. There were significant reductions after spraying in April, June and December. Eventual recovery was recorded but this was not so complete after treatment in June.

Poa trivialis. All doses applied in August gave 100% reduction, as did 3.75 and 3.25 kg/ha in April and 1.75 and 1.0 kg/ha in December when assessed at the first date after spraying. Regrowth was recorded at the second date of assessment. Amounts in June were too small for proper analysis.

Alopecurus pratensis. Only the effects of August and December treatments were analysed. All doses except 0.25 kg/ha in December gave 100% reduction, although some recovery was recorded after both dates of application.

Trifolium repens. There was little consistent short-term effect on this species. However, there was a general trend towards a long-term increase after all spraying dates except August.

DISCUSSION

Glyphosate was most effective for sward destruction in August. At this time a dose of 1.0 to 2.0 kg/ha gave better control of vegetation than 3.5 kg/ha in April or 3.75 kg/ha in June. Spraying in December was least effective but the doses applied at this time only ranged from 0.25 - 1.75 kg/ha.

Holcus lanatus and A. stolonifera were particularly susceptible in August; F. rubra and A. stolonifera, although checked severely, were more difficult to control. It is not clear whether the eventual recovery of any of the species, especially P. trivialis, was due to regrowth of treated plants or to seedling

Fig. 2a. The effects of glyphosate on grass tillers and clover petioles after spraying in April (___), June (---), August (.-.-) and December (....). Total numbers per 915 cm^2.

1st date of assessment

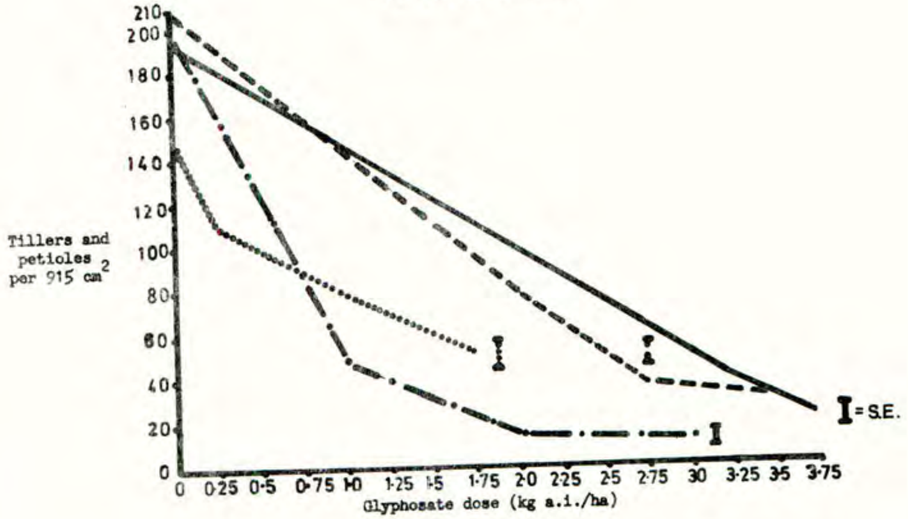
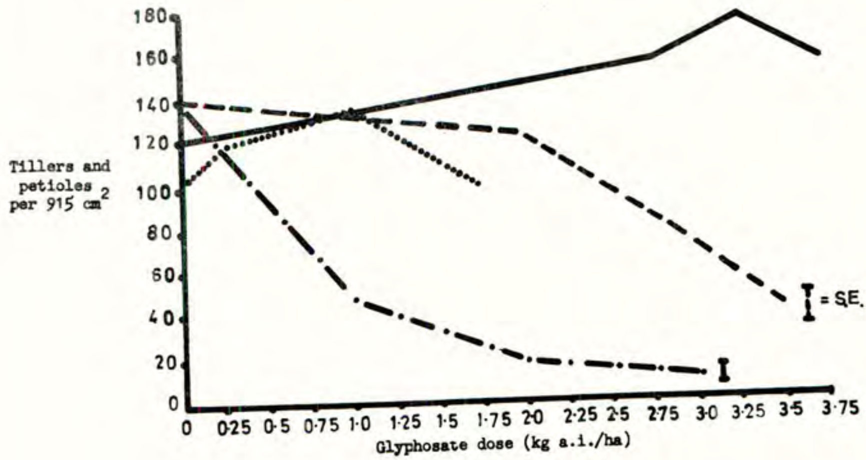


Fig. 2b. 2nd date of assessment



invasion.

Trifolium repens was more resistant than the grasses, especially in April. This result is in line with other work at the Weed Research Organization in which low rates of glyphosate have been used to suppress grass growth as a means of increasing white clover (Haggar, 1976).

The failure of the December treatment may have been due to the low rates of application at this time compared to the other three dates of spraying. The conditions at spraying may also have been a contributory factor. A period of heavy rain following treatment (Baird et al, 1972) and low light intensity (Upchurch and Baird, 1972) could have combined to reduce the effectiveness of the treatment.

From the results reported here it is clear that glyphosate in August at a rate of 1.0 to 2.0 kg/ha has considerable potential for sward destruction, prior to an autumn reseed. Used in this way, glyphosate would insure that the surrounding vegetation would not compete with the young seedlings during the vital 6 weeks of establishment. Any recovery of the old sward would be delayed until the following late spring, by which time the crop would be growing strongly.

