THE CONTRIBUTION OF TRIAZINE HERBICIDES TO INDUSTRIAL WEED CONTROL

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Summary. The present paper gives a review about mixtures of triazines with other herbicides for use in industrial weed control. Four new triazines GS 13528, GS 13529, GS 14254, GS 14259, are described as future candidates for industrial weed control.

INTRODUCTION

The most widely used herbicides for industrial weed control of the past, borates and chlorates, provided good weed control, but showed several disadvantages such as high doses to be applied, leaching, and in the case of sodium chlorate, fire hazard and corrosion of metals. Therefore it is not surprising that the interest in other chemicals for industrial weed control was very high and that in several countries chlorates and borates were replaced by newer herbicides among which the triazines have an important place. It will be the purpose of the present paper to review the development of the triazine herbicides as industrial weedkillers, to outline the present situation, and to describe recently developed triazines which may find some place in industrial weed control.

OLDER TRIAZINES

Among the triazine herbicides simazine, atrazine and prometone are the most important compounds for industrial use, either alone or in mixtures with other herbicides. As the three above mentioned triazines can be considered to be well known, it may be sufficient to recall only some of their fundamental features, which are essential for the understanding of the possibilities but also for the limitations of these triazines in industrial weed control:

Simazine (2-chloro-4,6-bis ethylamino-s-triazine, water solubility: 5 ppm)

- taken up by the roots, practically no activity on leaves
- good moisture conditions are necessary to activate the compound
- remains mainly in the surface layer of the soil, long residual effect against annual weeds
- weak activity on deep rooted perennials, e.g.: Taraxacum, Umbelliferae, Convolvulus, Equisetum, etc.

Especially to be applied where a relatively weed free area has to be kept clean; high safety factor when trees are present.

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine, water solubility: 70 ppm)

- activity through roots and leaves
- less dependent on soil moisture
- more effective than simazine on deeprooted perennials, e.g.: Convolvulus, Carex
- may cause selections of Setaria, Panicum, Vicia.

May be applied on already invaded areas; due to leaf activity more rapid effect than simazine.

Prometone (2-methoxy-4,6-bis isopropylamino-s-triazine, water solubility: 750 ppm)

- activity through roots and leaves
- may be leached into deeper soil layers
- phytotoxic against woody plants.

Very active herbicide with effect against normally triazine-resistant weeds as Cynodon Dactylon (high doses); useful in brush control.

The continuous use of these compounds may lead to a selected vegetation of surviving plants, which is typical of the herbicide used or gives rise to subsequent monocultures of specific plants, which, due to a certain tolerance to the applied herbicide, may invade the treated weed free area, thus spoiling a fundamentally good herbicidal effect. Typical of simazine treatments are selections of Convolvulus arvensis, Carex spec., Umbelliferae and other deeprooted perennials. Atrazine is known to prepare good growing conditions for Setaria spec. and Panicum sanguinale, which as monocultures spread over the originally weed free area. Typical survivors in methoxytriazine treated areas are Oxalis stricta or Galium aparine.

The tendency to build up resistant populations of survivors is not a feature of the triazines specifically but applies to all herbicides. Therefore, herbicide mixtures, composed of chemicals providing different spectra of activity are the answer to most of the problems in industrial weed control.

Thus during the past years a lot of development work was spent on composing mixtures and at present we may say that for example on railway tracks the triazines are mainly used in combination with other herbicides; the triazine component has long lasting effects against annual weeds, whereas the other partners have the purpose of enlarging the effect against triazine resistant plants or of increasing the initial effect.

The most important additives to triazines are aminotriazole and 2.4-D or other hormone-type weedkillers. Also dalapon may be useful. The final composition of such mixtures, i.e. the ratios of the different compounds must be adapted to the problem to be solved. Considering the wide variation of the vegetation to be controlled, it becomes obvious that a lot of different mixtures are necessary and it is impossible to answer in a general way the question, which herbicides are the best additives to triazines; it depends entirely on the type of vegetation. Thus a lot of mixtures of triazines with other herbicides have been developed and are in commercial use now or are still under development.

The most important commercially used mixtures may be summarized as follows:

1. Mixtures of Triazines

1.1. Atrazine + prometryne (mixture ratio 3 : 1)

- excellent effect against Setaria spec. and Panicum sanguinale
- better against Carex spec. than atrazine alone
- against established Umbelliferae not sufficient

Railway mixture used in Switzerland.

Other mixtures of chlorotriazines + methylthiotriazines are also possible.

2. Mixtures of Triazines with other Herbicides

In this group the triazine partner may be a mixture of different triazines itself, simazine and atrazine being the main compounds.

2.1. Triazines + aminotriazole + 2.4-D

- the triazines are dominant in this mixture

- generally good activity against grasses and broadleafed weeds
- not sufficient against Umbelliferae

Type of railway mixture used in Germany.

2.2. Triazines + Aminotriazole + 2.4-D

- aminotriazole is dominant

Special mixture against Equisetum.

2.3. Triazines + picloram + dalapon

- good effect against Carex spec. and Phragmites
- good effect against Setaria spec. and Panicum sanguinale

Railway mixture used in Austria.

2.4. Triazines + aminotriazole + dalapon + 2.4-D

Used on railways in Australia.

2.5. Atrazine + TBA + MCPA

Mixture used in England.

3. Special Mixtures

3.1. Triazines + bromacil + 2.4-D

- special mixture for areas invaded by Cynodon Dactylon and Sorghum halepense
- the triazine component is necessary to provide a sufficient residual effect.

3.2. Ametryne + 2.4-D

- very effective **against** **Cyperus rotundus**
- to this mixture simazine or atrazine may be added in order to provide a longer residual effect.

3.3. Triazines + borates
Triazines + borates + sodiumchlorate

- these mixtures are formulated as granules
- the main mixtures contain
  Atrazine (Atra-Bor 8P, Atratol 8P, Atratol 4P)
  Prometone (Pramitol 5P)

Used for industrial weed control in USA; effective against annual and perennial weeds, Cynodon Dactylon and Sorghum halepense included.

3.4. Triazine + aminotriazole + picloram + (2.4-D)

- this mixture is comparable with mixture 2.1., but contains in addition picloram (with or without 2.4-D)
- this mixture is superior to 2.1. as it is effective against Umbelliferae.

Doses

In order to give an idea about the ratios of the different components we give some general indications on the doses, calculated in kg a.i./ha:

Triazines	single or compositions of several compounds	5 - 10
Aminotriazole	normal	3 - 5
	special Equisetum mixtures	8 - 10

Dalapon	7 - 10
Bromacil	3 - 5
2.4-D, MCPP, 2.4.5-T	1 - 2
Picloram	0,5 - 1

The granules, mentioned under 3.3., are used at doses of 220 - 900 kg/ha final product or about 11 - 45 kg a.i./ha.

Compatibility

Wettable products containing triazines and dalapon are generally of a limited stability, as, especially in the presence of slight moisture already, a chemical breakdown of the herbicides may take place. It is recommended to keep the total amount of the herbicides as low as possible and to work with mixture ratios in favour of the triazines in such formulations.

NEW TRIAZINES

Among newer triazines the following compounds seem to be promising for different problems in industrial weed control:

GS 13528 2-chloro-4-ethylamino-6-sec. butylamino-s-triazine
(water solubility = 40 ppm)

GS 13529 2-chloro-4-ethylamino-6-tert. butylamino-s-triazine
(water solubility = 8.5 ppm)

GS 14254 2-methoxy-4-ethylamino-6-sec. butylamino-s-triazine
(water solubility = 620 ppm)

GS 14259 2-methoxy-4-ethylamino-6-6456. butylamino-s-triazine
(water solubility = 130 ppm)

As regards persistence under Swiss conditions (region of Basle) GS 13528 and GS 14254 are the least persistent (less than simazine or atrazine) whereas GS 13529 and GS 14259 are the most persistent (better than simazine, atrazine). (Table 1)

Table 1

Product	dose kg a.i./ha	Vegetation cover in % 11	22	133	403 days after treatment
GS 13528	5	70	7	20	90
	10	40	7	10	85
GS 13529	5	50	7	3	65
	10	40	2	0	3
GS 14254	5	30	7	80	90
	10	20	5	20	80
GS 14259	5	50	7	45	85
	10	30	4	2	3
simazine	5	60	7	4	95
	10	70	7	1	85
atrazine	5	40	4	5	95
	10	35	4	1	80

Original vegetation: covered appr. 100% of the surface and consisted mainly of Poa spec., Taraxacum spec., Trifolium spec.
Application on the 8th of July 1963.

Due to its relatively short residual effect, GS 13528 will have no place in industrial weed control as a single compound. However, it has proved to be an excellent additional triazine to simazine and atrazine in mixtures of the before-mentioned type 2.1. Its main advantage is to speed up the initial effect against grasses.

GS 14254 has a special value as an additional compound to the traditional triazines, as it shows specific activities against several problem weeds as Artemisia (Table 2), Setaria and Panicum species, and Cynodon Dactylon. Under Italian conditions GS 14254 at 20-30 kg a.i./ha gave a 100% kill of established Cynodon Dactylon, whereas with prometone the same result was only obtained with 50 kg a.i./ha.

Table 2

Effect on Artemisia verlotorum

Product	dose kg a.i./ha	herbicidal effect in % 52 days after treatment	138 days
GS 14254	5	40	85
	10	70	98
GS 14259	5	15	60
	10	40	85
GS 13528	5	10 - 15	45
	10	25 - 30	75
GS 13529	5	0	15
	10	< 5	20
simazine	5	5 - 8	15
	10	15	30
atrazine	5	35	45
	10	60	70
prometone	5	5	0
	10	35	75

Time of treatment: April 24th, 1965.
height of plants: approx. 10 - 20 cm.

Table 3 shows results obtained with GS 14254 and GS 14259 against a millet species, which served as a representative of the group of wild millets.

According to preliminary results GS 14254 and GS 14259 show also some promise in brush control. A timing experiment on Rubus spec. was very instructive as it showed up remarkable differences in activity of related compounds against this plant. GS 14254 has a similar good effect as prometone, whereas GS 14259 is distinctly inferior to the above compounds. In regard of time of application all the tested methoxytriazines provide a better final result when applied in March (before sprouting) compared to applications on fully developed plants. On the other hand we have indications that e.g. on Robinia Pseudacacia GS 14259 is more effective than prometone.

Table 3

Effect on millet

Product	dose kg a.i./ha	preemergence	postemergence
GS 14254	3	4	3
	1	3.5	2.5
GS 14259	3	4	3.5
	1	4	2
simazine	3	2.5	0
	1	1	0
atrazine	3	0.5	2.5
	1	0	2.5
prometryne	3	4	2
	1	3.5	2

rating: 0 = no effect
4 = 100% kill

The present experience with the four new triazines may be summarized as follows:

GS 13529 and GS 14259: In spite of the fact that the initial effect of these compounds starts only slowly, they are of special interest because of their long residual effect. Sufficient rainfall is necessary to activate these herbicides. The long lasting effect allows treatments in autumn and provides still good results during the following vegetation period. This is of special importance for regions with high rainfall in autumn and winter and low precipitations in summer (mediterranean region). GS 14259 is active against Setaria spec. and Panicum spec.

GS 13528 and GS 14254: These two triazines show a relatively rapid initial effect, but compared to simazine or atrazine a reduced residual activity. Both may have a place as components in mixtures with triazines providing a longer residual effect. GS 14254 is of special value, as it is very active against some problem weeds, as Artemisia, Cynodon Dactylon, etc.

GS 14259 seems to be promising as brush-killer.

There is hope that the one or the other of these new triazines may be able to fill gaps left by the herbicides used at present and that by mixing them with triazines or other herbicides, mixtures with wider spectra of activity may be composed.

"WEED CONTROL ON BRITISH RAIL"

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INTRODUCTION

Until 1955, British Rail's annual spraying programme depended upon the application of sodium chlorate (plus fire depressant), but the subsequent availability of the substituted ureas, triazines and uracils, has resulted in their commercial introduction in more recent years.

Having established that low rates of 3 to 4 lbs. diuron or atrazine/ac. would suffice to maintain high standards of weed control on deep, clean, stone ballast, it became necessary to discover the most effective answer to the more problematical resistant weeds existing in dirty ballast or on areas outside this position of the track. This paper illustrates how the selectivity of sodium chlorate can be advantageously combined with the above organic compounds to control such vegetation.

METHODS AND MATERIALS

Trials consisted of a minimum of three replicates arranged in randomized blocks, each plot being 10-15 square yards. Applications were carried out using a hand-lance fitted to a 4 stroke Villiers engine coupled to a ½" roller-vane pump. Treatments were applied in 80-100 gallons water/ac. over March-May.

Assessments made at the time of application, and at 1, 3 and 5 months after treatment were made by visual observations. Two factors were considered in each plot (i) area covered by grass, broad-leafed weeds and bare ground, allocated to a score of 10, 0 = no weeds, (ii) the vigour of grasses and broad-leafed weed each estimated on a scale 0 - 10. 0 = no vigour, 10 = fully vigorous. The stand of grasses and broad-leafed weed respectively, was derived from product of area covered x vigour. Tables show end of season assessments about 5 months after application.

In 1963, comparisons of diuron at 12 lbs. and 24 lbs./ac., atrazine at 10 and 20 lbs./ac., and bromacil at 4.8 lbs. and 9.6 lbs./ac. were made against diuron/sodium chlorate at 6.4/160 lbs., and 8/120 lbs./ac., and bromacil/sodium chlorate at 2.4/160 lbs. and 3.2/120 lbs./ac.

During 1964, cess trials aimed specifically at Taraxacum officinale (Dandelion) and Equisetum (Horsetail) involved the following treatments per acre : bromacil 5.6 lb 8.4 lbs. atrazine 11.375 lbs: 13.65 lbs. bromacil/sodium chlorate 3.2/120 lbs. 4.8/180 lbs. diuron/sodium chlorate 8/120 lbs. atrazine/sodium chlorate 6.5/120 lbs. bromacil/amino triazole/ammonium thiocyanate/fenac 3.2/4.5/4/1.8 lbs. 4.8/4.5/4/1.8 lbs./ac.

In 1965, a series of trials again designed to control deep-rooted resistant weeds concerned the application of bromacil 6.8 lbs./ac. bromacil/sodium chlorate 3.2/180 lbs. 4/140 lbs. and 5.6/60 lbs./ac. atrazine/sodium chlorate 8.125/140 lbs. ac. diuron/sodium chlorate 7.2/180 lbs./ac. bromacil/amino triazole/ammonium thiocyanate/fenac 3.2/4.5/3/1.8 and 3.2/6/4/1.8 lbs./ac.

Table 1.

Results of 1963 trials

Treatment	rate lb/ac.	Overall % control
Diuron	12	69
	24	78
Atrazine	10	88
	20	92
Bromacil	4.8	90
	9.6	93
Bromacil/sodium chlorate	2.4/160	98
	3.2/120	94
Diuron/sodium chlorate	6.4/160	98
	8/120	99

Table 2.

Results of 1964 trials

Treatment	rate lb/ac.	% control Taraxacum officinale	% control Equisetum spp.
Bromacil	5.6	50	57
	8.4	93	78
Atrazine	11.375	64	65
	13.65	68	61
Bromacil/sodium chlorate	3.2/120	80	75
	4.8/180	100	89
Diuron/sodium chlorate	8/120	71	45
Atrazine/sodium chlorate	6.5/120	71	76
Bromacil/amino triazole/ ammonium thiocyanate/ fenac	3.2/4.5/4/1.8	93	69
	4.8/4.5/4/1.8	71	74

Table 3.

Results of 1965 trials

Treatment	rate lb/ac.	% control Equisetum spp.	% control Convolvulus arvensis	% control Heracleum sphondylium	% control Overall
Bromacil	6.8	82	nil	63	74
Bromacil/sodium chlorate	3.2/180	94	98	84	94
	4/140	90	95	74	94
	5.6/60	84	58	74	89
Diuron/sodium chlorate	7.2/180	89	94	84	94
Atrazine/sodium chlorate	8.125/140	90	97	95	94
Bromacil/amino triazole/ ammonium thiocyanate/ fenac	3.2/4.5/3/1.8	43	3	nil	76
	3.2/6/4/1.8	75	nil	26	80

NOTE : A fire depressant was added to all mixtures containing sodium chlorate.

RESULTS

Tables 1 to 3 show the higher standards of weed control produced by mixtures and indicate the better efficiency of bromacil/sodium chlorate against Equisetum species. In addition to the weeds mentioned so far, the following difficult-to-kill weeds also frequent railway cesses and sidings in varying degrees of density: Potentilla (cinquefoil), Cirsium arvense (creeping thistle), Plantago (plantain), Senecio jacobaea (ragwort), Hypericum humifusum (St. John's wort). In all trials, mixtures produced better weed control against such resistant vegetation.

Aminotriazole combinations often appeared to be maintaining control 2 to 3 months after treatment, but deteriorated considerably after five months in September/October against Equisetum (horsetail), Convolvulus arvensis (bindweed) and Potentilla species (cinquefoils).

DISCUSSION

Timing of application is of considerable importance. The complexity of spray-train programmes necessarily means that some track must be treated before or after the optimum period of the year. This gives rise to the need for compromise, in that clean stone ballast would be treated in early spring by the application of a preventive treatment, while against most perennial weeds, especially late emerging Equisetum (horsetail), late spring/mid-summer application would be desirable. Traffic requirements however, generally result in a three month operation between mid-April and the end of June, where differential application of both straight residual-type compounds and "mixtures" are undertaken.

For the treatment of sidings, marshalling yards, cable runs, where both vehicular access and water supply presents an increasing difficulty, British Rail have acknowledged the advantages of granular formulations. On such sites there is frequently a much greater content of ash and soil in ballast and therefore a greater weed potential. Trials not reported here indicate that as in the case of spray applications mixtures of monuron at 10 lb/ac or bromacil at 4 lb/ac with sodium chlorate at 160 lb/ac give better results on deeprooted perennials than straight residual herbicides. On substantially weed-free sites granules giving 6 to 8 lb/ac monuron or atrazine and 2 to 4 lb/ac of bromacil are efficient as maintenance applications.

Collectively, three factors emerge, (i) that the principal deficiencies of sodium chlorate which are poor control of fine grasses and lack of autumnal persistence against seedlings, are effectively overcome by the addition of organic chemicals, (ii) that deeprooted weeds are more effectively controlled by mixtures containing sodium chlorate, (iii) bromacil and bromacil/sodium chlorate mixtures at lower rates per acre can be employed in the provision of high standards of weed control.

THE USE OF TOTAL HERBICIDES IN GERMANY

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Summary A general picture of the situation with herbicides in respect to total weedkilling in Germany is given. Mixtures of ureas, triazines, uracils with aminotriazole and/or phenoxycarboxylic acids are widely used. The remaining problems are some deeprooted hard to kill species, especially *Convolvulus* and *Equisetum*.

INTRODUCTION

For controlling weeds a large number of herbicides are now available which enable all problems relating to total or non-selective weed control to be solved. We basically distinguish between two groups of non-selective weedkillers, firstly the group of residual herbicides used for pre-emergence and early post-emergence applications, and secondly the group used for post-emergence applications comprising contact herbicides and translocated weedkillers which are primarily absorbed via the leaf. To achieve successful total weed control it is essential to be familiar with the prevailing vegetation and to have a good knowledge of the susceptibility of the different weed species to each active material.

Apart from obtaining eradication or prevention of all plant growth, it is generally desirable in non-selective weed control to gain a long residual action since repeated applications involve labour costs, but labour is scarce and the costs are most considerable. This desire for a long residual action can in principle be satisfied by a number of organic herbicides. Residual action, however, is usually a question of dose so that very often the realisation of desired persistence is foiled by a limitation of cost, at least in Germany. In this paper I wish to discuss only the application of herbicides on railway tracks and industrial premises.

CHEMICALS AND MIXTURES

The longest known single active ingredient to produce good herbicidal activity in applications to foliage and to the soil is sodium chlorate which also gives promise of developing a certain residual action. It is usually applied at a dose of 300 kg per hectare, which, however, must be raised to 500 kg per hectare for controlling deeprooted, perennial species. Most of the total herbicides marketed in Germany are based on sodium chlorate. In the last ten years there has been a decrease in the use of sodium chlorate, for which three reasons may be given:

1. Inadequate residual action is provided in very wet years;
2. the product is explosive in contact with organic material and the treated areas are readily inflammable;
3. sodium chlorate is a strong electrolyte.