It would be helpful if glyphosate could be used later than August in readiness for a reseed the following spring, thus allowing time for the breakdown of harmful turf during the winter months. Further work is needed on the effects of glyphosate sprayed later than August, but before December when results were somewhat disappointing.

The susceptibility of *H. lanatus* suggests that glyphosate might be used to selectively control this weed in rye-grass swards. Future work should investigate the effects of lower rates than those used in this experiment.

Acknowledgements

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Table 4

The effects of glyphosate on the main species present in a mixed sward. Assessed on two dates after spraying (grass tillers and clover petioles per 915 cm^2)

Assessments - Weeks after spraying

Date of Spraying	Dose (kg a.i./ha)	F. rubra		H. lanatus		A. stolonifera		L. perenne	
		6 LOG	19 LOG	6 LOG	19 LOG	6 LOG	19 LOG	6 LOG	19 LOG
11 April	3.75	13 (4.42)	99 (5.14)	2 (1.07)	2 (0.49)	2 (1.45)	14 (2.19)	0 -	9 (1.38)
	3.25	32 (4.56)	137 (6.32)	1 (1.05)	0 -	1 (1.47)	5 (1.34)	0 -	2 (0.42)
	2.75	46 (5.43)	107 (6.67)	3 (1.96)	2 (1.39)	4 (2.07)	27 (2.60)	0 -	5 (0.74)
	0	124 (7.04)	69 (6.29)	12 (3.98)	7 (2.90)	26 (5.16)	24 (4.22)	3 (1.49)	5 (1.61)
	Log S.E.	(0.30)	(0.44)	(0.39)	(0.38)	(0.38)	(0.53)	(0.23)	(0.45)
		6	24	6	24	6	24	6	24
29 June	3.5	10 (3.27)	18 (2.59)	1 (0.78)	4 (1.04)	5 (1.69)	6 (1.59)	1 (0.90)	0 -
	2.75	21 (4.93)	58 (4.50)	1 (0.64)	5 (1.24)	5 (1.89)	10 (2.13)	1 (0.51)	3 (1.25)
	2.0	62 (5.98)	78 (6.34)	4 (1.35)	13 (2.48)	6 (2.74)	8 (2.50)	1 (0.83)	6 (2.23)
	0	108 (6.92)	75 (6.34)	15 (3.98)	23 (4.28)	40 (5.13)	12 (3.15)	7 (2.07)	5 (1.53)
	Log S.E.	(0.30)	(0.46)	(0.43)	(0.49)	(0.49)	(0.53)	(0.39)	(0.42)
		4	42	4	42	4	42	4	42
17 August	3.0	3 (0.76)	2 (0.53)	0 -	0 -	0 -	0 -	NOT FOUND	
	2.0	7 (0.94)	8 (0.54)	0 -	0 -	0 -	0 -		
	1.0	29 (2.17)	22 (1.77)	0 -	0 -	2 (0.60)	1 (0.17)		
	0	111 (2.98)	83 (2.75)	14 (1.63)	12 (1.35)	35 (2.23)	4 (0.91)		
	Log S.E.	(0.17)	(0.20)	(0.11)	(0.12)	(0.13)	(0.12)		
		11	27	11	27	11	27	11	27
7 December	1.75	32 (1.99)	51 (2.54)	2 (0.56)	0 -	6 (1.26)	14 (0.94)	1 (0.38)	3 (0.74)
	1.0	53 (2.52)	87 (2.84)	2 (0.68)	2 (0.49)	7 (1.30)	4 (1.31)	0 -	2 (0.54)
	0.25	55 (2.46)	69 (2.69)	5 (1.02)	4 (0.69)	12 (1.43)	11 (1.46)	3 (0.56)	4 (0.75)
	0	66 (2.56)	66 (2.74)	13 (1.52)	8 (1.40)	26 (2.08)	7 (1.17)	10 (1.03)	3 (0.70)
	Log S.E.	(0.16)	(0.09)	(0.19)	(0.16)	(0.20	(0.21)	(0.17)	(0.19)

Table 4

The effects of glyphosate on the main species present in a mixed sward.
Assessed on two dates after spraying (grass tillers and clover petioles per 915 cm^2)

Date of Spraying	Dose (kg a.i./ha)	*P. trivialis*		*A. pratensis*		*T. repens*	
		Assessments - Weeks after spraying					
		6 (LOG)	19 (LOG)	6	19	6 (LOG)	19 (LOG)
11 April	3.75	0 -	1 (0.44)	TRACE ONLY		3 (2.25)	25 (2.37)
	3.25	0 -	2 (0.46)			1 (1.05)	27 (2.07)
	2.75	1 (0.44)	0 -			5 (1.98)	27 (4.02)
	0	7 (2.39)	4 (1.51)			8 (2.26)	6 (2.43)
	Log S.E.	(0.33)	(0.33)			(0.47)	(0.62)
		6	24	6	24	6	24
29 June	3.5	TRACE ONLY		TRACE ONLY		8 (1.95)	10 (2.31)
	2.75					7 (2.33)	2 (1.42)
	2.0					0 (-)	1 (1.16)
	0					16 (3.22)	1 (1.33)
	Log S.E.					(0.52)	(0.46)
		4	42	4 (LOG)	42 (LOG)	4	42
17 August	3.0	0 -	1 (0.38)	0 -	1 (0.44)	5 (1.20)	3 (0.25)
	2.0	0 -	2 (0.52)	0 -	1 (0.40)	5 (0.71)	5 (0.89)
	1.0	0 -	1 (0.29)	0 -	4 (0.82)	11 (1.36)	19 (1.11)
	0	9 (1.09)	6 (1.19)	1 (0.40)	17 (2.05)	7 (1.12)	9 (1.32)
	Log S.E.	(0.14)	(0.17)	(0.08)	(0.15)	(0.22)	(0.22)
		11	27	11	27	11	27
7 December	1.75	0 -	3 (0.39)	0 -	5 (1.11)	5 (0.86)	19 (0.91)
	1.0	0 -	8 (1.08)	0 -	7 (1.24)	9 (1.13)	19 (1.58)
	0.25	8 (0.94)	4 (0.96)	5 (0.81)	10 (1.47)	9 (1.02)	12 (1.24)
	0	9 (1.34)	4 (0.98)	7 (1.00	5 (0.97)	4 (0.99)	4 (0.84)
	Log S.E.	(0.17)	(0.20)	(0.16)	(0.20)	(0.22)	(0.24)

Proceedings 1976 British Crop Protection Conference - weeds

RELATIVE IMPORTANCE OF FACTORS INFLUENCING THE ACTIVITY OF HERBICIDES IN SOIL

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Summary A successful soil applied herbicide must have a high intrinsic activity, relative to its cost, and in most cases show selectivity for economically important crops. The effects that can occur when the herbicide is applied through soil are important in the way they affect this intrinsic activity and selectivity. The main factors which modify the intrinsic activity and selectivity of a soil applied herbicide, when used in the field, are:

Adsorption/precipitation of the chemical in soil
Soil moisture content and structure
Vertical distribution of the chemical in soil
Persistence of the chemical in soil
Variability in application rate and horizontal distribution

The adsorption/precipitation, persistence and movement of a herbicide are normally dominated by its molecular structure. Environmental factors which affect the activity and selectivity of a herbicide include; soil organic matter, clay and water content, soil structure (size, number and continuity of pores), soil pH and microbial activity, as well as rainfall and temperature. Generally no one of these variables dominates the others and all have to be taken into account when we try to explain or predict the effect of soil on the intrinsic activity and selectivity of a herbicide. Our ability to control these variables is extremely limited. Generally the behaviour of a herbicide in soil can only be improved by altering its molecular structure; this has to be done without reducing intrinsic activity and selectivity beyond commercially acceptable limits.

INTRODUCTION

In the search for new soil applied herbicides primary screens are designed to detect chemicals which have a high herbicide activity when applied to seeds, rhizomes, roots or the emerging shoots of weeds. The intrinsic activity can be measured by growing plants in a relatively inert media, such as sand, which has been treated with the chemical. This type of test also shows the degree of selectivity the chemical has for economically important crops. The effects that can occur when the herbicide is applied through soil are important in the way they affect the cost-effectiveness and reliability of activity and selectivity. As the testing of a new chemical progresses from pot tests in a controlled environment through small field plot trials to farm trials it is observed that:

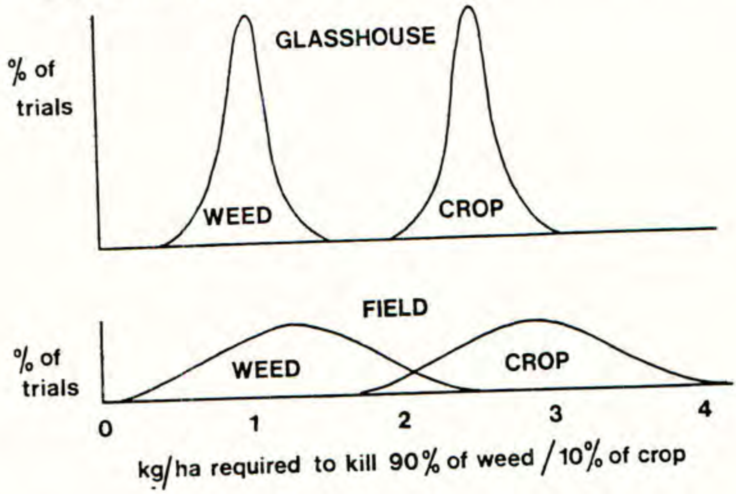
(a) its activity becomes more variable

(b) in most cases its activity decreases

(b) its selectivity between crop and weed may increase or decrease but it always becomes more variable.

A typical example is illustrated in Fig. 1.

Fig 1. Comparison of activity of a herbicide against crop and weed under laboratory and field conditions.



In our experience these changes are best understood and predicted by studying:

(i) adsorption/precipitation of the chemical in soil

(ii) soil moisture content and structure

(iii) vertical distribution of the chemical in soil

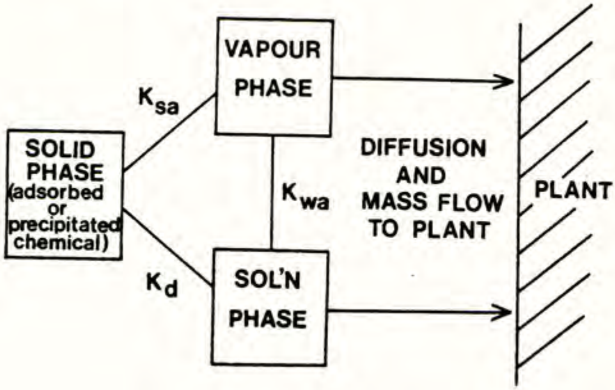
(iv) persistence of the chemical in soil