These three disadvantages of sodium chlorate have been overcome by the development of herbicides belonging to the groups of substituted ureas, triazines and uracils, since,

1. the residual action of the new products is considerably better as they are very much less soluble in water;
2. all these products may be applied close to combustible materials, i.e. in timber yards, on the premises of oil refineries, and in munition and fuel depots where sodium chlorate cannot be used;
3. the biggest customer for total herbicides in Germany is the Federal German Railways who do not use strong electrolytes for weed control. The explanation

for the refusal of the Federal German Railways to allow electrolytes to be used is that when the railway network was rebuilt insulated rails were laid as conductors for the automatic operation of points and signals, especially in the area of large stations and yards. If strong electrolytes are used for weed control around these installations, and what is more at such high application rates per unit area as 300 - 500 kg per hectare, a conducting film carrying the current from the insulated rail to ground may form in wet weather thus producing a short circuit. This case seldom arises, but it did happen in Germany in the mid-1950's when all trains in and out of Cologne Central Station were completely held up for several hours because all signals were set at stop as a result of the short circuit. The railway tracks in the area had previously been sprayed with calcium chlorate so that in consequence the Federal German Railways directed that strong electrolytes should no longer be used for controlling weeds on railway tracks.

The development of organic herbicides very largely met the requirements of industry and the railways since these products, as just mentioned, did not possess the unfavourable properties of sodium chlorate. Although the prices were usually very much higher, customers were prepared to pay them to a certain extent on account of their advantages. Products based on only one active ingredient belonging to the groups of ureas, triazines or uracils require application at such high rates that they are too expensive to be marketed, and in addition it was very soon noted that they did not control certain weed species which then became capable of building up populations even though originally they only had been of minor importance in the initial vegetation. In our experience following applications of simazine and atrazine such species as Convolvulus, Urtica, Rumex, Taraxacum, Galium, Equisetum, Senecio and Ranunculus became established. We have also found that occurrence of Plantago, Taraxacum, Galium, Senecio, Convolvulus and Equisetum increases after application of diuron or monuron. Bromacil does not affect the growth of Campanula, Taraxacum, Rumex, Achillea, Galium, Equisetum, Ranunculus and Convolvulus. Apart from Convolvulus, Equisetum, Galium and Taraxacum, other species which practically survive applications of all products are Heracleum, Pastinaca and Lathyrus. It should, however, be mentioned that Equisetum is very severely damaged by bromacil when applied at rates exceeding 8 kg per hectare, with the result that its occurrence is appreciably reduced in the following year.

In order to eliminate these observed failings, combinations were developed comprising herbicides of varying spectra of activity. Contact and translocated herbicides were added to the residual herbicides mentioned above with the aim of obtaining a broad spectrum of activity. Combinations of different residual herbicides may also considerably broaden the spectrum although the fact should not be overlooked that the weed species not affected by the residual herbicides are often the same for each of these products. The most outstanding contact and translocated herbicides are aminotriazole, phenoxycarboxylic acids, diquat and paraquat. The development of these combinations which may be mixed in many variations brought several very important findings to light. Firstly, the combination of different active ingredients may add to the effect of each component; secondly, the two components of a combination may surpass the anticipated added effect of each active ingredient; thirdly, the components may interfere with each other's effect. Although of a positive nature, varying results are obtained in combinations of aminotriazole with ureas, triazines and uracils. We have experienced that the best effects are given by combinations of aminotriazole and triazines, especially simazine which is not absorbed by leaves. This synergistic action is not so good in mixtures of aminotriazole and diuron which also produces a herbicidal effect on absorption via the leaf with the exception of grasses. We found that combinations of aminotriazole and bromacil gave practically only an additive effect. We have the impression that in mixtures of aminotriazole and phenoxyacetic acids the components may interfere with each other's effect. We also observed such interference to be particularly great in mixtures of diuron and 2,3,6-trichlorobenzoic acid. It was noticeable that diuron was less effective against grasses, especially Festuca, even when applied at a very high dose of 30 kg per hectare. On the other hand, we noted that a triple combination containing aminotriazole showed no interference with the effect of diuron. When TBA was sprayed one year after grasses had been killed by a diuron application, it was not found to stimulate grass growth.

To give more detailed information on the value of mixtures Table 1 summarises ten trials with diuron and bromacil. The applications were made from the beginning of April to the end of May. The evaluations were made four months after application. Diuron and bromacil show different action in respect to the different plant species and the combination of both provides better results against grasses and shows a broader weed spectrum. The addition of aminotriazole gives only better initial activity. If bromacil is not used in the combination then diuron plus aminotriazole is superior to diuron alone on grasses and the failing against Taraxacum and Plantago might be overcome by adding 2,4-D to the mixtures.

Table 1

	kg/ha	% Dicotyledoneae	% Monocotyledoneae	Hypericum	Galium	Taraxacum	Plantago	Linaria	Achillea	Cirsium	Convolvulus	Campanula	Rumex	Ranunculus	Equisetum
diuron	8	17	15	+	+	+	+	+	+	+	+				+
bromacil	8	15	0		+	+		+	+	+	+	+	+	+	
diuron + bromacil	4 + 4	10	0		+	+		+	+	+	+				+
diuron + bromacil + aminotriazole	4 + 4 + 4	10	0		+	+		+		?	+				+
diuron + aminotriazole + 2,4-D	8 + 4 + 2	10	5	+	+			+			+				+

Figures show percentage survival. + indicates spp. present.

All these observations show that the value of combinations can only be proved by testing them on the vegetation, and that purely theoretical combinations may lead to unexpected failures. Apart from aminotriazole, the different phenoxycarboxylic acids are suitable for mixtures with residual herbicides. Another factor to be borne in mind is that applications of a mixture of residual herbicides, phenoxycarboxylic acids and/or aminotriazole cannot be timed for all components of the mixture to produce optimum effectiveness. The residual herbicides should be sprayed early in the season when the vegetation begins to grow, whereas the contact and translocated herbicides should be sprayed later during the vegetation season. Combinations are thus a compromise because two spray applications of different products are too expensive.

The following combinations of different composition are used in Germany for non-selective weed control: borates + monuron, triazines + aminotriazole, triazines + aminotriazole + phenoxycarboxylic acids, triazines + bromacil + phenoxycarboxylic acids, diuron + bromacil + aminotriazole, diuron + aminotriazole + phenoxycarboxylic acids, diuron + aminotriazole + bromacil + phenoxycarboxylic acids, triazines + phenoxycarboxylic acids and diuron + aminotriazole. Paraquat and diuron + bromacil are prepared by tank mixing. The triazine combinations undoubtedly have the biggest share of the market.

The effectiveness of combinations is, however, not the only reason for them being used, which becomes evident especially when a close look is taken at the doses recommended for their application. The Federal German Railways, a big buyer of total herbicide mixtures, have practically set a price limit on the treatment of a certain area, a measure which has had its influence also on other buyers. This development compelled the manufacturers to recommend dose levels for their products low enough to ensure that the price limit would not be exceeded. In consequence, a situation arose from the very outset whereby applications of total weedkillers were usually producing effects close to the borderline because for price reasons the doses were too low. Although the available combinations provide control for a certain period at the given doses, most products do not remain residually active for longer than 4-5 months. This often inadequate residual control is, however, a factor that is least difficult to accept. The grave consequence of this method is that certain weed species not held in check by the applied doses become widespread. On comparing the dose recommendations in the U.S.A. with those in Germany, it is evident that the U.S. doses have a wide range, whereas in Germany the dose ranges are very small or only one dose is recommended which roughly corresponds to the lowest U.S. recommendation. In the U.S.A. the recommended doses are 2 to 4 times higher than ours, so that fully effective control is obtained in the first treatment year. In the following year an application at lower dose will be adequate, or it may be found more expedient to use another active ingredient or other mixtures for the subsequent treatment. We have always found in our experiments that it is a suitable practice to carry out the first treatment at high doses and then to use other active ingredients for the subsequent application.

Since it has been the practice for many years in Germany to carry out weed control with products which in their action were only just satisfactory, we have observed that in consequence a weed flora has developed which now makes very high demands on all products. Some species, usually of the deep-rooted type, present a special problem, for example weeds belonging to the genera Equisetum, Convolvulus, Pastinaca, Carex, Anthriscus, Heracleum, Tussilago, Rubus, and, in some places, Pteridium. Higher doses of phenoxycarboxylic acids and picloram will help to control most of these species although the toxicity hazard by drift to neighbouring crops is not slight, especially vineyards, hop-cultures and sugar-beets.

APPLICATION TECHNIQUES

To comment briefly on the application technique employed by the Federal German Railways, it might be of interest to note that they originally used a volume of 10,000 litres of water per hectare for treating railway tracks. Following the introduction of organic herbicides, the sprayer tenders were converted to apply volumes of about 2,000 litres of water per hectare, with volumes of 1,500 or 3,000 litres occasionally being used. These relatively high volumes are disadvantageous especially for applications of contact and translocated weedkillers because the sprays are applied in large droplet sizes and at low concentration. As a result weed species that are difficult to wet copiously, escape destruction and gain growing space. For the commercial treatment of industrial premises and road verges the applied volumes usually vary between 500 and 1000 litres of water per hectare, which is much more suitable. We had an opportunity of observing for ourselves how unfavourable high volumes are in trials on Equisetum which we carried out with aminotriazole in 1965. Doses of 10 and 15 kg of aminotriazole per hectare sprayed at a volume of 400 litres per hectare gave good control by producing a 90% suppression of regrowth in the following year, whereas following application of 15 kg of aminotriazole per hectare at a volume of 2,000 litres per hectare regrowth the next year was found to exceed 50%. Each spray application was made at the same stage of

Equisetum growth with the fronds fully developed. This shows that very much also depends upon the employed spraying technique for a weedkiller to produce its optimum effect.

Certain weed species are still causing us much trouble in Germany. But to overcome this difficulty it is not a question of more effective active ingredients and suitable spraying techniques because they are available; on the contrary, it is simply a matter of cost. The practice will perhaps have to be adopted of carrying out several spray applications using different active ingredients for each treatment, otherwise the difficulties may only become worse.

WEED PROBLEMS OF LOCAL AUTHORITIES

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Summary New chemicals are becoming available in increasing numbers to the Local Authority surveyor responsible for the maintenance of roads and public amenities. Some of these chemicals can be safely used to improve visibility on roadsides. Others can be used to raise aesthetic standards and replace the general labourer to increase productivity. New devices, chemical and mechanical, reduce the risk of drift, allowing a wider choice of chemicals and situations which may be treated. Some chemicals have been tried experimentally mixed in asphalt; pre-surfacing use of others is recommended to prevent the break up of paths by weeds.

INTRODUCTION

Surveyors' problems

One of the responsibilities of Local Authorities is management of our main roads, streets, footpaths, public rights of way, and other civic and rural amenities.

Every Local Authority has a weed control problem which rapidly increases in importance as the cost of labour rises, and with the increasing difficulty of obtaining people to carry out the hard and unrewarding manual work which the traditional methods of weed control demand. At the same time the public expects high aesthetic standards.

The science of weed control is becoming increasingly complex. Surveyors, engineers, and responsible Local Authority officials are confronted with an ever-growing number of products, and the correct choice among the large number of herbicides available is complicated. Very often those faced with this problem cannot spare much time to familiarise themselves with the products and techniques available since weed control generally plays a relatively small part of their overall responsibilities, although it may occupy much of the time of the lengthman or labourer employed to do the work.

This paper is an attempt to outline some of the more important chemicals which may be used in this field, both those currently employed, and those new chemicals which show promise. In addition, some of the ways in which the pesticide industry in general is attempting to overcome the problems associated with total weed control in Local Authority situations are discussed.

SOME CHEMICALS USED FOR TOTAL WEED CONTROL

Historically, total weed control for roadside and fence line situations started with the use of sodium arsenite over 50 years ago; (1),(2), this was rapidly replaced by sodium chlorate, and sodium borates which do not present the major hazard of high mammalian toxicity. These chemicals are still widely used, both alone, and in mixtures. Sodium borate, being granular, is applied by hand or by mechanical spreaders. Sodium chlorate, which is still probably the most widely used chemical by Local Authorities, is fairly rapid in action, controlling many weed species by contact action, and because of its high solubility it effectively controls many deep-rooted weed species. It is, however, corrosive to many metals, and when mixed with dry organic matter can present a fire hazard, (3).

Contact, or foliar-absorbed, chemicals such as pentachlorophenol, the quaternary ammonium compounds (e.g. paraquat and diquat) as well as the so-called "hormone" herbicides (MCPA, 2,4-D, 2,4,5-T, TBA, picloram) tend to be quick in action, but not very persistent. Mixtures of some of these foliar absorbed and some types of residual herbicides have been tried successfully, (4),(5).

Drift outside the target area from contact or hormone type herbicides can cause malformation and damage to nearby flowers and shrubs, and thus limits application in rural and suburban situations.

The mainly contact type herbicides, such as paraquat, as well as sodium chlorate, are sometimes used to clean up an area of dense weed growth, which is then kept weed free by applications of residual type herbicides.

Modern total weed control started with the discovery of persistent residual type herbicides. The substituted ureas monuron and diuron, followed by the triazines simazine and atrazine, and more recently the uracils, have revolutionised industrial weed control. For the first time it became possible to effectively prevent weeds from establishing themselves, by making applications of these chemicals before the growing season started. Ureas at 5 - 30 lbs a.i./ac., triazines at $3\frac{1}{2}$ - 20 lbs a.i./ac. and uracils at $2\frac{1}{2}$ - 15 lbs a.i./ac. properly applied rarely give rise to drift problems.

Sodium chlorate is frequently used with a fire depressant at 100 - 150 lbs/ac. with 5 - 8 lbs/ac. of monuron or diuron. Diuron at 4 - 5 lbs/ac. plus 4 pts/ac. of formulated paraquat is said to be safe for use round some tree bases such as Cherry and Laburnum which are sensitive to sodium chlorate and other herbicides. The addition of MCPA or 2,4-D at 2lbs/ac. will improve the effect on some broad leaf weeds, although great care must be taken to avoid drift, and high volumes with low pressures are recommended.

Recent trials in the United Kingdom have shown that the spectrum of activity of simazine and its speed of action can be enhanced by the addition of aminotriazole (6). This mixture should show the same margin of safety for use on non cropped land to that of simazine alone which is widely used selectively among some shrubs, trees and crops at dosage rates of 1 - 5 lbs a.i./ac.

WHERE TOTAL WEED CONTROL IS REQUIRED. APPLICATION EQUIPMENT

Local Authorities require total weed control most frequently in the following situations :-

1. Kerb or channel edges alongside main roads to improve kerb-edge visibility.

2. "Grips" or gulleys carrying water away from kerb edges into drains.

3. Round roadside sign posts, site screens, crash barriers.

4. Presurfacing treatments beneath the formation layer of shallow excavations for paths receiving asphalt.

5. Footpath edges, expansion joints, wall footings and fence lines.

6. A variety of specialised situations such as car parks, municipal transport depots, storage areas, sewage farms, paddling pools, lakes, reservoirs, public gardens.

<u>Roadside Weed Control</u>

Road widths can be effectively increased economically by treating a 6 - 12 in. band with total herbicides to reveal the kerb or channel edge. This conclusion has been reached by surveyors who have observed the wheel markings on roads with treated and untreated verges.

Application costs would be about £1. 7. 6d per mile including plant, depreciation, fuel, and labour, for a surveyor using his own equipment. Chemical costs can be as low as £1.12. 6d per mile for a planned six year programme, including one year when treatment might not be required. Contracting costs are about £3. 0. 0d per mile per annum depending upon the site conditions. The cost per mile for this operation by hand has been estimated at about £12 - £18.

Equipment used in this situation may vary from knapsack sprayers charged from hand-propelled water carts, to converted fire engines. Specially designed equipment for quick temporary assembly on lorries has also been developed.

Footpath weed control

Footpaths, especially in suburban and rural areas, frequently demand satisfactory total weed control. It is still common to find a worker hoeing from one end of a village to the other, and then repeating the process throughout the summer months. Granules from easily applied hand dispensers or knapsack sprayers charged with the appropriate product can reduce this to a single, safe, simple, annual operation.

Mixing herbicides with asphalt

For some years it has been accepted that presurfacing treatments of herbicides should be made prior to the laying of the formation layer to take asphalt. Atrazine, chlorate and borates, as well as other herbicides, have been used with success to prolong the life of asphalt surfaces by preventing the emergence and growth of vegetation through the path.

Trials have shown the effectiveness of borates with sodium chlorate or TCA (7). Recently a greenhouse technique has been developed for evaluating herbicides in this situation.

Increasing interest is developing in the incorporation of herbicides in asphalt (8). A trial comparing prometone, Tritac, fenac, erbon, TCA ester and TCA sodium salt, against Bermuda grass (Cynodon dactylon) showed that prometone applied in asphalt gave the best control of all the treatments (9).

Chlorthiamid mixed with bitumen has also been tried in Holland, Italy, and Germany where preliminary results are said to be highly effective. Trials of this nature have reputedly been carried out with bitumen used in canals, reservoirs, and dykes, and in sealing compounds applied to the outside of underground pipes (10).

Other areas

Granules are best suited to "spot" application in areas such as roadside gulleys, round roadside signs, and fence lines. While chest-mounted granule spreaders are more convenient for larger areas, small "pepper pot" dispensers are most suited to spot application. Flail grass cutting equipment dispenses with the need for gangs of labourers to cut and remove dead grass. However, the flail operator has to dismount from his tractor and cut round each road sign to maintain the effect, and thus blocks the road with a stationary vehicle. Soil sterilization round road signs and crash barriers allows continuous flail operation.

Where continuous application has to be made, such as along wall footings, footpath edges and between expansion joints, pressurised knapsack sprayers are sometimes used in combination with a water tender.

Suitable equipment must be provided for the chemical to be used. With insoluble wettable powders large equipment must have a pump to provide continuous agitation: corrosive chemicals need suitably protected sprayers. Some chemical companies specialising in products for Local Authority weed control hire out suitable equipment.

Probably the most satisfactory answer to total weed control problems for many authorities is to employ reputable contractors who are familiar with the most suitable chemicals, and have application equipment to do the work at the right time.

FORMULATIONS

The efficiency of a herbicide depends upon its formulation.

Granules

Root-acting chemicals, when well-formulated as dust-free granules, are probably some of the safest for use in built-up areas near flowering plants and ornamental shrubs. Mainly root-acting chemicals, such as atrazine, tend to be slow in action, although they can give a season's weed control.

Sprays

Sprays may be true solutions of soluble chemicals such as aminotriazole, or they may be wettable powders applied in suspension; or, alternatively, they may be mixtures of wettable powders and soluble chemicals suitably formulated. Examples of the latter are (i) sodium chlorate, monuron and 2,4-D, and (ii) MCPA, TBA and atrazine. In each case, the mixtures contain two basically different types of chemical, a soluble and mainly foliar absorbed part, and a residual or persistent component. Such formulations combine the merits and limitations of their constituent parts.

NEW METHODS IN DRIFT CONTROL

Equipment

Developments are taking place to reduce the risk of drift, therby broadening the choice of chemicals and the situations in which chemicals can be applied safely.

Dribble bars, which show promise in drift control, produce a similar distribution to that of a watering can rose. Vibro booms, and Vibro nozzles are adaptions on this theme to improve the distribution of a coarse spray and at the same time retain drift. Flood jets and wide angle nozzles, which apply a coarse spray at low pressure and thus cause little bounce, can prove useful in treating pavement areas.

Additives

Hydroxyethylcellulose is an anti-drift additive which thickens the spray, thereby reducing the formation of satellite droplets. The herbicidal properties of some chemicals have been shown to be unaffected by this material.

Studies have been carried out in North America and in this country to evaluate the safety of hydroxyethylcellulose for roadside application of hormone materials (11). Other materials used to reduce drift include sodium alginate, particulate spray, and invert emulsions. All these materials have been evaluated using wind tunnel techniques in the U.S.A. (12).

These additives when suitably incorporated at low concentrations alter the viscosity of the spray. This helps the formation of uniform large droplets, thereby preventing the active ingredient from being carried outside the target area in small droplets.

These materials have been developed from the continued search by the pesticide industry to solve the problems of weed control in industry and Local Authority situations. Similarly research has led to new chemicals which may find a place in this field.

NEW CHEMICALS

The following four chemicals are new herbicides in the industrial herbicide field. Whether or not some of them will find a place in the Local Authority field has yet to be determined.

Chlorthiamid in 7½% a.i. granular form is recommended for total weed control at doses of 220 lb for 6 - 8 month weed control and 275 lb for 12 months and over (13). This chemical is active against some of the deeper rooting perennial weeds such as horsetail (*Equisetum* spp.), dandelions (*Taraxacum officinale*), docks (*Rumex* spp.), and ground elder (*Aegopodium podagraria*). It can therefore be used with success in areas which have previously been treated with low dosage rates of residual type herbicides where these troublesome weeds have survived.