(v) variability of application rate and horizontal distribution

CHEMICAL ADSORPTION/PRECIPITATION IN SOIL

Pesticides in the solid phase, either adsorbed on to soil particles or precipitated, are unavailable to plants until they transfer to the solution or vapour phase in soil. Chemicals move to the plant either by diffusion or mass flow i.e. bulk movement of water or air containing the pesticide. The distribution of a chemical between the three phases is shown diagrammatically in Fig. 2. In practice it is impossible to distinguish between adsorption and precipitation, although low solubility is most likely to be limiting when the chemical first enters the soil. The maximum concentration of a chemical in the solution and vapour phases is governed by its solubility and vapour pressure, respectively. However, except in the immediate vicinity of undissolved chemical, adsorption reduces the concentration of chemical in the solution and vapour phases.

Fig. 2. Distribution of a chemical between solid, liquid and vapour phases in soil.



K_d is normally expressed as $\frac{\mu g \text{ pesticide/g soil}}{\mu g \text{ pesticide/ml water}}$

K_{wa} is normally expressed as $\frac{\mu g \text{ pesticide/ml water}}{\mu g \text{ pesticide/ml air}}$

K_{sa} is normally expressed as $\frac{\mu g \text{ pesticide/g soil}}{\mu g \text{ pesticide/ml air}} = K_d \times K_{wa}$

N.B. Although expressed here in terms of equilibrium constants, pesticide distribution between the three phases is rarely at equilibrium in soil systems; also adsorption is sometimes not completely reversible.

The properties of molecules which control their partition between the three phases are fairly well understood. K_{wa} can be estimated from the vapour pressure and water solubility of the chemical (1). Strength of adsorption can also generally be predicted from the physico-chemical properties of the molecule.

Neutral Molecules The partition of a chemical between the solid and solution phases, K_d can be estimated from the lipophilicity of the chemical; the higher its lipophilicity the higher its adsorption by soil organic matter. (K_{sa} can be calculated from K_d and K_{wa}). Partition between water and a relatively non-polar liquid such as octanol, can be used to measure liphophilicity (2). The higher the lipophilicity of a chemical the greater is the decrease in its activity in soil compared to an inert growth media. When K_d is greater than about 20 the decrease in activity of chemicals which move to plants by mass flow in the soil solution generally makes the rate of application required to control weeds uneconomic. A high K_d value can be due to the molecule being too lipophilic or the soil containing much organic matter. Diffusion coefficients in air are about

10,000 times greater than in water. Thus diffusion in air can be the dominant mechanism by which a chemical moves, even when the concentration of the chemical in the water is greater than in air, i.e. K_{wa} is greater than 1 (Table 1).

Table 1

Relationship between K_{wa} and mechanisms of herbicide movement to plants

K_{wa} of herbicide	Probable mechanism of movement to plant	Examples of herbicides	
		Name	K_{wa}
1	Almost entirely by diffusion in air phase	Methyl bromide*	4
10		1,2-Dibromo-* ethane	43
10^2	Mainly by diffusion in air phase	Trifluralin	3×10^2
10^3		EPTC Dichlobenil	2×10^3 3×10^3
10^4	By both diffusion and mass flow in both air and water phases		
10^5		Chlorpropham	5×10^5
10^6	Mainly by mass flow in water phase	Diuron	10^6
10^7		Atrazine	10^7
10^8	Almost entirely by mass flow in water phase	2,4-D	10^8

* Soil fumigants

Another consequence of the high diffusion coefficient in air is that chemicals which have a moderately high K_d but low K_{wa} can still move to the plants in sufficient quantities to produce an herbicidal effect. For example trifluralin has a K_d of about 20 but a relatively low K_{wa} of 3×10^2 and is available to plants. Even with such chemicals, adsorption in organic soils may make the rate required for weed control uneconomically high.

Cationic Molecules Positively charged molecules are strongly adsorbed by cation exchange sites on soil clays and organic matter. Activity in soil is so greatly reduced that their use as soil applied herbicides is uneconomic. As an extreme case the positively charged herbicide paraquat has a very high activity when applied to plant roots, 0.01µg/ml will kill most plants, but it is totally inactive when applied to soil. The adsorption, and thus activity, of molecules which protonate in the soil pH range 4 to 8 is normally too variable because most crops are grown on soils with a range of pH values.

Anionic Molecules Chemicals which are negatively charged in the pH range 4 to 8 are generally poorly adsorbed by soils due to charge repulsion and are therefore readily available to plants. Their activity is not influenced by soil organic matter content as much as that of neutral molecules. A notable exception to the above genrality is the herbicide glyphosate which although negatively charged at normal soil pH values is strongly adsorbed, probably due to a specific interaction between the phosphonate group and the soil particle surfaces.

Effect of Formulation on Adsorption Adsorption can be reduced by the addition of chemicals to block the adsorption sites. However the number of adsorption sites is thousands of times greater than the number of pesticide molecules applied. Consequently uneconomically large amounts of formulation additives are required to prevent adsorption of the herbicide. Additives can be used to increase the solubility of pesticides, but again the rates required are uneconomic, due to their adsorption and/or degradation.

SOIL MOISTURE CONTENT AND STRUCTURE

The effect of adsorption on the availability of chemicals is rarely as simple as suggested above. One of the main limitations of placing emphasis on K_d is that it does not take into account other factors which affect the concentration of chemical in solution and the rate of movement of chemical to plants. The availability of a chemical taken up from the solution phase decreases as the soil moisture content decreases because a greater proportion of the applied chemical becomes adsorbed and the rate of chemical movement to the plant by mass flow and diffusion decreases, although K_d may remain constant. On the other hand, the supply of a chemical which normally diffuese in the gaseous phase may increase as the moisture content decreases, due to an increase in the number and continuity of air filled pores. For soils with similar K_d values the activity of a herbicide tends to be higher in soils which have the higher moisture content at a given pF value. The structure of soil must also affect the availability of chemicals because of the size, number and continuity of water and gaseous filled pores.

A modest amount of data on the movement of chemicals to plants has been published; however, in most cases the chemical was uniformly mixed into sieved soil. Very little is known about the movement of chemicals to plants when they are applied to the soil surface, particularly to soils having 'natural' structures. In our opinion future research must put more emphasis on the rate of herbicide movement to seeds, rhizomes, roots and emerging shoots under the range of moisture conditions encountered in the field and less on the relationship between equilibrium partition values and activity.

VERTICAL DISTRIBUTION OF CHEMICAL IN SOIL

Effect on Activity It has been clearly demonstrated in many laboratory experiments that the position of a chemical in soil can have a major effect on its activity. Germination inhibitors are clearly best concentrated in the zone where seed and buds on rhizomes and tubers are germinating. Chemicals which are absorbed by roots, particularly by the mass flow mechanism, are best concentrated in the seedling rooting zone; they can be almost inactive if they remain on the soil surface. Chemicals taken up by the basal parts of the shoots, or emerging shoots, are best concentrated in the top few cm of soil but are then at the mercy of rapid fluctuations in soil moisture content. Diffusion, particularly in the vapour phase, must be the main mechanism by which chemicals move towards the basal parts of shoots.

Due to practical constraints herbicides are normally applied to the soil surface; with a few herbicides this is followed by incorporation into the top few cm of soil. Incorporation is normally used to prevent the rapid loss of more volatile chemicals, such as trifluralin. In some cases it also increases the reliability of weed control. For example, incorporation of diallate reduces its loss by volatilization and may also increase its availability for uptake by the base of the coleoptile of wild oats (3). With chemicals which are absorbed mainly by roots some movement of surface applied chemical into the soil is essential for activity. Leaching by rain is normally relied upon to produce sufficient movement; the higher the K_d value the more rainfall is required. With chemicals which have K_d values less than 5, e.g. atrazine, 1-3 cm rain may produce sufficient movement, however with K_d values greater than 10 more than 5 cm rain may be required. Root acting herbicides with the larger K_d values are more variable in performance, activity depending on the amount and time after application, of rainfall. In theory chemicals which have very low K_d values (1 or less) may be easily leached below the seedling roots and consequently the availability of the herbicide greatly reduced. In practice leaching of such chemicals may somewhat reduce their activity, due to a dilution effect, but it rarely greatly reduces activity because a large amount of rain is required to leach the chemicals below the rooting zone. For a given amount of rain the depth of leaching under field conditions is normally less than expected from theoretical and laboratory studies, particularly when the herbicide is sprayed onto a dry soil surface (4).

Effect on Selectivity The selectivity of a herbicide between crop and weed can be affected by the position of the herbicide in the soil if the crop and weed tend to absorb the chemicals from different depths in the soil. For example a herbicide concentrated near the soil surface may control a surface germinating and rooting weed but may be relatively safe to a deep rooting crop. To obtain this spatial selectivity the position of the chemical in the soil has to be reliably controlled. Chemicals which are readily leached (K_d <3) are unsuitable. When several chemicals have similar intrinsic activity it is better to choose the one with the lower mobility, e.g. terbutryne rather than simetryne, ametryne, prometryne and methoprotryne for pre-emergence weed control in wheat (5); occasional poor weed control (due to insufficient leaching of chemical into soil) being preferred to occasional crop damage (due to leaching of chemical into crop rooting zone).

In practise spatial selectivity in soil can sometimes be used to enhance the selectivity of a herbicide with marginal intrinsic selectivity; however it cannot be used to turn one with no intrinsic selectivity into a reliably selective herbicide in the field.

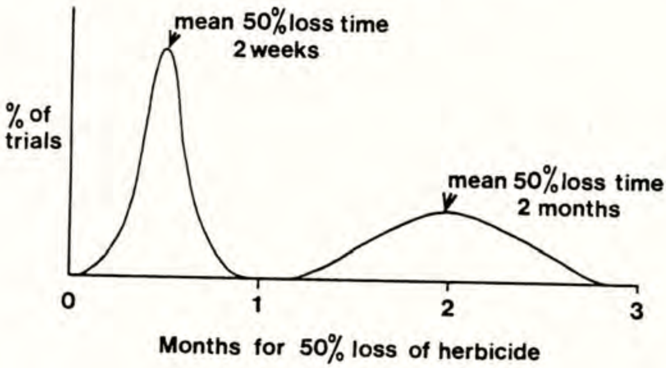
Effect of Formulation Formulation can be used to decrease or increase the rate of movement of chemicals in soil. Movement can be decreased by using slow release formulations, such as granules or capsules. However, as long as the chemical is inside the capsule or granule it is unavailable to the plant. In practice this causes an unaccceptable decrease in activity of the herbicide. Movement can be increased or decreased by the addition of surfactants. However the rates required to produce any appreciable effect appear to be uneconomic.