Picloram is active against many woody and herbaceous species when sprayed on the foliage at ½ to 2 lb/ac. Problem industrial weeds such as creeping thistle (*Cirsium arvense*) and bindweed (*Convolvulus arvensis*) have been controlled at rates from 1.3 to 4.0 lb/ac.(14). Granular formulations with borates have been developed in the U.S.A. for rangeland weed control.

Organic Arsenicals of relatively low mammalian toxicity are being developed in the U.S.A. where they are recommended as non-selective herbicides for use along roadways, ditches etc.(15). Their speed of action is fast; activity against some deep-rooted and rhizomatous grasses by some of these chemicals, including monosodium methanearsenate, is said to be high (16).

1,1-dimethyl-3-(3-*t*-butyl-carbamyloxy)phenyl urea is an experimental herbicide for soil sterilization and brush control. Woody weeds, including hardwoods and coniferous species, are said to be controlled. Doses are reported to vary from 4-6 lb of the 80% material to 15-25 lb for residual control of perennial weeds with underground rootstocks (17).

CONCLUSIONS

The search by the pesticide industry for new chemicals and safe means of using them is an intensive one. However, the higher productivity which these chemicals and techniques offer can only be achieved by the interest and collaboration of Local Authorities in their development and introduction for use.

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SPRAYING OF ROADSIDE VERGES:
LONG-TERM EFFECTS OF 2,4-D AND MALEIC HYDRAZIDE

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Summary Changes in the vegetation of roadside verges brought about by 2,4-D and maleic hydrazide (MH), singly and in combination, have been assessed relative to unsprayed control plots over a period of nine years. Rates of reversion after cessation of spraying have also been studied.

An annual spray in spring of MH + 2,4-D resulted in a short vegetation almost free from dicotyledonous plants and increasingly dominated by *Poa pratensis*. Coarse tufted grasses such as *Arrhenatherum elatius* progressively decreased. Use of MH alone led at first to grassy non-flowering short swards with abundant *Festuca rubra* and *Poa pratensis*, but after several years some dicotyledons increased and many invaded the plots. Treatment with 2,4-D alone ultimately gave a grassy sward of reduced height, with an increased proportion of *Festuca rubra* and *Poa pratensis* and with decreased amounts of *Arrhenatherum elatius*.

Reversions followed characteristic patterns, dependent on the composition of the vegetation when spraying ceased.

INTRODUCTION

Although the selective herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) and the growth regulator maleic hydrazide (MH) are in widespread use as sprays for the control of vegetation, information is sparse concerning the ecological effects of continued spray treatment over a prolonged period. To investigate the changes in the composition of the vegetation of sprayed roadside verges a series of experimental plots was established, a range of spray treatments applied, and the vegetation assessed from 1958 to 1966.

The results obtained over the first three years, and reported by Yemm and Willis (1962), show the extensive changes brought about by 2,4-D and MH as single sprays and by MH and 2,4-D in combination. Apart from the expected effects of 2,4-D on the dicotyledonous plants, and of MH on the height of the vegetation, substantial changes in the proportions of various grasses were found. The more recent observations throw further light on these trends and provide information on the characteristic communities ultimately developed under the various spray regimes.

The study has been extended by the cessation of spraying in some plots to establish the rates of reversion of the different ecosystems created as a result of spray treatment.

METHODS AND MATERIALS

The experimental site was the wide verges of Akeman Street, near Bibury, Gloucestershire, situated on the Oolite of the Cotswolds at about 460 ft above sea level, and with an annual rainfall of approximately 30 in. A series of 28 plots was marked out (approx. 22 yd long and 3 - 5 yd wide) in an area of fairly uniform vegetation; permanent quadrats of 0.5 m^2 were also established in each plot. Assessments of relative bulk of the different components of the vegetation of the quadrats and of the whole plots were made in spring, summer and autumn during the first three years of the investigation, but subsequently during the summer (July) only. Details of the subjective scoring procedures which showed very close agreement between the quadrat assessments and the "general" scores made on the whole plots are given by Yemm and Willis (1962).

Nine plots (with 3 controls) were sprayed with MH only, nine (with 3 controls) with MH + 2,4-D and two (with 2 controls) with 2,4-D only. Plots were sprayed once a year during early April, mid April or early May; however, it was found that these differences in time of spraying, although affecting the height of vegetation during spring and early summer, did not lead to appreciable differences in the floristic composition, so the results may be considered together.

Spraying was carried out by means of a boom fitted with cone-type nozzles for high volume application at low pressure. A commercial preparation of MH was applied, the dilute spray containing 5 lb MH as the amine salt in 80 gal water per acre. The 2,4-D spray was an acid-in-oil emulsion containing 12.5% wt./vol.2,4-D; a commercial preparation was used at 3 gal in 80 gal water per acre. MH + 2,4-D was a mixture of the two preparations* at the above rates.

RESULTS

The vegetation of the verges

The normal vegetation was a rough sward forming a closed community dominated by Arrhenatherum elatius and Dactylis glomerata. Grasses together made up more than half of the vegetation in most of the control plots, as shown in Tables 1 - 3. The finer-leaved rhizomatous grasses Festuca rubra and Poa pratensis were widely and fairly uniformly distributed but nowhere constituted a major part of the vegetation.

Of the wide range of dicotyledonous plants in the verges, the most widespread and abundant were Heracleum sphondylium and Anthriscus sylvestris. Also conspicuous were Cirsium arvense, Convolvulus arvensis, Stachys sylvatica and Urtica dioica. The many other plants present in smaller amounts have been listed by Yemm and Willis (1962).

Only minor variations in composition from year to year were found, no trends of change being detected. The average height of the vegetation, which flowered freely, was about 90 cm in July.

Effects of MH

A single annual spray of MH resulted in a short non-flowering sward in which Festuca rubra became increasingly plentiful. Even after the first spray treatment in 1958 the quantities of F. rubra and Poa pratensis were more than doubled whereas there was a marked decline of Arrhenatherum elatius and Dactylis glomerata. For the first three or four years the proportion of grasses to dicotyledons did not change much, but subsequently there was an increase in dicotyledons, largely due to the progressive rise of Plantago lanceolata and Galium cruciata, to the spread of Cirsium arvense, and to the invasion of the area by numerous low-growing annuals such as Veronica persica, Stellaria media and other weeds characteristic of arable land. However, Anthriscus sylvestris was almost eliminated, and Heracleum sphondylium reduced.

As Table 1 shows, there was a progressive decline of Agropyron repens, Arrhenatherum elatius and Dactylis glomerata and, after 1960, also of Poa pratensis, although this was favoured at first. By 1966 Festuca rubra made up over one-third of the total vegetation and nearly 80% of the grass population.

Flowering of grasses was considerably reduced, only few inflorescences developing in some seasons. The vegetative growth of the grasses was also much retarded, so that the average height of the vegetation was short compared with

* The proprietary products 'Regulox' and 'Vergemaster' were employed.

that of the control plots except where Cirsium arvense became widespread. The mean height of the sprayed vegetation in July 1958-1966 was only 36 cm, less than half that of the control areas. Plots sprayed in early April had made very little growth at the time of spraying, but those sprayed in early May had already made appreciable spring growth. These differences were apparent in the longer sward of the late-sprayed areas in May and June, but subsequently the differences evened out because of the resumption of growth by the early-sprayed vegetation while the late-sprayed areas were still checked.

Table 1.

The effects of MH on floristic composition

The figures give percentage relative bulk of the chief components and are averages of the assessments of the whole plots ("general" scores) in July 1958 - 1966. The mean values for the control plots for the whole period are given together with the Standard Errors of the means.

	Controls	Sprayed with MH annually							
	1958-66	1958	1959	1960	1962	1963	1964	1965	1966
Agropyron repens	7.7±0.5	9.3	9.9	8.4	6.0	3.4	1.2	2.5	3.0
Arrhenatherum elatius	27.3±1.4	17.0	13.2	3.9	1.7	3.7	0.7	3.0	1.7
Dactylis glomerata	10.9±1.6	5.8	6.6	2.8	3.3	1.0	3.8	1.3	1.7
Festuca rubra	7.6±0.8	19.6	15.8	29.4	35.0	32.0	25.4	30.0	40.0
Poa pratensis	4.6±0.4	13.6	11.1	15.6	8.3	6.4	5.0	1.8	1.7
Total grasses	65.2±2.3	66.2	57.1	60.1	56.8	48.2	38.3	40.0	52.5
Anthriscus sylvestris	4.8±0.9	2.8	4.3	0.3	0.7	0.1	0.1	0	0
Cirsium arvense	3.0±0.5	4.4	8.0	8.2	6.6	8.7	8.0	1.3	0.5
Galium cruciata	0.5±0.1	3.1	4.3	8.2	6.0	6.7	2.2	27.5	10.0
Heracleum sphondylium	8.6±1.5	3.6	4.1	1.0	1.8	4.8	2.7	2.5	0.5
Plantago lanceolata	0.5±0.1	0.9	3.0	3.2	10.3	12.6	30.0	10.0	12.5

Effects of MH + 2,4-D

The combined spray resulted in the reduction and ultimate extinction of most of the dicotyledonous plants and the development of a thick cover of Poa pratensis. The changes in the major species are given in Table 2, which shows the continued rise of grasses and loss of dicotyledons. After spray treatment for nine years in succession grasses made up more than 90% of the vegetation, Convolvulus arvensis and Calystegia sepium being the only dicotyledonous plants remaining in substantial quantities, escaping the effects of the spray by their late development. The umbellifers Anthriscus sylvestris and Heracleum sphondylium were rapidly reduced, as well as Cirsium arvense. In contrast to the action of MH alone, where the diversity of the vegetation increased, the combined spray resulted in a sward with few species represented and with Poa as a very strong dominant. This grass increased markedly even after one spray application, and by 1966 made up more than two-thirds of the total vegetation. In some areas it formed a pure stand. On the other hand Arrhenatherum elatius was quickly diminished almost to the point of elimination, together with Holcus lanatus and Zerna erecta; the last two species were, however, nowhere abundant initially. Dactylis glomerata and Agropyron repens were less susceptible to the spray but were gradually and significantly reduced. Festuca rubra was favoured, especially in the first year, but did not increase subsequently when in strong competition with Poa pratensis.

There was a very pronounced reduction in flowering and in height of the vegetation, which was on average only about 28 cm in July, less than one-third that of the control plots.

Table 2.

The effects of MH + 2,4-D

The table is constructed as Table 1.

	Controls	Sprayed with MH + 2,4-D						
	1958-66	1958	1959	1960	1962	1963	1964	1965	1966
Agropyron repens	7.0±0.8	5.3	2.8	8.3	3.7	3.7	2.3	1.5	2.4
Arrhenatherum elatius	18.2±2.3	3.1	1.6	0.9	0.8	2.3	1.2	1.0	1.0
Dactylis glomerata	13.1±1.3	5.4	13.4	5.9	7.9	11.7	6.8	3.4	3.8
Festuca rubra	1.3±0.2	10.9	9.9	9.1	9.3	5.3	3.9	5.2	10.0
Poa pratensis	4.5±0.9	43.7	44.8	57.1	55.8	58.3	73.7	72.5	73.3
Total grasses	47.1 ±3.2	73.9	74.9	81.9	80.0	80.8	88.7	84.6	92.5
Anthriscus sylvestris	4.5±1.0	0.9	0.3	0.3	0.1	0.1	0.1	0.1	0
Heracleum sphondylium	16.6±2.2	10.7	2.0	0.9	0.8	0.4	0.1	0.1	0.1

Effects of 2,4-D

Information on the effects of 2,4-D alone is more limited than for the other series, as spraying did not start until 1959 and only two replicate plots were treated. Nevertheless the results indicate appreciable changes in the proportion of the various grasses as well as the expected reduction in the population of dicotyledonous plants.

The main effects are shown in Table 3. After a single spray dicotyledons were reduced to less than one-fifth of the vegetation. Among the grasses the most striking changes were the decline of Arrhenatherum elatius and the increase of Festuca rubra and Poa pratensis. However, these trends were not so marked as in the other spray treatments.

Although flowering was not much affected by 2,4-D, the average height of the vegetation (57 cm, July 1959 - 1966) was considerably below that of the controls. This was largely due to the reduction in height, flowering and quantity of Arrhenatherum elatius.

Table 3.

The effects of 2,4-D

The table is constructed as Table 1.

	Controls	Sprayed with 2,4-D						
	1959-66	1959	1960	1962	1963	1964	1965	1966
Agropyron repens	3.5±0.8	7.5	3.0	10.0	7.5	3.8	1.8	8.7
Arrhenatherum elatius	17.3±1.4	25.0	20.0	22.5	16.3	10.0	3.8	5.0
Dactylis glomerata	10.0±1.4	17.5	15.0	15.0	15.0	25.0	13.8	25.0
Festuca rubra	5.1±0.7	7.5	7.5	5.0	12.5	17.5	15.5	17.5
Poa pratensis	3.7±0.6	7.5	22.5	15.0	15.0	27.5	41.2	20.0
Total grasses	54.6±1.7	77.0	82.5	80.0	82.5	93.7	90.0	85.0
Anthriscus sylvestris	3.6±0.8	1.0	1.0	0.5	1.3	0.5	5.0	4.2
Heracleum sphondylium	14.5±1.3	20.0	5.0	0.5	1.7	0.1	0.5	0.5

Reversion after spray treatment

Three plots sprayed with MH annually for four years were not sprayed after April 1961. Here reversion led to a somewhat higher proportion of grasses, the progressive loss of Festuca rubra (from 29% in 1960 to 10% in 1966), and a substantial increase in Arrhenatherum elatius (from 4% in 1960 to 22% in 1966). The re-establishment of a tall vegetation with large tufted grasses resulted in the suppression of Plantago lanceolata, Galium cruciata and the numerous low-growing dicotyledonous plants which had invaded the plots during the period of spray treatment. Free flowering of many of the species was noted in the year when spraying ceased, but heights were below average during the early stages of reversion.

Reversion after a spray regime of MH + 2,4-D led to a vegetation in which dicotyledons gradually increased. Some species, however, did not quickly re-establish such as Anthriscus sylvestris and Heracleum sphondylium which remained in small quantity until the fifth year of reversion as shown in Table 4. Cirsium arvense spread rapidly, and rhizomatous species, such as Stachys sylvatica, soon grew into the plots from the adjoining hedge-banks. Arrhenatherum elatius and Agropyron repens increased fairly uniformly from traces which survived the spraying, and Poa pratensis declined from its position of strong dominance to less than 10% of the vegetation in 1966. Only after reversion for five years did the composition of the vegetation closely approach that of the normal untreated verges. As in the reversion plots previously sprayed with MH, free flowering occurred in the year when spraying ceased, and the height of the vegetation fairly soon increased to that of the controls.

Table 4.

Reversion after treatment with MH + 2,4-D

The percentage relative bulk of the chief components of the vegetation are given; the values are means of assessments for the whole plots (three replicates). The plots were sprayed with MH + 2,4-D from 1958-1961, and then allowed to revert. The July records are listed.

	1962	1963	1964	1965	1966
Agropyron repens	2.3	4.5	5.8	6.7	8.3
Arrhenatherum elatius	2.8	5.3	11.7	12.5	17.5
Dactylis glomerata	5.8	9.2	16.7	14.2	8.3
Festuca rubra	4.2	4.0	3.7	4.5	2.0
Poa pratensis	61.7	45.0	25.8	18.3	9.2
Total grasses	78.3	66.7	65.0	58.3	46.7
Anthriscus sylvestris	0.7	0.1	0.7	0.7	3.4
Heracleum sphondylium	0	0.1	1.0	1.2	8.5

DISCUSSION

The quickest and most obvious effects of MH are the suppression of vegetative growth and the inhibition of flowering. Many workers since Deysson and Rollen (1951) have shown the suppression of mitosis and cell division by MH as well as chromosome breakage. Plants whose growing points are freely exposed may be expected to be more susceptible to the action of MH than rhizomatous forms where the underground buds can be reached only by appreciable translocation. This difference may in part account for the greater adverse effects of MH on the tufted grasses Arrhenatherum elatius and Dactylis glomerata than on Festuca rubra and Poa pratensis which fairly quickly recover from the effects of spraying. The tussock form and wide leaves of Arrhenatherum elatius and Dactylis glomerata probably also result in more extensive catching and absorption of the spray materials.

The adverse effect of MH especially on the large coarse grasses results in the formation of bare areas which are exploited not only by the finer-leaved grasses, but also by many dicotyledons developing from seeds blowing into the plots. Their success is enhanced by the reduced competition from the short grasses. A number of perennial dicotyledons, such as Anthriscus sylvestris and Rumex spp., however, are sensitive to MH and decline.

Suppression of flowering by MH is well known, development of floral buds being inhibited. However, most grasses were flowering freely some 15 months after spraying ceased, especially Festuca rubra and Poa pratensis. Resumption of flowering in the field appears more rapid than that found by Yemm and Willis (1962) under greenhouse conditions.

With the combined spray MH and 2,4-D, the selective herbicide results in the suppression of the broad-leaved plants and the fine-leaved rhizomatous grasses gradually extend into the bare ground created by the loss of the dicotyledons and of the coarse grasses. The more rapid spread of Poa pratensis than of Festuca rubra leads to the development of a thick sward after a few years, in which flowering is inhibited and vegetative growth suppressed largely by the action of MH. Some suppression of growth is, however, brought about by the 2,4-D acid-in-oil emulsion itself as well as certain small and relatively slow changes in the proportion of the grasses. The most notable effects on the composition of the vegetation were the reduction of Arrhenatherum elatius and the favouring of Festuca rubra and to a greater extent of Poa pratensis. The more extended records now available support the earlier suggestion (Yemm and Willis 1962) that Festuca is more sensitive to 2,4-D than Poa.

The rather slow rates of reversion in the MH + 2,4-D series of plots are not unexpected in view of the thick mat of Poa pratensis developed after spray treatment for several years. Conditions for seedling establishment in the dense sward are difficult and probably account for the delayed return to the normal vegetation of the control plots which is substantially richer in species. Only after about four years of reversion do the dicotyledonous plants re-establish in appreciable amounts, although Arrhenatherum elatius and Dactylis glomerata increase gradually from the time spraying ceases. These tall grasses spread from the small quantities which survive spray treatment, and only to a very minor extent from seedling development. Competition of the tall tussock formers with the low-growing Poa pratensis leads to its progressive and uniform decline.

Reversion of the very different type of vegetation resulting from the MH spray is contrasted in several respects, notably in the reduction in the number of species present and in the progression to a sward richer in grasses. Cessation of MH treatment leads to taller growth of the grasses and to the increase especially of Arrhenatherum elatius with the consequent decline of many of the low-growing annuals which are eliminated by competition.

Acknowledgments

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CHEMICAL CONTROL OF JAPANESE KNOTWEED

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Summary Japanese knotweed (Polygonum cuspidatum Sieb. and Zucc.) which grew annually to 8 ft in a dense stand was not controlled by a 2,4,5-T/2,4-D mixture applied in water or diesel oil, but was by a single foliar spray of picloram as the K salt at 3 lb a.i./ac applied in June. A dense sward of grasses became established within a year.

A foliar spray of bromacil at 24 lb a.i./ac severely weakened the stand and when repeated the following year gave complete control. Residues persisted in the soil and prevented the development of vegetative cover for over 16 months.

Granular formulations of either picloram or bromacil applied in June were not as effective as sprays.

INTRODUCTION

Japanese knotweed is a herbaceous perennial, which produces dense stands of annual shoots, often 9 ft tall. Since its introduction in 1825 it has spread to waste ground in many towns and in railway cuttings. At Bristol an infestation developed in 1960 on made-up ground resulting from the construction of 'hard' tennis courts on a steeply sloping site adjacent to a new University hostel. By 1962 roots and shoots were obstructing the drainage system and were causing cracks in the concrete paths and tennis courts.

Fleshy turgid erect shoots emerge in March and by April may be a foot high and about an inch in diameter with small inrolled leaves. Less vigorous shoots are more horizontal, cranked at the nodes, bearing fully expanded heart-shaped leaves. The most vigorous shoots reach about 4 ft by May, 6 ft by June, 8 ft in July and up to 10 ft by the end of the season. They usually arise near the base of those of the previous year, so that eventually a culm is produced. Other shoots are produced from buds on the extensive rhizome system. Rhizomes may be ½ in. to 2 in. in diameter, fleshy to woody and are recorded spreading 15 - 20 ft laterally (Pridham,1966). The true roots also become woody and on this stoney site penetrated to depths of more than 3 ft.