PERSISTENCE IN SOIL

In the glasshouse most screening tests for herbicidal activity are normally run for a period of only a few weeks. Often this does not adequately reveal the effect of the chemicals persistence on its long term availability, and thus activity. A soil applied herbicide must control weeds over a period of weeks or months because in the field weed seeds and rhizomes, etc. may germinate erratically over long periods. Herbicide application can not be delayed much after crop germination because weed competition may reduce yields; some herbicides may also damage the crop if it has emerged. Also, the sensitivity of weeds to soil applied herbicides decreases rapidly as they increase in size.

The persistence of a chemical in soil is dependent on many environmental factors, such as soil moisture content, temperature, microbial activity, adsorption and with some chemicals pH. Normally degradation is most rapid in moist (about 100 cm suction), warm (20-30°C) soil, which only weakly adsorbs the chemical (some pesticides degrade most rapidly under flooded anaerobic conditions). Although a chemical does not have a fixed time for loss of 50% it is important with all soil applied herbicides to do sufficient laboratory and field trials to define both the average and variability of its persistence under the conditions in which it will be used (Fig 3).

Fig 3. Variability of 50% loss time of two herbicides.



Attempts to predict the relative stability of various chemical functional groups in soil are useful to help design the persistence required. If a herbicide has too short a persistence a very high, uneconomic, rate of application is required to give longer term weed control. If the herbicide is too persistent it may damage following crops if they are sensitive to it. Also if a chemical is very persistent, average 50% loss time greater than six months, possible ecological effects would have to be considered very carefully before it was widely used. Almost all soil applied herbicides developed to date have average 50% loss times ranging from one week to three months. The persistence of a herbicide should not be too dependent on environmental conditions, otherwise weed control will be too variable. For example, the rate of hydrolysis of a herbicide should not vary greatly within the pH range 4-8.

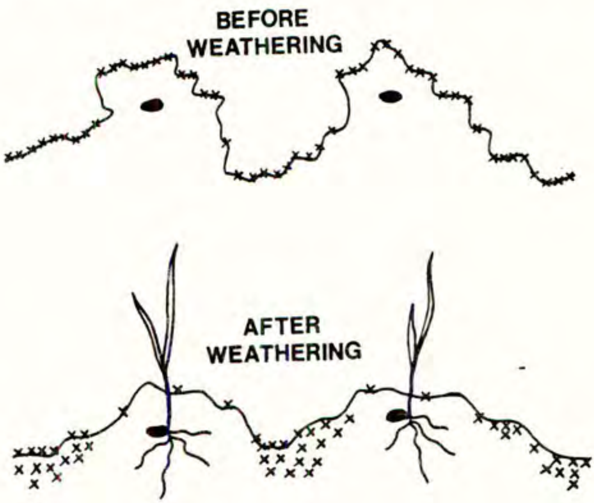
Effect of Formulation Formulation can be used to control the persistence of a chemical. Slow release formulation, such as granules are used to prevent the rapid loss of surface applied volatile herbicides such as dichlorbenil and triallate. Slow release formulation may also be used to increase the persistence of a chemical by protecting it from microbial degradation and/or chemical hydrolysis. Although difficult, this can be technically achieved. However due to the inevitable reduction in the initial activity of the herbicide and the extra formulation costs it is not used in practice. When more prolonged weed control is required it is more reliable and cheaper to either increase the rate of applications and/or to make repeat applications.

RATE OF APPLICATION AND DISTRIBUTION OF CHEMICAL OVER SOIL SURFACE

In efficiently executed laboratory and small field plot trials the rate of application is usually within 10% of the intended dose and the chemical is uniformly distributed over the soil surface. It is often forgotten that due to practical constraints, and in some cases poor spraying techniques, this is not always true in farmers field. It is difficult to avoid missing strips and overlapping sprays. It is almost impossible to achieve a uniform application on the headlands. In practice some farmers do not accurately adjust pumps, nozzles and boom height. Even when they are accurately adjusted the boom will bounce and tilt when driving over an uneven field. When a herbicide is incorporated by harrowing or rotavating this may increase or decrease the uniformity of chemical distribution across the field. The net effect of these factors is that under practical conditions the rate of application within a field varies several fold and this increases the variability of the herbicides activity and selectivity. On a microscale the distribution of the chemical across the field can vary 50 fold (6).

Horizontal redistribution of a chemical can occur during weathering of the soil surface, particularly when the soil surface is very uneven at the time of spraying. A diagrammatic example of this effect is shown in Fig. 4.

Fig 4. Horizontal distribution of chemical before and after weathering of sprayed soil surface.



After weathering the horizontal distribution of the chemical may be very uneven and some weeds may be exposed to relatively low doses of herbicide, particularly those growing from within large clods of soil.

DISCUSSIONS AND CONCLUSIONS

The main factors which modify the intrinsic activity and selectivity of a soil applied herbicide, when used in the field, are

(i) adsorption/precipitation of the chemical in soil
(ii) soil moisture content and structure
(iii) vertical distribution of the chemical in soil
(iv) persistence of the chemical in soil
(v) variability in application rate and horizontal distribution.

Adsorption/precipitation, persistence and movement of a herbicide are normally dominated by its molecular structure. Environmental factors which affect the activity and selectivity of a herbicide include, soil organic matter, clay and water content, soil structure (size, number and continuity of pores), soil pH and microbial activity as well as temperature and rainfall. No one of these variables dominates the others and all have to be taken into account when we try to explain or predict the effect of soil on the intrinsic activity and selectivity of a herbicide. Our ability to control these variables is extremely limited. Also no economic improvements in the activity and selectivity of soil applied herbicides have been achieved by formulation, with the exception of using slow release formulation to reduce volatilization of surface applied volatile herbicides. We can control the initial vertical distribution of herbicides, e.g. by discing them into the soil and their initial horizontal distribution by careful application to fine seed beds.

In practice the only way to make a major improvement in the availability of most soil applied herbicides is to modify their physico-chemical properties, i.e. by synthesising alternative molecular structures. However the possibilities for improving a chemicals behaviour in soil is severly restricted by the necessity of maintaining high intrinsic activity and selectivity. Finding a chemical with optimum soil behaviour and high intrinsic activity and selectivity is a rare event. Out of hundreds and thousands of chemicals screened world wide only about 100 have emerged as successful soil applied herbicides. Some of these have far from ideal behaviour in soil, e.g. some of the more volatile ones have to be incorporated. There is obviously much scope for improvement in soil applied herbicides.

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SOIL TEXTURE CLASSIFICATION FOR THE ADJUSTMENT OF HERBICIDE DOSE

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Summary The ADAS soil texture classification based on hand texturing is described and its use for recommendation of herbicide dose discussed. Studies on the adsorption of simazine by standard soils covering a range of textures support the validity of this texture assessment as a basis for adjusting herbicide dose on different soils.

Resumé Le système ADAS pour classer la texture du sol par le toucher à la main est décrit et l'usage de ce système pour la recommendation de la dose de l'herbicide est discuté. Des études sur l'adsorption de la simazine par les sols standards couvrant une étendue des textures supporte la validité de cette cotisation de la texture pour l'adjustement de la dose d'herbicide sur les sols differents.

INTRODUCTION

It is well known that the dose of many soil acting herbicides has to be varied according to soil texture. On light sandy soils crop damage will occur unless a relatively small dose is applied,while using a rate suitable for sandy soils on well bodied soils would result in poor weed control. Thus there is a need for a simple and quick but reliable system of soil classification to which herbicide dose can be related.

The dose required for effective weed control varies according to the adsorptive capacity of the soil and the recommended dose for herbicides such as simazine, lenacil and pyrazone increases with soil adsorptive capacity. Adsorption of many compounds is well correlated with organic matter content and tends also to increase with clay content. A knowledge of the organic matter content gives a better indication of adsorptive capacity than clay content but both of these determinations are time consuming and it is not very practicable to analyse soil from every field. Except in peaty areas like the Fens, soil organic matter content depends on cropping system. In ley-arable rotations, soils will tend to be higher in organic matter than those in all arable rotations, and organic matter will be particularly high in soils recently out of old grass. Under mainly arable cropping however, mineral soils tend towards an organic matter content which very largely depends upon the texture. A soil textural assessment should therefore be able to classify arable soils according to their organic matter content and hence adsorptive capacity and herbicide dose.

ADAS TEXTURAL SYSTEM

The ADAS textural system is based on the "feel" of moist soil moulded between finger and thumb. It is simple, quick, and easy to learn. It is widely used in advisory work for assessing the available water capacity, workability, stability and suitability for mole drainage of soils. There is an obvious advantage in using an already established and accepted system and experience has shown that it lends itself to the assessment of herbicide dose.

Soil textures are assessed using the following criteria:-

i) Soils which can be readily moulded into cohesive balls are "loams". This group is subdivided into sandy, silty, clay loams etc.

ii) Predominantly sandy soils are recognised by their grittiness. Sand is subdivided into coarse, medium, fine and very fine size grades.

iii) Predominantly silty soils are recognised by their smooth silky feel.

iv) Predominantly clayey soils are recognised by their capacity to take a "polish" when moulded and by the resistance of clods to deformation.

v) Organic soils - ie soils relatively high in organic matter but not high enough to be classified as peaty - are recognised by their colour and soft silky feel.

The textural system is a modification of a system developed in New Jersey and is distinct from the USDA system which is precisely linked to particle size analysis. The assessments using the ADAS procedure are subjective but the technique is easily learnt and, with experience, has satisfactory reproducibility. Although the USDA system, is more precise, the separations between textural classes are arbitrary and, in any case, soil surveyors and other users in practice do most of their assessments using a similar technique in the field with an occasional check by analysis.

The ADAS texture classification for mineral soils is given in Table 1.

Table 1

ADAS Soil Texture Classification

Coarse sand	CS	
Sand	S	Usually encountered only in subsoils
Fine sand	FS	
Very fine sand	VFS	
Loamy coarse sand	LCS	
Loamy sand	LS	
Loamy fine sand	LFS	
Loamy very fine sand	LVFS	
Coarse sandy loam	CSL	
Sandy loam	SL	
Fine sandy loam	FSL	
Very fine sandy loam	VFSL	
Loam	L	
Silty loam	Zyl	
Silt loam	ZL	
Sandy clay loam	SCL	
Clay loam	CL	
Silty clay loam	ZyCL	
Sandy clay	SC	
Clay	C	Usually encountered only in subsoils
Silty clay	ZyC	

TEXTURAL GROUPS FOR HERBICIDE DOSE

First Classification

In 1970 the ADAS textures were separated into four main groups, three of which were further divided into sub-groups (Table 2).