Due to the nature of the ground the network of roots and rhizomes could not be grubbed up satisfactorily. The stems were easily brashed down in May, but only died completely if severed from the culms. Many produced side shoots 5 ft high within a month, and though brashing was repeated, by the end of the season there was complete cover 4 ft high. Similar treatment the following year produced no noticeable reduction in vigour. Hence in 1962 chemical methods of control were commenced using amitrole T, and a 2,4,5-T/2,4-D mixture applied in water or in diesel oil. More recently bromacil and picloram were applied as sprays or as granules. Of the materials tested only foliar sprays of bromacil or picloram applied in 1965 provided a satisfactory control: particulars of these trials are now described.

METHOD AND MATERIALS

About 400 square yards were infested but the fragmentary distribution prevented the replication of treatments in a statistical layout. The sprays were applied by means of a gear pump and 8 ft lance with a cranked ¼ in. Long Ashton nozzle using a special 6/64 in. long range disc aperture to produce large droplets with a minimum of drift. The output was 3½ pints per minute at 30 p.s.i. The sprays were applied in June to knotweed up to 8 ft high. Granular herbicides were distributed by hand.

Sample plots of 30 ft^2 were laid down in each treatment and the number and length of live or completely dead shoots measured at intervals during the season. In November culms and roots were dug up and potted in John Innes No.1 compost and forced in a greenhouse at 60°F. Subsequent growth was measured.

The herbicides were applied on 3 June 1965 on a dry still day. Rain did not occur on 3rd or 4th June but fell on the 5th (.41 in.) and 6th (.22 in.).

The treatments were:
Plot 1, Bromacil 80% w.p. at a rate of 24 lb a.i./225 gal/ac, a repeat of the treatment applied on 11th June 1964,
Plot 2, Picloram at a rate of 3 lb a.i./ac formulated as granules containing 1% picloram and 44% boric oxide carrier,
Plot 3, Picloram at a rate of 3 lb a.i./ac in 225 gal/ac formulated as the potassium salt,
Plot 4, Untreated.

RESULTS

Table 1 summarises the measurements made on the treated stand and on the new growth the following year.

Dominant stems in the control, plot 4 reached 6 ft by 16th June, 8 ft by 27th July and 9 ft by the end of the season, in a dense stand of mean height 22, 28 and 48 in. respectively. The number of stems increased during the early season but then some of the weaker lower stems died off. Flowering extended from August throughout September. In the following season, stems 1 ft on 29th March grew to 6 ft by May. Cover was then complete. The volume of growth was slightly more than in the previous year, produced by fewer but longer shoots. Four small culms with shoots 3 ft high, dug up on 5th November 1965 showed well developed rhizomes and root systems, with buds on the crown and on the rhizomes. After being forced for 5 weeks two culms had produced shoots 3 ft long. By June 1966 the four culms had produced eight shoots of mean length 26 in., the longest being 47 in. and their root systems had completely filled their 8 in. pots.

The application of bromacil at 24 lb/ac in 1964 killed the original growth but a few new shoots were produced in late summer. Measurements made in October 1964 in the sample plot gave 83 dead shoots, of total length 3486 in. and five live, of total length 10 in. Table 1 shows that in May 1965 there was a significant reduction in the amount and height of new growth. Following the application in 1965 these new shoots died quickly and by July only 3% were still alive, very significantly less than in all other plots. By October all the stems had rotted away leaving a completely bare soil surface. By November most culms were rotten at the centre and it was difficult to find living samples worth potting. Of the four selected only one survived and by June 1966 had produced two weak shoots with chlorotic leaves and four roots one inch in length. In spring 1966 this plot produced one feeble shoot which later died, and remained bare throughout the season.

The application of granules of picloram at 3 lb a.i./ac led to some interveinal chlorosis and marginal necrosis of the leaves and finally some of the smaller stems died, but dominant stems were unaffected and reached 6 ft by 16th June, 7-8 ft by 27th July and over 9 ft by the end of the season. Table 1 gives the mean heights of 25, 37 and 57 in. in May, July and October and shows that the proportion surviving, and the mean height of live and dead stems was substantially the same as in the untreated control. Growth the following season was vigorous and did not differ significantly from that in the control.

Table 1 Effect of herbicides on growth of Japanese knotweed per 30 square feet

Treatment	1			2			3			4		
Material	Bromacil			Picloram			Picloram					
Rate/acre	24 lb.			3 lb.			3 lb.			Untreated		
Method	Spray			Granules			Spray					
	No. of shoots	Total length (in.)	Mean length (in.)	No. of shoots	Total length (in.)	Mean length (in.)	No. of shoots	Total length (in.)	Mean length (in.)	No. of shoots	Total length (in.)	Mean length (in.)
24.5.1965 shoots live	62	940	15**	94	2371	25	87	2616	30**	121	2649	22
3.6.1965 Treatments applied												
27.7.1965 shoots live	2***	15	8***	67***	2490	37	36***	1679	47***	139	3852	28
% surviving	3			71			41			115		
dead	27	404	15	7	56	8	25	618	25	4	40	10
7.10.1965 shoots live	0***	0	0***	29	1658	57	5***	166	33	55	2650	48
% surviving	0			31			8			46		
dead	9	117	13	25	546	22	56	1939	35	4	120	30
6.5.1966	1	6	6***	58	2284	39	2	31	16***	76	3084	41

** Results significantly different from those of untreated control at the 1.0% level, *** at the 0.1% level.

In contrast, two weeks after spraying picloram at 3 lb a.i./ac the tips and terminal leaves had become deformed and died. Lower leaves followed and by July much of the foliage and smaller stems had died. By October almost all the stems had died back to ground level. The proportion killed was then equal to that of bromacil in plot 1 and very significantly more than that of all other plots. Significantly longer stems and a greater proportion were killed by the spray than by the granules. Samples of the nodular mass of culm, rhizomes and roots were dug up in November. In many, the central tissues were completely rotten, supported only by the outer woody layers. The least moribung samples were potted and forced, but all died without producing shoots.

By the following year almost all the culms in the trial area had died. Table 1 shows that new growth was negligible. The grasses Agrostis stolonifera, Poa annua and pratensis, Holcus lanatus with some field speedwell Veronica agrestis covered about 30% of the bare ground in May and increased to complete cover by August.

DISCUSSION

Observations and measurements made since 1961 confirm the outstanding vigour of this herbaceous perennial and the threat that its extensive root and rhizome system constitute to drains, retaining walls, tarmacadam surfaces etc. Cutting down the stems did not appreciably weaken the plant, and the root system cannot be grubbed up effectively.

At Bristol, it soon recovered from foliar sprays of amitrole-T or a 2,4,5-T/2,4-D mixture at rates twice those normally recommended and though the use of diesel oil as a carrier for the 2,4,5-T/2,4-D was noticeably more phytotoxic, no lasting control was achieved. Both Pridham (1963) and Ahrens (1963) reported the relative failure of these and other related herbicides in the U.S.A. and more recently Ferron (1965) in Canada has confirmed their results. Hence in 1964 bromacil was selected for trial because it had shown promise for the control of deep rooted perennials by virtue of its high toxicity and persistence in the soil (O'Neil, 1963). Bromacil wettable powder at a rate of 24 lb a.i./ac severely weakened the stand and a second application in the following year gave complete control. High rates are essential. Earlier trials had shown that a rate of 16 lb/ac gave no lasting control and that granular formulations at 16.8 and 8.4 lb a.i./ac were even less effective causing only superficial damage.

Following the second application at 24 lb/ac, the soil surface has remained bare for over a year with no development of vegetative cover. The persistence of bromacil residues at the high rate required would be hazardous in agricultural situations, or on sloping sites where there would be a risk of erosion once the cover of knotweed was destroyed. In contrast, picloram residues were less persistent and a dense cover of grasses was established within a year. Wiltse (1964) and Lawson (1965) have also observed that grasses are relatively unharmed by picloram and may increase when other species are killed. Whilst picloram granules applied in June gave little control of the knotweed, the spray was as effective as two heavy doses of bromacil and hence foliar applications of picloram at 3 lb a.i./ac are to be preferred for the control of Japanese knotweed. Recent work by Ferron (1965) and Pridham (1966) support this conclusion.

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THE USE OF PICLORAM AS A RESIDUAL HERBICIDE FOR INDUSTRIAL WEED CONTROL

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Summary Results are presented showing that picloram as a soil or foliar application is effective in controlling perennial broad-leaved weeds including some not adequately controlled by other herbicides in current use. Mixtures of picloram with bromacil or monuron give better total weed control than bromacil or monuron alone and can be used to prevent growth in late winter or spring applications. Doses of picloram required range from about 8 oz/ac for maintenance applications on relatively weed-free areas to 16 oz/ac for initial treatments on established vegetation. Equisetum spp. (horsetails) Linaria vulgaris (toadflax) and Cardaria draba (hoary pepperwort) appear to be resistant at 32 oz/ac.

INTRODUCTION

Industrial weed control in Great Britain is at a stage where low doses of residual herbicides, primarily atrazine, bromacil and diuron are used at intervals usually once a year during the winter or spring months to maintain considerable areas free of growth. A limited number of weeds, mainly deep rooted broad-leaved perennials, are not adequately controlled by low doses or, in some cases, high doses of these residual herbicides. In practice it is generally necessary to control such weeds with additional herbicides often applied as foliar sprays during the growing season. While in most cases satisfactory results can be obtained, the use of a soil-acting residual herbicide effective on these difficult species would be preferable. This applies particularly to herbicides formulated as granules for use by industry.

The first published report (Hamaker, 1963) on the Dow herbicide picloram described the compound as effective on broad-leaved weeds when applied as a pre-emergence soil treatment or foliar spray. A later report from California (Laning, 1963) indicated that soil application of 1-2 lb/ac gave good control of established Convolvulus arvensis (field bindweed) and Cirsium arvense (creeping thistle) without appreciable effect on established grasses. The subsequent development of picloram in the U.S.A. and other countries has been primarily for brush control, for noxious or injurious weed control in rangeland or pastures and, at low doses, for selective weed control in crops. In Great Britain, apart from selective use in cereals and possibly bracken control, the main scope for picloram appears to be for general vegetation control in industry in mixtures with other herbicides.

The present report describes work in evaluating picloram as a residual herbicide in spray and granular formulations with bromacil and monuron.

MATERIALS AND METHODS

1964. Over May-July picloram at doses of 1-2 lb/ac was applied by knapsack sprayer at 50-150 gal/ac as a water solution of potassium salt containing 2.4 lb picloram per gallon on observation plots containing a variety of broad-leaved weeds on seven main sites in England and Wales. Comparisons were made with bromacil used as 50% water-soluble powder and monuron as an 80% wettable powder applied at similar spray volumes. A mixture of picloram and 2,4-D as water-soluble amine salts and containing 2.4 lb 2,4-D and 0.65 lb picloram per gallon was used in some experiments. On some sites (Sharpness and Coryton) applications were made on broad-leaved species surviving applications of residual herbicides in the previous year.

1965. Replicated small plot (4 x 4 yd) trials were put down on five established vegetation sites over March-May with sprays of the same formulations of picloram, bromacil, 2,4-D plus 2,4,5-T, bromacil plus picloram, bromacil plus 2,4-D/2,4,5-T and picloram plus 2,4-D, applied in water at 70-80 gal/ac using a knapsack sprayer fitted with a 4-nozzle boom, 00 ceramic fan jets and pressure regulating valve set at 20 psi. The 2,4-D plus 2,4,5-T was an ester formulation containing 5 lb 2,4-D and 2½ lb 2,4,5-T per gallon used in preference to 2,4-D alone as giving better control of a wider range of herbaceous and woody weeds. A granule containing 2% bromacil, 0.3% picloram and 43% B_2O_3 was also applied by shaker pack at doses which gave similar amounts of bromacil and picloram as spray applications. Spray doses for picloram were ½, ¾ and 1 lb/ac alone and combined with bromacil at 4 and 5 lb/ac, bromacil alone being used at 4, 5 and 6 lb/ac. Previous work (Montgomery, 1965) had shown that at least 5-6 lb/ac bromacil was required for satisfactory perennial grass control under the conditions of these experiments. Table 1 lists the main species and their distribution at the time of application. Visual assessments of percentage ground cover of live vegetation and species surviving were made during the season.

Table 1.

Description of Sites

	Main species (Those in brackets not on all plots).
HAYES Sand and gravel substrate	Grasses: Dactylis glomerata, Arrhenatherum elatius. Broad-leaf: Tanacetum vulgare, Urtica dioica, Cirsium arvense, Dipsacus fullonium, Conium maculatum, (Arctium lappa), (Potentilla reptans), (Rumex obtusifolius), (Rubus fruticosus). Distribution: Grasses all plots but varying from nearly 90% plot area down to 25%. Similar variable occurrence of broad-leaf with P.reptans, A.lappa, Rumex and Rubus present only on some plots.
BRAMSHILL Sandy soil	Grasses: Agrostis tenuis, Aira praecox, (Juncus effusus) Broad-leaf: Hypochaeris radicata (main sp.), (Rumex acetosella, heather, pine seedlings). Distribution: Grasses varying from 20 to 70% of plot area. H.radicata all plots varying from 12 to about 70 rosettes per sq.yd. Other species present on only some plots.
THEALE Medium loam	Grasses: Agrostis stolonifera, Vulpia bromoides, (Festuca rubra), (Dactylis glomerata). Broad-leaf: Taraxacum officinale, Achillea millefolium, Artemisia vulgaris, Plantago lanceolata, Trifolium pratense, (Linaria vulgaris), (Chrysanthemum leucanthemum),(P.reptans), (Lotus corniculatus). Distribution: Grass cover varying from 50 to 80% with F.rubra and D.glomerata only on some plots. T.officinale all plots 10 to 40%.
BARRY Ashes	Grasses: D.glomerata, A.elatius. Broad-leaf: P.reptans,A.vulgaris,P.lanceolata,A.millefolium R.fruticosus,(Rumex crispus),(Pastinaca sativa),(Daucus carota),(L.vulgaris),(U.dioica),(Diplotaxis tenuifolia). Distribution: 60-90% grass cover on plots,variable in density. 10-30% broad-leaf.
ASHFORD Heavy soil	Grasses: Agrostis spp. and D.glomerata. Broad-leaf: C.arvense(main sp.),A.millefolium,P.lanceolata, T.pratense, R.repens, (Cirsium vulgare), (Polygonum spp.), (T.officinale), (U.dioica). Distribution: 25-60% grass on plots. 5-50% C.arvense all plots with above broad-leaf.

1966. Small plots. Granular formulations (Table 2) were applied in unreplicated plots on established vegetation on thirteen separate sites. At three sites duplicate plots were put down on very similar vegetation at an interval of a month or more. Doses of products varied from 150-500 lb/ac according to the weed problem, details of which are given in recording the results. Methods of application and assessment were the same as in 1965.

Table 2

Products (1966)

Product	Abbreviation	Composition
Granular monuron-borate	MB	4% monuron, 40% B_2O_3
Granular monuron-picloram-borate	MPB	2.8% monuron, 0.2% picloram, 42% B_2O_3
Granular bromacil borate	BB	1.5% bromacil, 44% B_2O_3
Granular bromacil-picloram-borate	BPB	1.3% bromacil, 0.2% picloram, 44% B_2O_3
Granular monuron-chlorate-borate	MCB	2.4% monuron, 36% sodium chlorate, 11% B_2O_3

User trials. The monuron-picloram-borate granule (Table 2) was selected for user trials on a large number of electricity transformer stations in England. Most sites were 500 sq.yd. or less but a few were over an acre. A standard dose of 360 lb/ac of product was used from March onwards applied by spinning plate spreader. Vegetation cover on individual sites varied from 0 to 100% and a wide variety of species were present including C.arvensis, C.arvense, Rumex spp. (docks), Calystegia sepium (bellbine), Ranunculus repens (creeping buttercup) and Potentilla reptans (creeping cinquefoil).

RESULTS

1964

Tables 3 and 4 record the main results from 1964 plots in terms of the percentage regrowth of broad-leaved species in 1964 and again in 1965. In describing results from these and other trials the term 'good control' means 90% bare ground or dead vegetation and 'very good control' means 95%. Picloram at 1-2 lb/ac gave good control of P.reptans, C.arvensis, C.arvense, Rubus spp. (brambles), Senecio jacobaea (ragwort), Tripleurospermum maritimum spp.inodorum (mayweed), Reseda lutea (wild mignonette), Tussilago farfara (coltsfoot), R.repens and Chamaenerion angustifolium (willow herb). There was survival and regrowth of Equisetum arvense (horsetail), Cardaria draba (hoary pepperwort) and Linaria vulgaris (toadflax).

1965

Control of broad-leaf in grasses

Table 5 shows the average percentage of broad-leaved species (listed in Table 1) present 4-6 months after treatments. Picloram plus 2,4-D at ½ + 2 lb/ac gave the best control with 8% or less survival on four out of five sites; on the other site at Hayes with application in March there was 6% broad-leaf, mainly Tanacetum vulgare (tansy) in June which increased to 15% in September together with 5% regrowth of P.reptans. With picloram alone at ¾ lb/ac broad-leaved survival varied from 7-13% and with ½ lb/ac from 10-25%, the main species present being T.vulgare, Hypochaeris radicata (cat's ear), L.vulgaris and Rubus spp. Of these weeds only L.vulgaris appeared resistant at a higher dose of 1 lb/ac.

By September broad-leaved species had increased on plots treated with 2,4-D plus 2,4,5-T at three of the five sites, the average percentage varying from 45 to 60%. At Bramshill, 2,4-D plus 2,4,5-T gave fairly good control of H. radicata

Table 3 Percentage survival/regrowth of broad-leaved weeds 1964/5

Site: SHARPNESS
Soil: Medium clay.
Av.annual rainfall: 32"
Application date: 20.5.64

Main spp.
10-15% P.reptans, R.repens, C.arvensis, C.arvense in perennial grasses.

Treatment and dose lb/acre		Months after application	Percent survival
Picloram	1.8	5	0
		14	5
Bromacil	6	5	25
		14	95
Bromacil + picloram		5	1
	3½ + 1.8	14	20
Bromacil + chlorate		5	10
	3½ + 190	14	80
Untreated			15

Site: As above but on ground treated with residual herbicides in 1963.
Application date: 14.4.64

Main spp.
P.reptans, C.arvense, T.officinale, Rubus spp. and C.draba.

Treatment and dose lb/acre		Months after application	Percent survival
Bromacil + picloram		6	5
	1½ + 2	15	16 (L.vulgaris)
Atrazine + picloram		6	5
	3½ + 2	15	22 (C.draba)
Monuron + picloram		6	12
	3½ + 2	15	10
Untreated in 1964			95

Site: MIDDLEWICH
Railtrack gravel ballast, ash cess.
Av.annual rainfall: 30"
Application date: 13.5.66

Main spp.
C.angustifolium, T.officinale, Crepis sp. T.farfara, Rubus spp., E.arvense, grasses.

Treatment and dose lb/acre		Months after application	Percent survival
Picloram	2	4½	5
		13	10 (E.arvense)
Atrazine	7½	4½	30
		13	25
Diuron	12	4½	25
		13	12
Bromacil	3½	4½	12
		13	15
Amitrole	4	4½	14
		13	30
Untreated			30

Site: CORYTON
Soil: light, sandy, treated with monuron in 1963.
Av.annual rainfall: 22"
Application date: 29.5.66

Main spp.
S.jacobaea, S.vulgaris, T.maritimum inodorum, R.lutea.

Treatment and dose lb/acre		Months after application	Percent survival
Bromacil	1.2	3	15
	2	3	3
Picloram	1.2	3	7
Bromacil + picloram	1.8 + 1.2	3	2
Untreated in 1964			65

Table 4 Percentage broad-leaved weeds surviving/regrowing in 1963/4

BARRY App. 18.6.64

Treatment and dose lb/ac.		Main species	Months after application 3½	12	Species surviving
Picloram	2	C.arvensis,P.reptans, Rubus spp.	0	0	
Picloram	1	C.arvensis,P.reptans, Rubus spp.	10	10	(P.reptans)
Picloram	1	C.arvensis,P.reptans, Rubus spp.	0	10	(E.arvense, R.crispus)
Picloram	2	C.arvensis,C.arvense, R.crispus,Rubus spp.	0	10	(E.arvense)
Picloram	1	C.arvensis,Rumex spp., Rubus spp.,E.arvense.	10	10	(E.arvense)
Picloram	2	R.repens,C.arvensis, Rumex spp.,E.arvense, Rubus spp.	10	10	(E.arvense, L.vulgaris)
Picloram + 2,4-D	1½+6	Rubus spp.,S.jacobaea, P.aquilinum,A.vulgaris, Solanum dulcamara	20	8	(P.aquilinum)
Picloram + 2,4-D	1 +4	Rubus spp.,S.jacobaea, P.aquilinum,A.vulgaris, S. dulcamara.	20	30	(P.aquilinum)
Picloram + 2,4-D	½ +2	Rubus spp.,E.arvense, L.vulgaris.	20	8	(L.vulgaris, Rubus spp.)
Picloram + 2,4-D	1 +4	Rubus spp.,P.reptans, C.arvensis,S.jacobaea, Rumex spp.,L.vulgaris	5	20	(Rubus spp., Silene vulgaris & seedlings)

CANVEY App. 21.7.64

Treatment and dose lb/ac.		Main species	Months after application 11	Species surviving
Picloram + 2,4-D	1 +4	Rubus spp.,Prunus spinosa,C.arvense, U.dioica	10	(Rubus spp.)
2,4-D + 2,4,5-T	2.4+1.2	Rubus spp.,P.spinosa, C.arvense,U.dioica	50	(Rubus spp.)

BRAMSHILL App. 13.8.64

Treatment and dose lb/ac.		Main species	Months after application 10	Species surviving
Picloram + 2,4-D	½ +2	Rubus spp., C.arvense	20	(Rubus spp.)
Picloram + 2,4-D	1 +4	Rubus spp., C.angustifolium.	10	(Rubus spp.)
Picloram + 2,4-D	2 +8	Rubus spp.,C.angustifolium,P.aquilinum, Betula spp.	5	(Rubus spp.)
2,4-D + 2,4,5-T	2 + 1	Rubus spp., Populus spp.	15	(Rubus spp.)

(18% survival) similar to picloram at ½ lb/ac but significantly worse than picloram plus 2,4-D at ½ + 2 lb/ac. On the other site there was no significant difference between all treatments.

Table 5

Percentage broad-leaf present in grasses at the time of application (A) and 4-6 months later (B)

	Picloram						Picloram + 2,4-D		2,4-D + 2,4,5-T	
Dose lb/ac	½		¾		1		½ + 2		2 + 1	
	A	B	A	B	A	B	A	B	A	B
HAYES applied 17.3.65	23	10	35	12	25	10	33	20	28	55
BRAMSHILL applied 3.4.65	65	23	60	10	65	7	65	5	50	18
THEALE applied 29.4.65	50	10	50	7	40	3	50	5	50	60
BARRY applied 20.5.65	25	25	23	13	20	10	18	8	25	45
ASHFORD applied 26.5.65	55	1	50	0	50	0	50	2	55	8

Means of 2 replicates. Species are given in Table I.

General vegetation control with bromacil-picloram mixtures

Figures 1 and 2 show the results obtained in comparing bromacil with bromacil plus 2,4-D/2,4,5-T and bromacil plus picloram for general vegetation control on five sites.

At Hayes with application at a very early growth stage in March there was no grass survival with all treatments. On broad-leaf the best treatments were 4 or 5 lb of bromacil with 1 lb of picloram spray applied or granules at 5 lb + ¾ lb/ac bromacil plus picloram all with less than 11% broad-leaf survival. All other treatments showed significantly more broad-leaf including bromacil alone at 6 lb/ac or combined with 2,4-D/2,4,5-T at 5 lb/ac. Surviving species with these treatments included P.reptans, C.arvensis, Rubus spp., T.vulgare and Rumex obtusifolius (broad-leaved dock). At Bramshill with application in early April there was again no survival of grasses at the end of the season. On the dominant broad-leaved species, H.radicata, bromacil at 6 lb/ac was not very satisfactory with 20% survival but 4 lb/ac bromacil with either 2,4-D plus 2,4,5-T or picloram at ¾ lb/ac gave good control. With the granular treatments there was still 14% survival of H.radicata at 6 + 0.9 lb/ac bromacil plus picloram. At Theale, with application in late April there was survival of Festuca rubra (red fescue) with spray application of bromacil at 4 lb/ac and also a little survival with granules at up to 6 lb bromacil per acre. Broad-leaf control was significantly better with all picloram mixtures than with bromacil and bromacil plus 2,4-D/2,4,5-T and there was no significant difference between ½ and 1 lb/ac picloram. In September P.reptans was beginning to re-establish on plots receiving the highest dose of picloram. Granular treatments were not as good as spray applications, there being 12% survival of broad-leaved species with bromacil plus picloram at 6 + 0.9 lb/ac. At Barry, with application on the 20th May and adequate rainfall afterwards, grass control was good with all treatments. Bromacil and bromacil plus 2,4-D/2,4,5-T failed to control P.reptans and Rubus spp. All spray applied bromacil plus picloram treatments gave much better results with 10-18% broad-leaf survival in late August. L.vulgaris was the main surviving species and regrowth of Rubus was noted in October. Granular treatments, with the exception of the top dose, gave significantly worse control than all spray treatments. At Ashford, with application towards the end of May and in a lower rainfall area than Barry, satisfactory grass control was not obtained from bromacil at up to 5 lb/ac and

Fig. 1

Percentage survival of vegetation following applications of bromacil and picloram

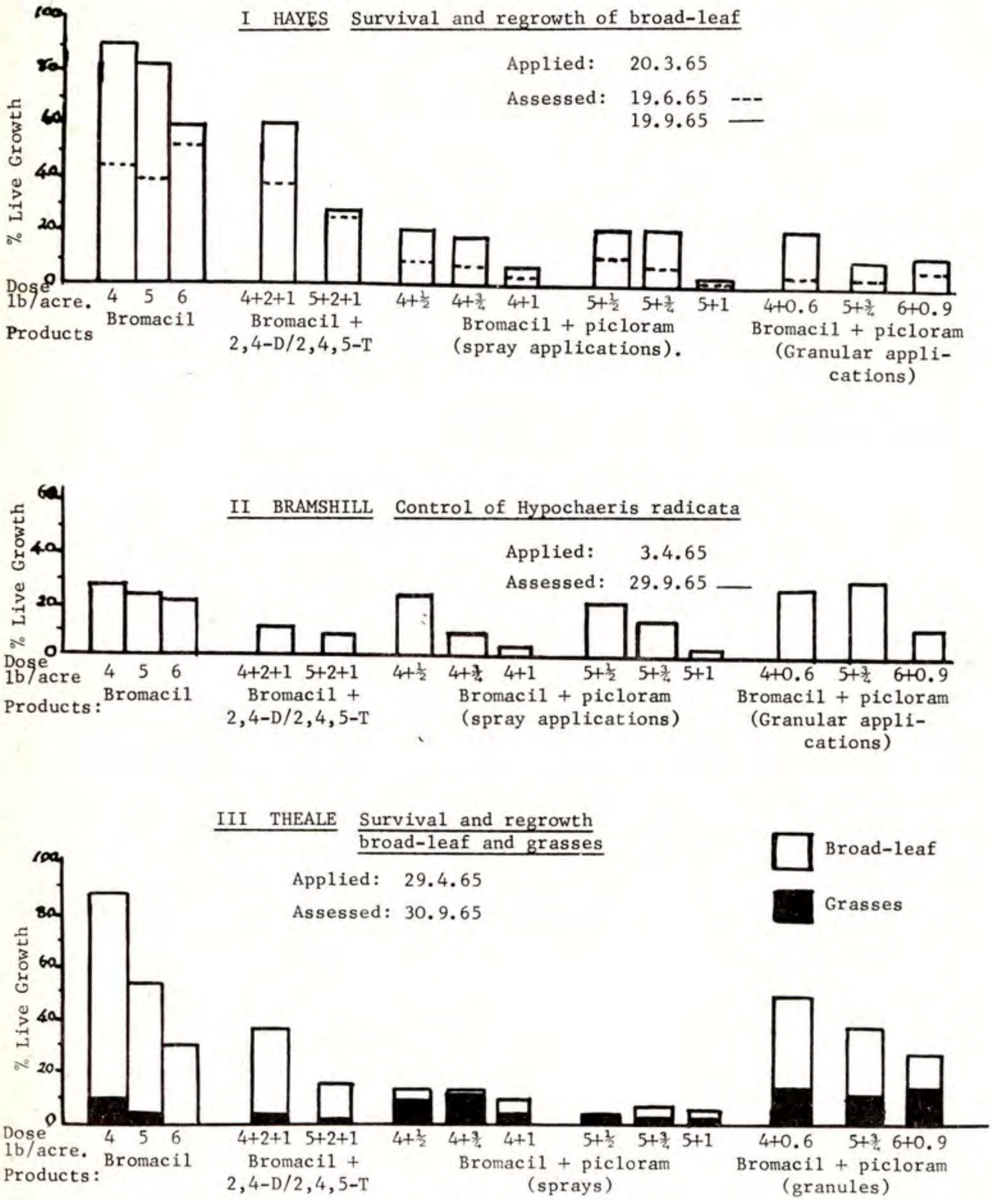
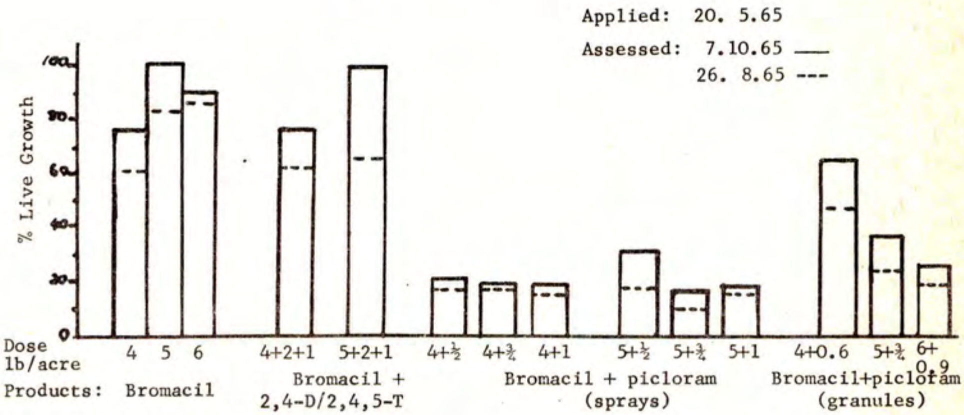
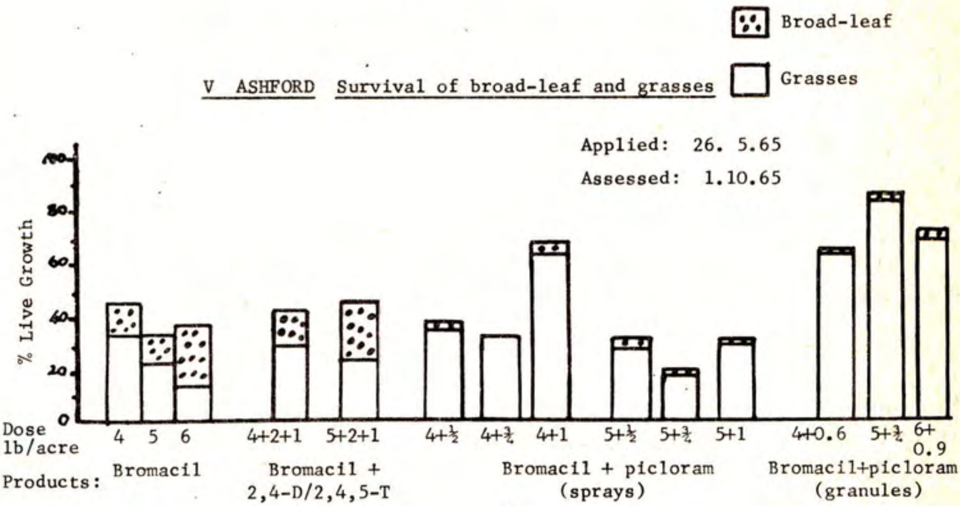


Fig. 2

IV BARRY Survival of broad-leaf



V ASHFORD Survival of broad-leaf and grasses



Means of 2 replicates on all experiments.

there was still 13% survival, primarily of D.glomerata, at 6 lb/ac. Broad-leaf control was very good with all treatments containing picloram whereas with bromacil and bromacil plus 2,4-D/2,4,5-T there was up to 20% survival of C.arvense and Polygonum bistorta (bistort).

1966

Tables 6 and 7 show results from small plots.

Grass control

The monuron borate formulation at 250-350 lb/ac gave good grass control except on Deschampsia caespitosa (tussock grass) at two sites. The monuron-picloram borate granule used at the same doses and containing a lower amount of monuron was similar except that in addition to D.caespitosa, D.glomerata was not as well controlled on two sites. Both bromacil granules gave very good control of all grasses including D.caespitosa. The monuron-chlorate-borate formulation was generally good but significantly worse than bromacil on D.caespitosa and on D.glomerata on two sites.

Broad-leaved weeds

With monuron-borate control of broad-leaf was poor on eight out of eleven sites, species not controlled including C.arvense,C.arvensis, T.farfara, Plantago spp.(plantains), P.reptans, S.jacobaea and a number of umbelliferous species such as Pastinaca sativa (parsnip) and D.carota (wild carrot). Bromacil borate gave better broad-leaf weed control than monuron borate but was still not satisfactory even at top dose on seven sites, the following main species surviving: R.repens, C.arvense, C.arvensis and C.angustifolium. Bromacil-picloram-borate granules gave very good broad-leaf control except on C.angustifolium at two sites and on C.draba at a third. Monuron-picloram borate gave good (90%) control of broad-leaf on all sites though there was regrowth of Reseda luteola (weld) at one site and of C.arvense, Plantago spp., C.arvensis and R.repens at another with application in March at a dose of 0.7 lb/ac picloram. With monuron-chlorate-borate, broad-leaved weed control was less than 90% on only two sites if the application was not made too early in the year, the results from Swindon and Westerleigh showing better control with application in May rather than in March or April. The main species surviving on the two sites where control was not satisfactory were T.farfara, C.draba, C.arvense, Urtica dioica (stinging nettle), R.repens and C.arvensis.

User trials

A sample survey of results on electricity transmission sites showed very good (95%) control on over 90% of the sites treated. There was, however, some survival of C.arvensis and P.reptans mainly on sites treated in May or later in the year and some new growth of weeds like Senecio vulgaris (groundsel) late in the season from early application. Results were significantly better than from applications of granular bromacil borate in the previous year. Damage to adjacent cultivated plants, shrubs and trees was reported from adjacent gardens on one site in about 350 treated, compared with an average of one in nearly 700 in the previous year.

DISCUSSION

The results show that picloram gives useful control of a wide range of herbaceous broad-leaved weeds. Species susceptible or moderately susceptible to soil or foliar applications early in the season include: A.millefolium, A.lappa, A.vulgaris, C.arvense, C.arvensis, P.reptans, Plantago spp., R.repens, S.jacobaea, T.officinale, T.farfara and U.dioica. Some weeds, including perennial Rumex spp., may be more susceptible to foliar sprays later in the year. Absorption from soil is evidently effective though generally less so than foliar absorption as plants become established. Picloram appears to leach rather more readily from soils than bromacil or other residual herbicides commonly used for industrial weed control. While the chemical is of low toxicity to humans, livestock and wild life, reports suggest that in soil it is fairly resistant to microbiological breakdown (Ritty, 1964). Damage can be caused to plants and trees on cultivated areas which are sometimes very close to industrial sites. In user trials during 1966 under just these conditions some

Table 6 Heavy Vegetation Sites Percentage survival grasses(G) and broad-leaf(B) after granular treatments in 1966.

Product (see Table 2)	Doses lb/acre product	MB G	MB B	MPB G	MPB B	BB G	BB B	BPB G	BPB B	MCB G	MCB B
Site and main species											
HAYES (1) Applied 8.5.66 Assessed 19.9.66	250	0	80	15	10	0	45	0	35	25	35
D.glomerata, A.elatius, C.angustifolium, C.arvense	350	7	45	10	10	0	70	5	25	5	5
T.farfara, A.sylvestris, P.lanceolata, T.officinale H.radicata.	500	0	38	0	2	0	10	0	25	8	10
Main spp. surviving:		T.farfara C.arvense P.lanceolata				C.angustifolium C.arvense		C.angustifolium		T.farfara	
HAYES (2) App.29.3.66 Ass. 28.6.66	250	0	40	0	50	0	60	0	35	0	70
C.draba, R.crispus, A.lappa, U.dioica, C.arvense,	350	0	30	0	20	0	20	0	60	0	60
A.elatius, P.annua.	500	0	60	0	10	0	20	0	20	0	50
Main spp. surviving		C.draba C.arvense A.lappa		C.draba		C.draba U.dioica		C.draba R.crispus		C.draba C.arvense U.dioica	
BARRY App.18.5.66 Ass.31.8.66	350	0	50	5	10	0	30	0	25	5	25
D.glomerata, A.elatius, P.lanceolata, D.carota, P.reptans, L.corniculatus, H.radicata, C.nigra	500	0	40	5	5	5	30	5	5	5	5
Main spp. surviving:		P.lanceolata P.reptans R.crispus				P.lanceolata P.reptans C.nigra					
FELTWELL App.16.5.66 Ass. 7.9.66	350	10	40	25	1	0	2	4	1	45	5
D.glomerata, Festuca spp, A.elatius, P.sativa, D.carota, P.lanceolata, C.arvensis, A.millefolium.	500	0	20	10	0	0	15	0	2	5	5
Main spp. surviving:		D.carota C.nigra		D.glomerata		C.arvensis					
CATERHAM (1) App.15.3.66 Ass. 8.7.66	250	0	30	0	20	0	60	0	30	10	30
R.repens, C.arvense, P.lanceolata, C.arvensis, V.chamaedrys, D.glomerata, P.reptans.	350	0	30	0	15	0	60	0	5	5	35
Main spp. surviving:		C.arvense P.reptans R.repens P.lanceolata		C.arvense P.lanceolata C.arvensis R.repens		R.repens (C.arvense)				C.arvense R.repens	
CATERHAM (2) App.20.5.66 Ass.22.9.66	250	0	60	5	35	0	90	0	10	30	20
Species as above plus A.repens on some plots	350	0	30	20	10	0	100	0	5	20	30
	500	-		10	2	10	50	0	0	-	
Main spp. surviving:		C.arvense P.lanceolata C.arvensis V.chamaedrys		A.repens		C.arvensis C.arvense R.repens				R.repens C.arvensis P.lanceolata D.glomerata	
KINETON App.25.5.66 Ass.12.9.66	250	60	30	80	20	5	80	8	20		
D.caespitosa, D.glomerata, P.reptans, A.millefolium, C.angustifolium, C.arvense, T.officinale	350	20	70	50	20	0	55	0	5		
	500	45	15	45	5	0	60	0	5		
Main spp. surviving:		D.caespitosa P.reptans		D.caespitosa		C.arvensis (C.angustifolium)		(R.crispus)			

Table 7 Light Vegetation Sites % Survival of grasses (G) and broad-leaf(B) after granular herbicide treatments in 1966

Product (see Table 2)	Doses lb/acre product	MB		MPB		BB		BPB		MCB	
		G	B	G	B	G	B	G	B	G	B
SWINDON (1) App.31.3.66 Ass.30.8.66	150	0	50	0	30	0	1	0	2	0	30
S.jacobaea, T.maritimum inodorum, P.lanceolata, C.angustifolium, T.officinale.	250	0	40	0	20	0	2	0	1	0	15
Main spp. surviving:		S.jacobaea P.lanceolata		(R.luteola) S.jacobaea						R.luteola (S.jacobaea) P.persicaria	
SWINDON (2) App.17.5.66 Ass. 30.8.66											
Species as above plus P.annua	150	0	40	0	40	0	5	0	10	0	5
	250	0	40	0	10	0	5	0	5	0	5
Main spp. surviving:		S.jacobaea P.lanceolata		S.jacobaea							
WESTERLEIGH (1) App.18.4.66 Ass.30.8.66	150	0	20	0	40	0	40	0	50	3	10
C.angustifolium, T.officinale, A.vulgaris, H.lanatus.	250	0	15	0	5	0	40	0	20	0	10
Main spp. surviving:		C.angusti-folium T.officinale				C.angusti-folium (A.vulgaris)		C.angusti-folium		C.angusti-folium T.officinale	
WESTERLEIGH (2) App.23.5.66 Ass.30.8.66	150	0	15	0	25	0	20	0	10	5	25
Species as above.	250	0	5	0	5	0	10	0	10	0	5
Main spp. surviving:						C.angusti-folium		C.angusti-folium			
SHARPNESS App.23.5.66 Ass.30.8.66 P.annua, V.sativa, Trifolium campestre. T.officinale	150	8	2	5	0	5	0	5	0	10	2
CATTERICK App.28.4.66 Ass.14.9.66	150	40	10	60	5	15	55	20	5	70	5
R.repens, D.caespitosa, C.arvense, D.glomerata	250	15	5	25	0	10	50	20	5	35	5
	500	15	5	10	0	0	15	5	5	15	1
Main spp. surviving:		D.caespitosa		D.caespitosa		R.repens				D.caespitosa	
CUMBERNAULD App.26.4.66 Ass.13.9.66	150	5	90	10	20	2	40	20	50	5	25
R.repens, R.obtusifolius, Bellis perennis,	250	0	25	10	25	0	50	0	15	0	10
D.glomerata, Agrostis spp.	500			0	0	0	90	0	0	0	5
Main spp. surviving:						R.repens					

damage was observed from one site in about 350 treated. Generally such damage is due to drainage water carrying herbicide from a treated area to cultivated ground at a lower level and, in the case of shrubs and trees, to absorption through roots growing in the treated area. In addition to the work described here, user trials with granular formulations containing picloram were put down on 430 other electricity transformer stations in different parts of the country. No damage to adjacent cultivated plants has been reported. Spray applications of picloram with other herbicides were made on forty other industrial sites in 1966, damage being reported from one site. On the evidence available so far it seems doubtful that picloram presents any significantly greater hazard than other residual herbicides at present in use for industrial weed control.