Table 2

First Classification of ADAS Textures for Herbicide Dose

Texture class	Sub group	Group
Coarse sand Sand Fine sand Very fine sand		Sands
Loamy coarse sand Loamy sand Loamy fine sand	Very light soils	Light soils
Loamy very fine sand Coarse sandy loam Sandy loam Fine sandy loam	Light loams	
Very fine sandy loam Silty loam	(Silts and warps)	Medium soils
Loam Silt loam Sandy clay loam	Medium loams	
Clay loam Silty clay loam	Heavy loams	Heavy soils
Sandy clay Clay Silty clay	Clays	

This classification has been used successfully for the purpose of matching herbicide dose to soil type. With some herbicides, doses have been varied according to the main groups only, whereas with others, finer distinctions have been made and a wider range of doses has been recommended to cover individual sub-groups (Fryer and Makepeace, 1972). For example, the dose recommended for simazine in maize varies from 1.12 kg/ha on light soils to 1.68 kg/ha on medium and heavy soils. A much wider range is recommended for lenacil in sugar beet, varying from 0.90 kg/ha on very light soils, 1.33 kg/ha on light loams, 1.82 kg/ha on silts and warps to 2.24 kg/ha on medium loams: sands and heavy soils are excluded.

Modified Classification

Experience in using the first classification and further information on soil organic matter contents in the textural groups has shown the need for some adjustments. Loamy coarse sands are no loger considered suitable for the safe and effective use of soil acting herbicides because of the variability of the soil within fields, their proneness to drought, and the relatively high mobility of herbicides in these soils under high rainfall conditions. Because of this variability and the difficulty of chosing a suitable dose, crop damage has been common in such fields. Loamy coarse sands have therefore been moved from the "very light soils" group to the sands. Similarly the coarse sandy loams have been found to be more appropriate to the "very light soils" group than the previous "light loam" group because of risk of crop damage. Finally the subdivision of the medium soil group has been eliminated and the silt loam transferred to the heavy soil group. This modified classification with appropriate clay percentages is shown in Table 3.

Most soil acting herbicides are marketed in several countries using different systems of soil texture classification. The USDA system is used in USA and some other countries so a comparison between ADAS and USDA systems would be of interest. Also shown in Table 3 therefore are the equivalent textures given by the USDA system. Use of the USDA system would result in a very different grouping of light and very light soils. Five ADAS textures fall into the USDA "sandy loam" texture and four ADAS textures fall into the USDA "silt loam".

Table 3

Modified Classification of ADAS Texture and Equivalent USDA Textures

ADAS Texture	Texture Group	% Clay	USDA Texture
Coarse sand		0	Sand
Sand		0	Sand
Fine sand	Sands	0	Loamy sand
Very fine sand		5	Silt loam
Loamy coarse sand		5	Loamy sand
Loamy sand		5	Sandy loam
Loamy fine sand	Very light soils	5	Sandy loam
Coarse sandy loam		10	Sandy loam
Loamy very fine sand		10	Silt loam
Sandy loam	Light soils	10	Sandy loam
Fine sandy loam		10	Sandy loam
Very fine sandy loam		20	Silt loam
Silty loam		20	Silt loam
Loam	Medium soils	25	Loam
Sandy Clay loam		25	Loam
Silt loam		30	Silty clay loam
Silty clay loam	Heavy soils	35	Silty clay loam
Clay loam		40	Clay loam
Sandy clay		40	Clay
Silty clay	Very heavy soils	50	Clay
Clay		55	Clay

ADSORPTION STUDIES

Recently the capacity to adsorb simazine has been determined using the method of Williams (1968) for the soils kept at Cambridge as standards for each textural group. The amount of simazine adsorbed by these soils from an aqueous solution of 3 mg/litre of simazine during 18 hours of end over end shaking at 20°C is given in Table 4. Each figure is the mean of three determinations.

Table 4

Adsorption of Simazine by Soils of Standard Textures

Soil texture	Simazine adsorption mg/kg of soil	Mean	Texture group
Loamy coarse sand	0.90	0.90	Sands
Loamy sand	1.00		
Loamy fine sand	2.18	1.74	Very light soils
Coarse sandy loam	1.84		
Loamy very fine sand	2.94		
Sandy loam	3.00	2.78	Light soils
Fine sandy loam	2.40		
Very fine sandy loam	4.10		
Silty loam	3.02		
Loam	3.82	3.52	Medium soils
Sandy clay loam	3.12		
Silt loam	3.30		
Silty clay loam	3.16	3.30	Heavy soils
Clay loam	3.42		

The adsorption studies showed that the amounts of simazine adsorbed by soils in the sand, very light soil and light soil groups were distinct from one another and from the medium and heavy soils. There was no distinction, however, between medium and heavy soils. Use of the USDA texture system resulted in as wide a range of adsorptive properties in the sandy loam group as in the ADAS "light" and "very light" soils combined. These results therefore support the validity of the modified textural classification as a basis for adjusting simazine dose on sands, very light, light and medium/heavy soils. They do not suggest that different doses are required for medium and heavy soils which is in line with current recommendations.

Acknowledgement

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