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FIELD TRIALS WITH SIMAZINE/AMITROLE MIXTURES

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Summary Several logarithmic applications, of three different ratios of amitrole/simazine wettable powder mixtures, were made to established perennial vegetation to discover which mixture gave the best control at the end of a growing season. It was found that the ratio of 2:1 (lbs a.i.) simazine to amitrole gave the greatest reduction in volume live growth at the six sites treated. Amitrole/simazine mixtures were much quicker in initial effect that atrazine, which is known to be slightly quicker in action than simazine alone.

INTRODUCTION

The safety of simazine to many trees and ornamental shrubs is well known (1). Simazine/amitrole mixtures have been tried experimentally in this country for a number of years (2), and are widely used on the continent for controlling deep-rooted perennial weeds in vines, pome and citrus fruits (3).

From established practice in situations such as railways, and from confirmatory trials carried out in 1965, it was known that high rates of up to 5 lbs a.i./ac of amitrole, in combination with different triazines, would control some species which are resistant to dosage rates of up to 10 lbs a.i./ac. of atrazine or simazine alone. Earlier research trials from Chesterford Park had shown that small quantities of amitrole could lower the amount of simazine necessary to control simazine susceptible species.

The purpose of the trials, the results of which are summarised here, was to establish which ratio of simazine to amitrole was the best one to give a growing season's control on established vegetation, and to compare the speed of action of such a mixture with that of atrazine. In addition, the effect of simazine/amitrole mixtures on a number of weed species was studied.

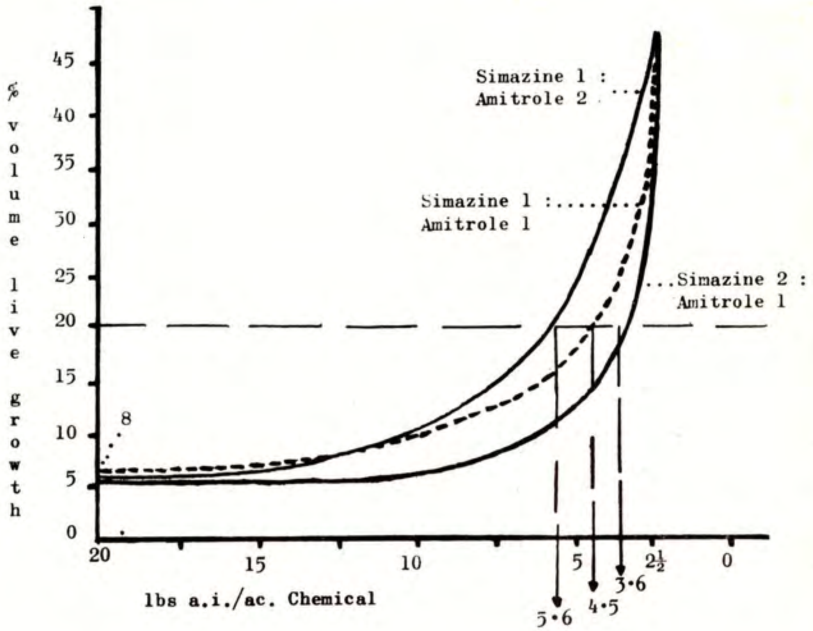
METHOD AND MATERIALS

Formulated simazine plus amitrole wettable powder mixtures, in the ratio of 2:1, 1:1, and 1:2 of a.i. were applied, and atrazine was used as a comparison. A Chesterford logarithmic sprayer (boom width 15 ft) and mini-log sprayer (boom width 4·5 ft) were used to make applications from 20 lbs a.i./ac. to 5/8 lbs or 1 1/4 lbs at seven sites. In addition, the simazine 1: amitrole 1, mixture was applied at 5, 10 and 20 lbs a.i./ac. replicated three times. Treatments were made in April, except on two occasions when May/June applications were made, to populations of various established weed species. Assessments of the volume of live growth were made during the season. Those illustrated were made in September and show the volume of live growth surviving at the end of the growing season when treatments had been applied between ten and twenty-one weeks.

Figure 1

Illustrating percentage volume live growth surviving application of three simazine/amitrole mixtures (Mean results - six sites 10-21 weeks after application.)

100% = Untreated control



RESULTS

Results are summarised in the figures. Figure 1 shows that a 20% volume in live growth (i.e. an 80% reduction) was produced by the following doses of mixtures :-

simazine 2 : amitrole 1	at 3·6 lbs a.i./ac.
simazine 1 : amitrole 1	at 4·5 lbs a.i./ac.
simazine 1 : amitrole 2	at 5·6 lbs a.i./ac.

Superior total weed control was maintained at higher dosage rates with mixtures favouring simazine.

Figure 2, i and ii, shows that it takes up to 12 weeks for atrazine to reach maximum effect (necrosis and chlorosis of vegetation), while a simazine/amitrole mixture can produce maximum effect within three weeks.

The susceptibility of a number of weed species, such as ground elder (Aegopodium podagraria), docks (Rumex spp), and dandelions (Taraxacum officinale), which are normally fairly resistant to simazine was evaluated (table 1).

Figure 2

Illustrating the speed of action of a 1:1 ratio simazine/amitrole mixture with that of atrazine at various dosage rates at one site

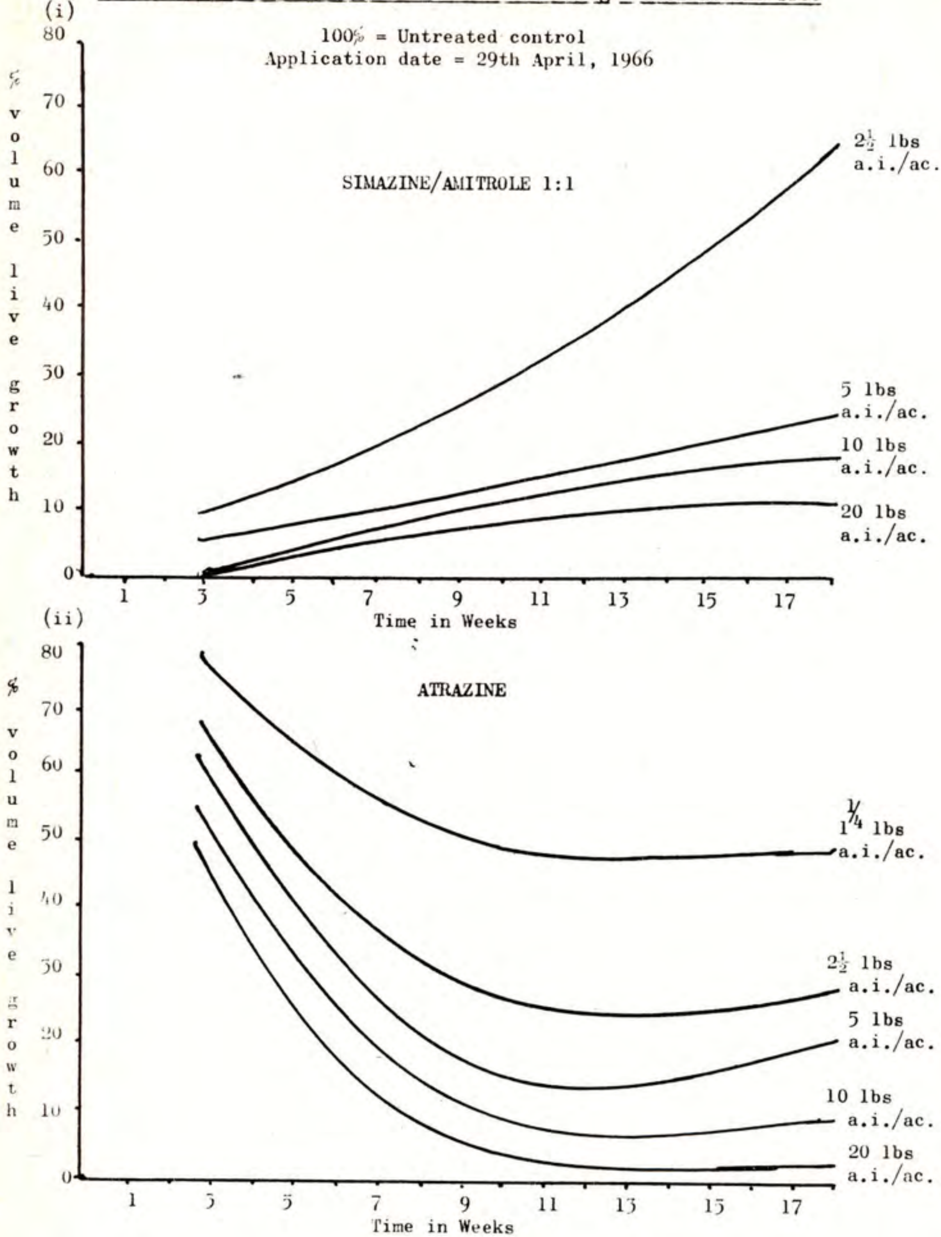


Table 1.

Response of various weed species to different doses of simazine/amitrole in a 1:1 ratio

S = susceptible plant appears killed.
MR = plant affected, but may recover and reproduce.
MS = plant appears susceptible, will probably die.
R = no significant effect.

Weed species		lbs a.i./ac. 20	10	5	$2\frac{1}{2}$	$1\frac{1}{4}$
Acer Pseudoplatanus (Sycamore) *	(P)	R	R	R	R	R
Achillea Millefolium (Yarrow)	(P)	S	S	S	R	R
Aegopodium Podagraria (Ground Elder)	(P)	S	S	MS	MS	MR
Agropyron Repens (Couch)	(P)	MS	MR	R	R	R
Agrostis Gigantea (Black Bent)	(P)	S	S	S	MR	R
Agrostis Tenuis (Common Bent)	(P)	S	S	MS	MR	R
Brachypodium Sylvaticum (Slender False-Brome)	(P)	S	S	MR	MR	R
Bromus Mollis (Soft Brome)	(A) or (P)	S	S	MS	MR	R
Centaurea Scabiosa (Greater Knapweed)	(P)	S	MR	R	R	R
Cirsium Arvense (Creeping Thistle)	(P)	MS	MS	R	R	R
Convolvulus Arvensis (Field Bindweed)	(P)	MR	R	R	R	R
Crataegos Monogyna (Hawthorn) *	(P)	MR	R	R	R	R
Crepis spp. (Hawksbeards)	(A) or (P)	S	S	MS	MR	R
Dactylis Glomerata var.Collina (Cocksfoot)	(P)	S	S	S	MS	MR
Festuca Rubra.sub sp.Rubra,var.Rubra(Red Fescue)	(P)	S	MS	MR	R	R
Fumaria spp. (Fumitory)	(P)	S	MR	R	R	R
Geranium Molle (Dove's-Foot Cranesbill)	(A)	S	MS	MR	MR	R
Geranium Robertianum (Herb Robert)	(A) or (P)	MS	MR	R	R	R
Glechoma Hederacea (Ground Ivy)	(P)	S	S	MR	MR	R
Heracleum Sphondylium (Hogweed)	(P)	S	MS	MR	R	R
Holcus Lanatus (Yorkshire fog)	(P)	S	S	MR	R	R
Hypericum Hirsutum (Hairy St.John's Wort)	(P)	S	S	S	MS	MR
Lotus Corniculatus (Birdsfoot-Trefoil)	(P)	S	S	S	MS	R
Malva spp. (Mallows)	(P)	MR	MR	R	R	R
Medicago spp. (Medick)	(A) or (P)	S	S	S	S	MS
Mercurialis Perennis (Dog's Mercury)	(P)	S	S	S	S	MS
Pastinaca Sativa (Wild Parsnip)	(P)	S	MS	MR	R	R
Plantago spp. (Plantains)	(P)	S	S	S	R	R
Potentilla Reptans (Cinquefoil)	(P)	MS	MS	MR	MR	R
Quercus Robur (Common Oak) *	(P)	S	S	MS	MR	R
Ranunculus Repens (Creeping Buttercup)	(P)	S	S	MS	MR	R
Rubus spp. (Brambles) *	(P)	S	S	MS	R	R
Rumex spp. (Docks)	(P)	S	MS	MR	R	R
Sherardia Arvensis (Field Madder)	(A)	S	S	S	MR	R
Sonchus Arvensis (Perennial Sowthistle)	(P)	S	MR			
Taraxacum Officinale (Dandelion)	(P)	S	MS	MR	R	R
Trifolium spp. (Clover)	(P)	S	S	S	MR	R
Tussilago Farfara (Coltsfoot)	(P)	S	MR	R	R	R
Urtica Dioaca (Nettle)	(P)					MR
Veronica Chaemadrys (Germander Speedwell)	(P)	MR	MR	MR	R	R

* = seedling or young plant ; P = perennial ; A = Annual

DISCUSSION AND CONCLUSIONS

Mixtures of simazine + amitrole would appear to have advantage in the following respects :-

1. 20 lbs a/ac of such mixtures will control or check a number of species which are normally fairly resistant to triazines applied alone.

2. The mixtures show rapid effect, while it takes up to three months to show maximum effect with atrazine alone.

3. Mixtures in the ratio of 2:1 in favour of simazine gave the greatest reduction in volume of live growth at the end of a growing season.

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REGENERATION FROM DEPTH OF SMALL RHIZOME FRAGMENTS OF AGROPYRON REPENS (L.) BEAUV., AEGOPODIUM PODAGRARIA L. AND POLYGONUM AMPHIBIUM L.

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Summary Small rhizome fragments of three weed species were planted at various depths in pipes filled with soil in a greenhouse to test their regenerative ability. Rhizomes from the previous year and from the current year were tested. *Polygonum amphibium* grew through greater depths of soil than did *Agropyron repens* or *Aegopodium podagraria*. Tests were also made to investigate why leaves of *A. repens* occasionally open prematurely underground and consideration is given to the effects of this on shoot regrowth from small fragments of this species.

INTRODUCTION

It is often stated that if *Agropyron repens* is ploughed under sufficiently deeply it will not re-establish. Vengris (1962) when testing a hypothesis on the mechanical control of *Agropyron* found that very few rhizome fragments 1 in. long (2.5 cm) with an average of 1.4 buds each were able to survive from 4 in. (10.2 cm) depth when planted in the field. However, fragments 6 in. (15.2 cm) and or 12 in. (30.5 cm) long with averages of 8.0 and 16.4 buds respectively were better able to survive from planting depths of 4 or 6 in. Kraus (1912) planted 12 cm long fragments of *Agropyron repens* with 4-5 buds each at various depths in glass and in metal containers and found that even when planted as deep as 40 cm a few shoots managed to emerge. He obtained similar results in the field. He noted that many shoots failed to reach the surface particularly from deeper plantings and that on a number of these shoots leaves had opened prematurely and had rotted *in situ* or had been sloughed off with passage through the soil, which he suggested had been the cause of death of the parent shoot.

The following four experiments were carried out to investigate these questions further and especially the reason for the failure of shoots from small fragments of *A. repens* to emerge successfully from depth.

METHOD AND MATERIALS

In the first two experiments (carried out in England) small fragments of rhizomes were planted at approximately 5 cm from the bottom of 1, 2 and 3 ft lengths of 3 in. diameter plastic down-water pipes filled with a light sandy loam soil. These pipes, which were split longitudinally and resealed with plastic insulating tape to aid recovery of the rhizomes, were placed erect with their bottom ends in boxes of soil. A number of drainage holes were bored 1 in. from the bottom of the pipes, which were watered both around the sides and from above. The pipes were kept in a greenhouse with a minimum temperature of 15°C. In the first experiment 6 replicates of 1-node lengths with a centrally placed bud of the previous year's rhizomes of *Agropyron repens*, *Aegopodium podagraria* and *Polygonum amphibium* were used and in the second experiment eight 2-node fragments of the current year's rhizomes. The sizes of planting material used are given in Table 1.

Table 1.

Sizes of rhizome fragments (cm)

	Expt. 1.		Expt. 2.	
	length	diameter	length	diameter
P. amphibium	3.4-6.6	0.3 -0.7	8.2-22.0	0.2 -0.55
A. podagraria	3.2-9.1	0.2 -0.45	5.5-14.5	0.15-0.25
A. repens	2.0-5.4	0.15-0.25	3.8- 9.6	0.15-0.3

In the third experiment 30 x 2 cm lengths of Agropyron rhizomes of the current year with a single node were incubated on moist filter paper in petri dishes at 25°C without light. The enfolding sheaths of the new shoots were measured after 14 days. In the fourth experiment 30 x 2 cm fragments of Agropyron repens rhizomes of the current year with a single central node were planted 15 cm deep in heavy loam soil in 20 cm diameter enamelled metal pots. The enfolding sheaths of the shoots were measured after 37 days. Experiments 3 and 4 were carried out in Germany.

RESULTS

The results of experiment 1 are given in Table 2.

Table 2.

Shoots grown from 6 x 1-node fragments of the previous years rhizomes planted at 25, 58 and 86 cm depth

(Planted 18 March, harvested after 9 weeks)

	Depth planted (cm)	No. of shoots that grew	No. of shoots that emerged	No. of shoots dead or dying at harvest	Av. length of all regrowing shoots (cm)	Longest shoot (cm)
P. amphibium		4	2	2	15.8	35.2
A. podagraria	25	3	0	0	3.2	4.0
A. repens		5	0	4	6.1	8.0
P. amphibium		5	1	4	32.8	61.1
A. podagraria	58	6	0	0	10.7	21.4
A. repens		5	0	3	9.3	15.8
P. amphibium		5	0	2	38.2	65.1
A. podagraria	86	7	0	0	5.5	10.3
A. repens		3	0	2	9.2	10.5

Aegopodium has been included in this table although it is the leaf stalks and not stems which grow upwards through the soil; all stems with the exception of flowering shoots normally remain below ground. The last but one column in Tables

2 and 3 applies only to underground parts, but the last column does include aerial parts when present.

The results of experiment 2 are given in Table 3.

Table 3.

Shoots grown from 8 x 2-node fragments of the current years rhizomes planted at 25, 58 and 86 cm depth

(Planted 11 August, harvested after 6 weeks)

Species	Depth planted (cm)	No. of shoots that grew	No. of shoots that emerged	No. of shoots dead or dying at harvest	Av. length of all regrowing shoots (cm)	Longest shoot (cm)
P. amphibium	25	5	3	2	23.6	30.7
A. podagraria		19*	0	0	5.7	18.8
A. repens		14	1	4	15.8	53.2
P. amphibium	58	8	0	6	20.9	44.2
A. podagraria		7	0	0	9.2	15.4
A. repens		12	0	5	16.6	30.4
P. amphibium	86	8	0	2	30.4	70.6
A. podagraria		9	0	0	6.2	12.0
A. repens		13	0	5	21.4	40.4

* Aegopodium can grow several leaves from each node

Approximately half the new shoots of Polygonum and Agropyron in these two experiments were dead or dying at harvest. Several Agropyron shoots were beginning to die at the apex, a feature noted by Kraus (1912), while Polygonum just as frequently started dying from below.

No statistical comparison of these experiments is possible because of the different sized fragments, the different number of replicates and the variable number of shoots that grow. However, relative to Polygonum and Aegopodium, it appears that Agropyron grew longer shoots from the new rhizomes in the second experiment.

All living shoots of Polygonum and Agropyron were cut up into 1-node lengths after harvest and incubated on damp cotton wool at 22°C to test their regenerative ability. None of these fragments grew and all died very quickly.

One or two shoots of Agropyron had leaves opened underground that were bent or crumpled, similar to the effect noted by Kraus (1912). Experiments 3 and 4 were carried out to see whether this effect was associated with the growth limits of the enfolding sheaths. The resultant lengths of these sheaths in both experiments are presented in Table 4.

Table 4.

The average lengths (cm) of enfolding sheaths of aerial shoots of A. repens regrowing from 2 cm 1-node lengths of rhizome.

	Sheath (numbered from base) 1	2	3	4	5
Expt. 3 grown in moist air at 25°C	0.3	0.6	1.5	2.8	4.1
Expt. 4 grown from 15 cm depth in soil	0.2	0.9	1.7	3.6	6.5

The number of replicates giving the average per sheath varies with the number of fragments in each experiment that had reached that particular stage of growth by harvest.

DISCUSSION

The conditions in the pipes of soil were very different from field conditions, but the results show what these species can achieve under good growing conditions. In the first experiment Polygonum was able to survive from greater depths than the other two species, although this was probably due to the greater diameter and hence greater food reserves of its rhizomes. In comparison the second experiment shows that Agropyron grew longer shoots from the new rhizomes (2-node plantings) than from the 1-node older ones while Polygonum and Aegopodium did not.

Aegopodium leaves did not reach the surface in any planting although one reached 21.4 cm in length. None of the leaves of Aegopodium had died at harvest although about half of all shoots of the other two species were moribund or dead.

The maximum length of the sheaths on Agropyron shoots was thought to be a possible factor limiting shoot emergence, but the results of experiments 3 and 4 show that although the maximum sheath length of the German clone investigated was only 5 - 8 cm. Unprotected leaves were capable of penetrating the soil undamaged (the maximum unprotected leaf in soil in experiment 4 was 5.3 cm, long). These results do not necessarily apply to the English material although in experiment 2 the longest Agropyron shoot penetrated about 16 in. of soil and must have had long unprotected leaves (the lengths were not measured).

It appears from the available evidence that small fragments of Agropyron are probably limited in regrowth from depth mainly by the available food reserves as suggested by Vengris (1962). The limited lengthening ability of the sheaths may, however, be of importance in some circumstances as shown by shoots with crumpled or sloughed-off leaves. Sheath lengths may, of course, depend to a certain extent upon the clone and the size of the rhizome present, while the ability of leaves to penetrate the soil undamaged may depend upon soil conditions and the leaves remaining rolled.

ACKNOWLEDGMENTS

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A STUDY OF THE EFFECTS OF RHIZOME LENGTH, SOIL NITROGEN AND SHOOT REMOVAL ON THE GROWTH OF AGROPYRON REPENS (L.) BEAUV.

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Summary This paper reports a factorial experiment conducted in seed boxes investigating three levels of each factor mentioned in the title.

Defoliation every 14 days prevented new rhizome growth, and apparently exhausted the food reserves of 3 in. rhizome pieces within 35 days. With 9in. pieces defoliation reduced food reserves slowly unless additional nitrogen was supplied. Defoliation every 28 days did not exhaust reserve nutrients and allowed new rhizome growth.

Added nitrogen increased above ground growth mainly by increasing leaf size, and to some extent by stimulating tillering. No treatment appreciably affected bud activity.

INTRODUCTION

Couch grass, Agropyron repens (L.) Beauv. is well known as a troublesome arable weed. Palmer (1958) and Palmer and Sagar (1963) have given full descriptions of the plant and the method of vegetative propagation. The grass produces abundant rhizomes which contain large nutrient reserves. There may be up to 2,000 lb/ac of available carbohydrate (Buchholtz, 1962). The rhizomes bear a bud at each node in the axil of a scale leaf, the usual internode length being about 1 in. There may be 800 in of rhizomes, and a similar number of buds per ft^2 of land (Proctor, 1960). The majority of these buds will usually be dormant; the apical bud tends to inhibit the development of lateral buds. This type of dormancy, due to apical dominance, has been discussed in detail by Audus (1959). If the apical bud is removed an axillary bud near to it takes over its function of suppressing lateral bud development.

In N. America another form of dormancy is associated with high temperatures and long day length in late spring (Johnson and Buchholtz, 1962). However, this type of dormancy does not appear to have been demonstrated in Britain, where dormancy due to apical dominance is probably of primary importance.

The nutrient reserves in the rhizome provide for rapid regeneration but this is regulated by the mechanism of apical dominance. Destruction of active buds usually activates about an equal number of dormant buds. The controlled regeneration ensures that the food reserves and the supply of buds are used economically.

Methods of control by cultivation aim at reducing the supply of food reserves and the buds by stimulating and destroying successive crops and shoots. Desiccation of the rhizomes assists the process. Such methods are often satisfactory but require so much time that it is necessary to leave the land fallow.

Herbicides such as amitrole, dalapon and TCA can give good control, but complete eradication of couch is unusual unless large doses are used. Several workers, for example Procter (1960) and Carder (1965), have shown that the best control follows combinations of herbicidal and cultivation treatments.

With both types of method, an increased proportion of active buds is able to lead to improved control, since active buds are more susceptible to mechanical damage and herbicides are translocated to them more rapidly. Sagar (1960 and 1961) has discussed this point. Increased shoot growth will reduce food reserves, at least in the earlier stages.

At present two practical methods of increasing bud activity are known. Firstly, dormancy may be reduced or even eliminated by cutting the rhizomes into short pieces. However, even with 6 in. pieces there may still be a proportion of dormant buds. (Vengris, 1962) To ensure that all viable buds shoot, the rhizomes must be reduced to single node sections, a difficult matter in the field.

Secondly, dormancy may be reduced by a high level of nitrogen in the rhizomes (Dexter, 1936; Johnson, 1958; Meyer and Buchholtz, 1958). Recently McIntyre (1964 and 1965) has shown that as well as stimulating bud activity nitrogen may affect the pattern of development of seedlings. For example, a high level of nitrogen causes most of the buds in the axil of the first leaf to form tillers. With limited nitrogen the majority produce rhizomes. According to Dexter (1936) and Schirman and Buchholtz (1960) the rate of depletion of food reserves due to control practices may be hastened by an ample supply of nitrogen.

This experiment examines the effects of rhizome length, soil nitrogen and defoliation. Defoliation was intended to represent a control measure, for instance the removal of shoots by cultivation or by means of a herbicide. Defoliation will of course not be exactly equivalent to either of these treatments, but to avoid complication only one method of limiting shoot growth was used, that of removing the shoots at ground level. Buchholtz (1962) has shown that frequent cutting leads to rapid depletion of the nutrient reserves. While there is a considerable amount of information regarding the direct effects of rhizome size, nitrogen and defoliation, the interactions between these factors appear to have been largely neglected. This experiment is an attempt to rectify the omission.

MATERIALS AND METHODS

The experiment was conducted in wooden boxes of size 24 x 13 x 6 in. A 3^3 factorial design was used, each box representing a single plot. The boxes were divided vertically into three equal sections by means of plastic sheeting, to allow rhizome growth to be assessed at three dates. There were two replications of the 27 treatments, which were all combinations of the following main treatments:-

Length of rhizome segment	3 in., 4.5 in., 9 in.
Added soil nitrogen	Nil, 100, 200 lb/ac. N.
Frequency of defoliation:	14, 28, 56 days.

The rhizomes used were obtained from a field near Begbroke Hill. It was not possible to obtain clonal material but the rhizomes used were collected from a very small area, and no variation was seen in the parent plants.

Unbranched rhizomes of approximately uniform thickness, colour and internode length were selected, and the apical section was removed. Very young, old, or discoloured rhizomes were discarded, as were any bearing active buds. A total of 108in. of rhizome was planted in each box, i.e. 12 x 9 in. pieces, 24 x 4.5 in. pieces or

36 x 3in. pieces, according to the treatment. One third of the rhizome segments were planted in each section of the box, at a uniform 2 in. depth. The total weights of rhizome and number of nodes in each section were approximately constant for all segment lengths: the mean figures were 1.46 g. dry matter and 39.3 nodes respectively.

A sandy loam soil from Begbroke farm was used. Stones were removed by screening, and 5% DDT powder was added at 1 oz per bushel of soil as a precaution against soil pests. Nitrogen was supplied as ammonium sulphate nitrate (26%N). For the nitrogen treatments, 15.3 g. or 30.6 g. of fertiliser per bushel of soil were used, equivalent to 100 or 200 lb/ac nitrogen, mixed to the depth of soil in the boxes, approximately 150 ppm and 300 ppm of nitrogen.

The experiment was planted between April 25th and 27th with the boxes placed in their proper order in the open. Ample water was given twice weekly and weeds other than couch were removed frequently. The first shoots appeared 7 days after planting and therefore the 14 and 28 defoliations were first carried out at 21 and 35 days, by cutting at soil level with scissors. At each cutting the stage of leaf development, numbers of primary and axillary shoots, and dry weights were recorded.

Rhizome growth was assessed at 21, 35 and 63 days from planting, by digging the plants from one section of each box. Most of the soil was removed by shaking after which the plants were washed and dried. On each occasion soil was replaced to avoid disturbing rhizomes in adjacent sections. When harvesting and defoliation dates coincided, shoots were not removed before the plants were dug.

The final harvest was between June 29th and July 1st. Mean temperatures during the experiment ranged from about 10°C in early May to 15°C at the end of June, with the lowest minimum 3°C on May 10th. As the boxes were watered, soil moisture was never a limiting factor to growth.

After drying, weights of the planted rhizome pieces, new rhizomes, shoots and roots were determined. The length and numbers of nodes of new rhizomes were recorded, with numbers of active and dormant buds on the planted rhizomes. Buds with a shoot more than 0.25 in. long were classed as active; in practice nearly all the active buds had shoots at least an inch long.

In the results section, all figures are the average for one box section.

RESULTS

a) Rhizome, shoot and root weights

There were no appreciable differences at 21 days from planting. At this date none of the material had been defoliated. While the planted rhizomes had lost about 20% of their original dry weight, to an average of 1.08 g., the loss was almost constant for all rhizome lengths and all levels of soil nitrogen.

Average rhizome, shoot and root weights for the main treatments at 35 and 63 days are shown in Table 1. While these overall mean values are of some interest they must be interpreted with care since they show the average response for each factor at all levels of the other two main treatments.

At 35 days only the 14 day defoliation treatment had been applied, 14 days previously. The 28 day and 56 day treatments were identical, no shoots having been removed.

The greatest effects were those of defoliation. Considering first the planted rhizome segments, it will be seen that in the absence of defoliation weights had started to recover at 35 days and by 63 days were approximately at their original level of 1.46g. However, when the plants were defoliated at 21 days, the rhizomes continued to lose weight, to an average of 0.89g. at 35 days, 39% below the planted weight.

Further defoliation at 14 day intervals did not reduce the dry weight further.

Table 1. Mean weight (g) of planted rhizome segments, new rhizome growth, and of shoots and roots.

Main Treatment	35 days from planting*		63 days from planting			
	Planted rhizomes	Shoots	Planted	New rhizomes	Shoots	Roots
3 in. segments	0.98	1.07	0.99	0.81	2.81	0.93
4.5 in. segments	1.06	1.31	1.25	0.71	2.90	1.13
9 in. segments	1.11	1.25	1.39	0.64	2.85	1.00
No added N	1.08	0.99	1.19	0.43	1.88	0.69
100 lb/ac	1.02	1.22	1.22	0.71	2.66	0.93
200 lb/ac	1.05	1.43	1.22	1.02	4.02	1.45
14 day defoliation	0.89	0.64	0.90	0.02	0.62	0.20
28 day defoliation	1.08	1.49	1.25	0.33	2.39	0.79
56 day defoliation	1.18	1.50	1.48	1.80	5.56	2.07
Standard error	±0.04	±0.08	±0.05	±0.06	±0.11	±0.05

* At 35 days new rhizome growth and root weights were negligible.

Defoliation every 14 days almost entirely suppressed new rhizome growth, and greatly reduced root development. Defoliation at 28 day intervals had similar but less marked effects.

Added nitrogen greatly stimulated root and shoot growth and increased the length and weight of new rhizomes. Varying the length of the parent rhizomes had relatively small effects. While the larger rhizomes lost weight more slowly, they produced a greater weight of shoots at 35 days.

These main treatment effects are of less importance than the interactions, some of which were considerable. From the point of view of control the rhizome weights are of primary importance. As might be expected there was a large nitrogen x defoliation interaction with regard to new rhizome growth and a similar but smaller interaction relating to the pieces of planted rhizome. These effects are shown in Tables 2(a) and 2(b).

Table 2. Weights (g) of rhizomes at 63 days after planting. (Mean for all lengths of planted rhizome).

(a) New rhizome growth

	No added N	100 lb/ac	200 lb/ac	Mean
14 day defoliation	0.01	0.01	0.04	0.02
28 day defoliation	0.19	0.31	0.51	0.33
56 day defoliation	1.08	1.81	2.52	1.80
Mean	0.43	0.71	1.02	

S.E. Body of Table ±0.08 Marginal means ±0.05

(b) Planted rhizomes

	No added N	100 lb/ac	200 lb/ac	Mean
14 day defoliation	1.00	0.87	0.83	0.90
28 day defoliation	1.26	1.25	1.24	1.25
56 day defoliation	1.32	1.54	1.58	1.48
Mean	1.19	1.22	1.22	

S.E. Body of Table ±0.11 Marginal means ±0.06

With frequent defoliation (Table 2 b) added nitrogen reduced the weight of the planted rhizomes. This was mainly due to the response of the 9 in. pieces (Table 3); it will be seen that added nitrogen had little effect upon the 3 in. segments. With 14-day defoliation in the absence of extra nitrogen the 9 in. pieces apparently gained weight slightly between 35 and 63 days. However, with 100 lb/ac added nitrogen they lost weight appreciably during this period.

With new rhizome growth, there was also a substantial nitrogen x planted rhizome length interaction (Table 4). At the high level of nitrogen the short parent rhizomes produced more new rhizome growth. This response was of course greatest in the absence of defoliation. From Table 2 (a) it will be seen that frequent removal of shoot growth suppressed new rhizome growth almost completely.

Table 3. 14 day defoliation. Weight of planted rhizome (g) at 63 days from planting.

	No added N	100 lb/ac	200 lb/ac	Mean
3 in. segments	0.76	0.74	0.82	0.77
4.5 in. segments	0.99	0.80	0.87	0.88
9 in. segments	1.25	1.08	0.81	1.04
Mean	1.00	0.87	0.83	

S.E. Body of Table ±0.04 Marginal means ±0.02

Table 4. Weights of new rhizome (g) at 63 days from planting. (Mean for all defoliation treatments.)

	No added N	100 lb/ac	200 lb/ac	Mean
3 in. segments	0.40	0.74	1.30	0.81
4.5 in. segments	0.47	0.70	0.94	0.71
9 in. segments	0.40	0.69	0.83	0.64
Mean	0.43	0.71	1.02	

S.E. Body of Table ±0.11 Marginal means ±0.06

The weights of shoots and roots at 63 days are shown in Tables 5 and 6. There were no appreciable differences between the three rhizome lengths but nitrogen greatly increased shoot and root development. Defoliation of course decreased shoot growth, and also reduced the amount of roots. In both tables a large nitrogen x defoliation interaction appears.

Table 5. Weights of shoots (g) at 63 days from planting. (Mean for all lengths of planted rhizome.)

	No added N	100 lb/ac	200 lb/ac	Mean
14 day defoliation	0.55	0.59	0.71	0.62
28 day defoliation	2.06	2.20	2.90	2.39
56 day defoliation	3.03	5.20	8.45	5.56
Mean	1.88	2.66	4.02	

S.E. Body of Table ±0.19 Marginal means ±0.11

Table 6. Weights of roots (g) at 63 days from planting. (Mean for all lengths of planted rhizome.)

	No added N	100 lb/ac	200 lb/ac	Mean
14 day defoliation	0.16	0.19	0.25	0.20
28 day defoliation	0.68	0.67	1.03	0.79
56 day defoliation	1.24	1.92	3.05	2.07
Mean	0.69	0.93	1.44	

S.E. Body of Table ±0.08 Marginal means ±0.05

(b) Bud activity

There were only small variations in the percentage of active rhizome buds. Differences due to the length of the rhizome pieces were negligible. Defoliation reduced the proportion of active buds significantly, while added nitrogen gave a small increase (Table 7). The figures at 35 and 63 days were very similar; almost no more buds became active after the experiment had run for 35 days.

Differences in the numbers of shoots were slightly greater. There was again very little variation between the planted rhizome lengths, but both defoliation and nitrogen significantly increased the number of shoots, mainly by causing the plants to tiller at or just above ground level (Table 8).

Table 7. Percentage of active buds at 63 days from planting. (Mean for all lengths of planted rhizome.)

	No added N	100 lb/ac	200 lb/ac	Mean
14 day defoliation	41.1	43.5	43.3	42.6
28 day defoliation	47.1	42.6	52.7	47.5
56 day defoliation	52.8	49.7	51.8	51.4
Mean	45.5	45.8	50.2	

S.E. Body of Table ±4.1 Marginal means ±2.4

Table 8. Numbers of above-ground shoots at 63 days from planting. (Mean for all lengths of planted rhizome.)

	No added N	100 lb/ac	200 lb/ac	Mean
14 day defoliation	37.0	35.3	40.7	37.7
28 day defoliation	39.7	34.0	40.5	38.1
56 day defoliation	22.5	26.2	37.3	28.7
Mean	33.1	31.8	39.5	

S.E. Body of Table ± 3.9 Marginal means ± 2.3

DISCUSSION

According to Buchholtz (1962), the available carbohydrate content of couch grass rhizomes may amount to between 30% and 50% of the total dry matter. In the present experiment the mean dry weight of rhizomes in each box section was 1.46 g and therefore the reserve of nutrients at planting was probably between 0.44 g and 0.73 g.

During the first 21 days of the experiment while the first flush of shoots was produced, the rhizomes lost on the average 0.38 g. This loss, which was approximately the same for all rhizome lengths and all levels of nitrogen, would appear to represent at least 50% of the reserve nutrients. In the absence of defoliation, the rhizomes had started to recover dry matter by 35 days, and at the termination of the experiment were approximately at their original planted weight.

However, removal of the shoots at 21 days led to a further loss of dry matter. At this stage there were differences due to the nitrogen and rhizome length treatments but with defoliation the average weight of the rhizomes at 35 days was 0.57 g less than at planting (Table 1). It appears that under the experimental conditions the mean effect of removing two crops of shoots was to exhaust most, if not all, of the reserve nutrients. Continued removal of shoots at 14 day intervals did not reduce the rhizome weights further.

The average dry weight of shoots removed increased from 0.18 g at 21 days to a maximum of 0.44 g at 49 days, and then fell to 0.20 g at 63 days. This result also suggests that with defoliation food reserves at the end of the experiment were very much reduced. It seems likely that at this stage the plants were existing on the nutrients produced by photosynthesis between defoliations.

The effects of nitrogen upon the rate of attrition of food reserves were of particular interest. With frequent defoliation, the weights of the planted rhizomes at 63 days show a large and highly significant nitrogen x segment length interaction (Table 3). In the absence of extra nitrogen the 9 in. pieces weighed only 0.21 g less than at planting. However, when 100 lb/ac added nitrogen was given, the loss of weight was 0.65 g, approximately the same as that obtained with the 3 in. rhizomes. If these losses are related to the estimated nutrient reserves it appears that without added nitrogen the 9 in. rhizome pieces lost only between 29% and 48% of their reserve nutrients during the course of the experiment. However, where 100 lb/ac of added nitrogen was given almost all the reserve nutrients were used.

With frequent defoliation, the effects of nitrogen appear to have been exerted mainly during the second half of the experiment. At 35 days the weights of the 9 in. segments were approximately the same for all nitrogen treatments. With 100 lb/ac added nitrogen the rhizomes continued to lose weight during the following 28 days. However, in the absence of extra nitrogen the rhizome weights recovered slightly during this period.

The 3 in. rhizome pieces lost most of their estimated reserves as a result of defoliation, nitrogen having little effect upon the rate of exhaustion. Defoliation at 14 day intervals almost entirely prevented new rhizomes being formed. With short pieces of rhizome it seems probable that good control would be obtained by one or two defoliations, followed by a more positive control measure such as an application of a translocated herbicide or ploughing. With longer rhizomes, attrition of the food reserves is slow unless ample nitrogen is available. Where it is not feasible to reduce the rhizomes to relatively short pieces, and where the time available for control is limited, added nitrogen may be of assistance.

Without frequent defoliation added nitrogen assisted the recovery of the planted rhizomes and increased the growth of new rhizomes (Table 2). Appreciable weights of new rhizome were produced even where shoots were removed every 28 days. With this regime, nitrogen increased the production of new rhizomes considerably; it is clear that in these circumstances nitrogen is likely to increase rather than diminish the stock of reserve nutrients.

Similarly, it appears that with a high level of nitrogen cutting the rhizomes into short pieces without also dealing with shoot growth may lead to a more rapid build up of nutrients. From Table 4 it will be seen that in the presence of nitrogen the short pieces of parent material produced a greater weight of new rhizomes than the longer pieces. At present it is difficult to explain this effect.

The overall effect of added nitrogen was to increase the weight of above-ground growth and roots considerably (Table 2). Neither added nitrogen nor rhizome length affected the proportion of active buds appreciably (Table 5). Defoliation reduced bud activity slightly perhaps by reducing the supply of nutrients available for new bud development. Nitrogen led to a small increase in the number of above ground shoots by stimulating tillering, and slightly increased the rate of leaf emergence; this effect has been demonstrated previously by McIntyre (1965). However, the increased production was mainly due to the production of larger, heavier leaves.

It is not clear why the proportion of active buds was almost constant for all treatments. Bud activity was unusually high: with all plots between 40% and 50% of buds produced shoots. It is possible that the rhizomes, which were collected from an arable field, contained ample stored nitrogen at planting.

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SOME EXPERIENCE OF TESTING NEW HERBICIDES ON PERENNIAL WEEDS IN POTS

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Summary An attempt was made to establish five perennial weeds in pots for the purpose of testing new herbicides. Polygonum amphibium L., Tussilage farfara L. and Sonchus arvensis L. grew successfully and were treated when well established with six herbicides. The effects of these herbicides on the shoots and rhizomes or roots are described. Picloram killed all three species at 0.25 lb/ac. Dicamba was almost as active on P. amphibium and also killed S. arvensis, but was less effective on T. farfara. Methyl 4-aminobenzenesulphonylcarbamate (M&B 9057) at 4 lb/ac was most active on T. farfara. MH, fenoprop and 2,4-D at 4, 2 and 1 lb/ac, respectively, gave inadequate control of P. amphibium and T. farfara but the latter two each killed S. arvensis. The advantage of pot experiments, especially for the observation of qualitative effects on below-ground organs, is considered. Cirsium arvense (L.) Scop. and Aegopodium podagraria L. proved less easy to grow and some factors in their establishment are discussed.

INTRODUCTION

The testing of new herbicides against a wide range of annual crops and weed species has been a regular feature of the work of the A.R.C. Unit of Experimental Agronomy and, more recently, of the A.R.C. Weed Research Organisation, for many years. This work has also included a few selected perennial weeds such as Agropyron repens, but very little information has been collected on the susceptibility of other important perennial species to new herbicides.

Field experiments are not satisfactory for primary screening work on perennials owing to the difficulty of finding suitable areas of uniform infestation and the need to make observations over a long period, especially of the underground parts. A start has been made in the field establishment of small plots of Rumex obtusifolius and A. repens for secondary screening (Anon, 1965) but there is also a need for work with many herbicides on a smaller scale. It is hoped that in due course there will be routine testing of new herbicides against a wide range of perennial weeds established in pots. Meanwhile some preliminary work has been done to see which of the important species can be grown satisfactorily in pots. This report is mainly concerned with one experiment in which the establishment of five species was attempted. The three species which grew successfully were treated with a range of herbicides including picloram, dicamba and methyl 4-aminobenzenesulphonyl-carbamate (M&B 9057). Older herbicides included for comparative purposes were 2,4-D, fenoprop and MH.

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METHODS AND MATERIALS

The aim was to establish single plants per pot of five species, each from clonal stock material. Single-node sections were cut from mature rhizomes of Polygonum amphibium L., Tussilago farfara L., and Aegopodium podagraria L. which had been grown in pots for some months. For Cirsium arvense (L.) Scop., 1.5 in. sections of underground stem (shoot bases) were used, and for Sonchus arvensis L. 1.5 in. lengths of true root, with buds already formed.

These were all planted on 17th June 1964, at 1 in. depth, in 8 in. diameter plastic pots filled with a compost comprising 2 parts of silty loam soil and 1 part of limestone sand. The pots were placed outside and watered as necessary.

On 9th September, P. amphibium, T. farfara and S. arvensis plants were sprayed with a range of herbicides at 58 gal/ac. The sprays included Tergitol NPX 0.1% as a wetter and were applied with a laboratory spraying apparatus comprising a single Teejet E-type nozzle travelling at 1.2 mph. The plants were protected from rain for 24 hours and were then given a thorough overhead watering. The pots were kept outdoors in a randomised block layout for a further 10 months. Observations on the shoots were made periodically; and at the final "harvest", fresh weights and dry weights of all shoots above ground and the dry weight of rhizomes and/or roots, were measured.

There were three replications. Results were treated statistically by analysis of variance. Treatments which killed all three replicates were excluded from the analyses.

Following the failure of A. podagraria and C. arvense to establish themselves in the above experiment, a number of further attempts were made to obtain improved growth from small fragments. Single-node sections of rhizome of A. podagraria were taken in August 1964 and placed on moist filter paper in petri dishes with or without prior soaking for 24 hours in distilled water, or in solutions of indolylbutyric acid ("Seradix"). In March and June 1965 single-node rhizome sections were cut from various parts of the rhizome system, and their growth in a soil compost was observed. A similar series of tests was made with C. arvense but sections of root were used rather than the underground stem used previously. There were also additional petri dish tests in September 1964 and July 1965 with various soaking and washing treatments and applications of α-naphthylacetic acid (NAA) to the ends of root sections.

RESULTS

Establishment of test plants

Most of the fragments of C. arvense planted in June 1964 produced shoots but these turned pale when only an inch or two high and subsequently died back. On examination it was found that no new roots had been formed. At the same time that these pots were set up, some fragments of roots, 1.5 in. long, were also planted but these were only slightly more successful; most of these also died. The roots from which these fragments were taken had probably been formed in the previous season. From the subsequent studies using 1.5-2 in. root fragments, it was concluded that the younger roots, produced in the current season, gave better establishment even when quite immature. Roots only 1.5 mm in diameter had some regenerative capacity, but those 3-5 mm in diameter gave more reliable results. Regeneration from old root material was not consistently bad. There were failures from June plantings of small fragments in both years, but larger fragments up to 6 in. long were successful and in March small fragments also grew well. In August andSeptember, root which was thought to have been formed in the previous sèason gave moderately good establishment provided it was not washed or soaked. In the course of attempts to improve production of new roots by soaking the root fragments in dilute solutions of "Seradix", it was found that any soaking, whether in the rooting hormone, or in de-aerated distilled water, or in running tap water, reduced both root and shoot development. Apparently some essential substance is leached out of the roots. In view of Bonnett and Torrey's experiments (1965) on *Convolvulus arvensis* it seems possible that the reduction in formation of new roots might have been due to loss of IAA. Sagar and Rawson (1964) on the other hand have obtained a positive response to gibberellic acid. The attempt to reproduce this effect of leaching in July failed, and it is presumed that the roots may be in a more critical condition in late summer than at other times. In this particular case it may have been a prelude to a general deterioration which has sometimes been noted in *C. arvense* after it has been grown in 10 in. pots for about 18 months. In some cases, the roots in the lower part of the pot decay over winter, and occasionally a whole pot has died out completely. The nature of this degeneration is not explained. It might be thought to be because the roots are unable to penetrate to their accustomed depth in the soil, but a similar rotting has been noted by Sagar and Rawson (1964) in plants in the field.

A.podagraria also failed to grow satisfactorily from the material planted. A few plants emerged and grew very slowly; others died back or did not even emerge. In some cases it appeared that the bud had sprouted but had grown horizontally and exhausted its reserves before emerging. In a subsequent test, soaking rhizome sections in a solution of "Seradix" increased rooting but the shoots were then suppressed. Multi-node lengths of rhizome have given more reliable establishment in June but growth is usually slow for the first month or two.

Regeneration appeared to be more vigorous in March when single node sections from the previous season's growth, or apical sections with one developed node, gave good results. Older rhizome, presumably then about 20 months old, was less successful.

P. amphibium, *T. farfara* and *S. arvensis* all grew readily, and from this and other plantings it does not appear that the selection of planting material or the time of year is critical for these species.

Herbicide experiment

By the time of spraying, *S. arvensis* had rosettes 12-15 in. across and stem elongation was just beginning. The root system was well developed with many adventitious buds and occasional secondary shoots emerged.

T. farfara had large rosettes comprising leaves up to 7 in. in diameter. *P. amphibium* had main shoots with up to 20 nodes, 18 in. long and 3-7 axillary shoots from the lower nodes. Both these latter species had vigorous new rhizomes, a few of which had emerged at the edge of the pots to give secondary shoot systems.

The spraying was carried out in bright warm weather and symptoms from 2,4-D, fenoprop, picloram and dicamba began to develop within a few days. MH and M&B 9057 took several weeks to show their first effects.

By the beginning of November, after 2 months, the top growth of *P. amphibium* and *S. arvensis* had all been killed back by frost. *T. farfara* was still green until somewhat later in the winter. All began re-growing in April, *T. farfara* producing flowers, and the other two species tufts of leaves.

Regular observations were made over the next few months until the plants were harvested in July, ten months after treatment. The final results are summarised in Table I.

Table 1.

The effects of six herbicides on P. amphibium, T. farfara and S. arvensis

Dry weight as % of controls

		P. amphibium		T. farfara		S. arvensis	
		above ground (a)	below ground (b)	above ground (a)	below ground (b)	above ground (a)	below ground (c)
Herbicide	lb/ac						
picloram (K)	0.06	48	43	112	75	0	0
	0.25	0	0	0	0	0	0
	1.0	0	0	0	0	0	0
dicamba (amine)	0.06	70	69	106	109	0	0
	0.25	4	4	136	101	0	0
	1.0	1	1	52	17	0	0
M&B 9057	1.0	90	97	121	81	91	111
	4.0	90	93	0	17	25	47
MH (amine)	4.0	53	56	103	65	-	-
fenoprop (K)	2.0	76	74	134	94	0	0
2,4-D (amine)	1.0	67	63	106	51	0	0
L.S.D. (P=0.05)		21	20	33	22	46	60

(a) comprising all shoots above ground level.

(b) comprising roots, rhizomes and shoot bases.

(c) comprising roots and shoot bases.

P. amphibium. 2,4-D, as expected, caused initial epinasty and gradual death of the shoots but regrowth the following year was almost normal. Rhizome development may have been temporarily arrested but no buds were killed. Fenoprop had no more effect than 2,4-D either on shoots or on rhizomes, in contrast to previous experience, (Parker 1962) when fenoprop gave excellent control at this dose; the plants then, however, were treated at a much earlier stage.

Picloram caused typical deformities of the new growth and then death of the shoots within 8 weeks. There was a small amount of recovery from 0.06 lb/ac (1 oz/ac) in the spring but none from 0.25 or 1 lb/ac. Observations on the rhizome system showed that 0.06 lb/ac had killed the rhizome for some distance back from the tip. Some of the most distal of the remaining buds had made abnormally weak growth or died back after a while, but others, immediately basal to these, had produced vigorous new rhizomes. Further back a number of other buds had emerged to produce aerial shoots. The original crown and a few of the most proximal lateral buds were dead, probably because these had been making active growth at the time of treatment.

Dicamba had similar effects to picloram on both shoots and rhizomes. There was some damage to the rhizomes at 0.06 lb/ac, but control was still not complete at 0.25 or 1 lb/ac, only one replicate being killed at each of these higher doses.

M&B 9057 at 4 lb/ac caused gradual death of shoot tips and some retardation of rhizome growth, but recovery was vigorous in the following spring.

Maleic hydrazide at 4 lb/ac, gradually stopped shoot growth in the autumn and retarded regrowth somewhat in the spring. Effects on rhizome development were very striking. The tip and some sub-apical buds were completely inhibited, though not rotted. Further back the buds developed for a few cm and then ceased growth. The tips of these appeared dead but there may have been viable buds on the closely spaced nodes of these branches. On lateral branches found further back, the tips had been similarly killed and some secondary branches arising from them had also been inhibited but others had eventually been able to make normal growth. No lateral buds on the original rhizome had remained dormant. Where new rhizomes had developed they showed the normal dormancy of most lateral buds. A lower dose of 1 lb/ac MH, which was only applied to this species, had little effect on the shoots or on the total weight of roots and rhizome produced, but it did cause inhibition of rhizome apices and of the first sub-apical branches to be produced.

T. farfara. 2,4-D and fenoprop caused deformity of new growth in the autumn and this was reflected in reduced flowering in the spring. This was to be expected as the leaf rosettes of one season are the source of the flowers for the following year. Both compounds damaged some of the rhizome system, especially the extreme basal and apical regions of the main rhizomes, but the tertiary branch rhizomes were mainly undamaged and emerged to produce abundant healthy foliage.

Picloram had more severe initial effects than 2,4-D and the 0.25 and 1 lb/ac doses resulted in complete kill. 0.06 lb/ac reduced flowering and damaged the rhizomes in the same way, and to about the same extent, as 2,4-D at 1 lb/ac.

Dicamba at 0.06 and 0.25 lb/ac caused deformities of new growth initially but had less effect on flowering than did 1 lb/ac 2,4-D. At 1 lb/ac there was rather more extensive damage to rhizomes but there was vigorous new production of foliage.

M&B 9057 at 1 and 4 lb/ac seriously interfered with new growth in the autumn, but the lower dose surprisingly did not affect the flowering in the spring. Some flowers opened at 4 lb/ac but many rotted before opening. Leaf emergence was delayed at 1 lb/ac and completely suppressed by 4 lb/ac. Basal and distal regions of the rhizomes were killed, leaving short sections of the main rhizomes with some stumps of branches. These had attempted to sprout but had repeatedly aborted to form a swollen mass of unhealthy buds. Presumably they might eventually have recovered.

MH at 4 lb/ac first caused mottling of the new foliage and then a purpling of old foliage. There was no effect on flowering in the spring, nor on new foliage. The tips of the main rhizomes were killed back but there was normal emergence of the branches.

S. arvensis. 2,4-D, fenoprop, picloram and dicamba all caused deformities of new growth, followed by death of the old foliage and, eventually, death of the whole root system, at 1 lb, 2 lb, 0.06 lb and 0.06 lb/ac respectively.

M&B 9057 resulted in yellowness of the new foliage after about a month, followed by death of the foliage after 2 months. 1 lb/ac had little effect on regrowth in the spring, but 4 lb/ac caused it to be very pale and much of it died back. At the time of harvest, most of the larger roots were apparently undamaged, but there was a reduction in fibrous roots and a great many shoots had aborted as on T. farfara to give knobbly masses of abnormal buds. Only in one replicate were there a few healthy shoots. MH was not applied to this species.

DISCUSSION

The establishment of perennial weeds in pots, from small root and rhizome fragments has proved simple for Polygonum amphibium, Sonchus arvense and Tussilago farfara, and also for A. repens and Agrostis gigantea in other experiments not reported here. C. arvense, A. podagraria and Convolvulus arvensis have been more difficult. The factors involved in ease of establishment with the latter three species seem to be partly seasonal. Further studies on these will be of interest, not only for the purposes of experimental herbicide work, but also with regard to the natural pattern of their development and their ability to regenerate in the field.

The quantitative results from herbicide experiments on perennial weeds in pots are of limited value in predicting the performance of a particular dose of herbicide in the field, but, provided some standard, well-known herbicides are included, the results should be of some practical value; and much can be learnt of the way in which the herbicides act, and in particular, of the way in which plants recover. The stage of development of the plants can be quite precisely known at the time of spraying by washing out spare plants; and similarly at the end of the experiment the complete plant system can be safely retrieved and studied.

Apart from the final destructive assessment, the condition of the underground parts can be observed periodically, simply by knocking the soil mass out of the pot. Owing to the natural tendency for rhizomes and roots to spread laterally, they inevitably reach the outside of the soil mass and then continue to grow round or down the side of the pot. Consequently a large proportion of the rhizome and root growth is visible on the surface of the soil mass. To what extent growth is abnormal as a result of contact with the pot is not certain. It is possible that some rhizomes are deflected upwards and emerge when they would normally not do so, but the majority continue to grow horizontally and may grow to a length of 6 to 8 ft by repeatedly circling the pot. In this respect standard pots are much superior to boxes, in which rhizomes are liable to get "trapped" in corners. They are also preferable to cylindrical tins or drums, as the tapered sides allow the soil mass to be easily removed and replaced. In the course of the experiment, observations on the underground parts are normally restricted to one replicate only, in case the brief exposure to light or other physical disturbance should influence the behaviour of the roots or rhizomes, but there has been no indication of any interference with the pattern of development on any of the species studied so far.

Brief conclusions from this one herbicide experiment include the following: P. amphibium was killed by picloram at 0.25 lb/ac. It was also very susceptible to dicamba. 0.06 lb/ac of either compound was equivalent to about 1 lb/ac of 2,4-D in causing partial kill of the rhizome system. Fenoprop at 2 lb/ac was no better than the 1 lb/ac dose of 2,4-D. MH caused interesting interference with apical dominance in the rhizomes but 4 lb/ac was not enough to prevent quite strong recovery. This species appears resistant to M&B 9057.

T. farfara was also killed by picloram at 0.25 lb/ac, and 0.06 lb/ac was again equivalent to about 1 lb/ac of 2,4-D. Dicamba, however, was only a little more effective than 2,4-D and fenoprop was less so. M&B 9057 was highly effective at 4 lb/ac, killing most of the rhizome system and preventing all shoot development up to ten months after treatment. MH at 4 lb/ac did no more than 2,4-D at 1 lb/ac.

S. arvense was very susceptible to the four growth regulator herbicides, being killed by picloram, dicamba, 2,4-D and fenoprop at doses of 0.06, 0.06, 1 and 2 lb/ac respectively. M&B 9057 at 4 lb/ac did not kill the root system but almost completely prevented all aerial growth for 10 months.

A feature of the action of all the herbicides on the rhizomatous species was that the growing tip of the rhizome was the part to be first or most easily damaged in spite of its distance from the point of application on the shoots. This supports the concept of translocation to active metabolic "sinks". After the apex had been damaged, sub-apical buds sprouted and were often, in turn, affected. Recovery, where it occurred, usually came from buds relatively near the original shoot system. By the time these more basal buds sprouted, presumably much of the herbicide in the plant had been dissipated or metabolised. Means are now being studied, whereby apical dominance in the rhizomes can be overcome prior to herbicide treatment, so that as many as possible of the lateral buds are "sinks" at a time when there is the maximum amount of herbicide present in the plant.

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POT EXPERIMENTS WITH NEW HERBICIDES ON *Allium vineale* L.

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Summary. Of eleven herbicides incorporated into the soil before sowing, di-allate, tri-allate, chloramben and naptalam each showed partial selectivity against *A. vineale* in wheat, but none was completely satisfactory. Among a wide range of post-emergence treatments, those causing some kill and/or suppressing development of scapes and aerial bulbils included paraquat 1 lb/ac, fenoprop 4 lb/ac, 2,3,6-TBA 0.25 lb/ac, dicamba 0.5-2 lb/ac, tricamba 0.5-2 lb/ac, picloram 0.12-0.5 lb/ac, 2-chloro-9-hydroxy-fluorene-(9)-carboxylic acid (IT 3456)1-4 lb/ac, 2-chloro-6-t-butyl-o-acetotoluidide (CP 31675)6 lb/ac, MH 1-4 lb/ac, amitrole 2-4 lb/ac and 2-chloro-4-fluoro-phenoxyacetic acid 1 lb/ac. Some of these are of possible interest in cereals, but selectivity is not likely to be wide with any. Only at non-selective doses did any of these compounds kill all minor offset bulbs, but lower doses of several of them, notably dichlorprop, fenoprop, 2,3-6-TBA, dicamba and picloram shortened the dormant period of the minor offset bulbs and caused premature sprouting in early autumn. It is suggested that these herbicides, combined with autumn cultivation should be tested further as a means of reducing the carry-over of dormant bulbs into subsequent crops, so preventing the build-up of an infestation where the rotation cannot be adjusted to include spring-sown cereals.

INTRODUCTION

Allium vineale L. is a troublesome weed of pastures and winter cereals on heavy land. Cultural methods of control on arable land involve late autumn or spring ploughing, and a rotation of mainly spring-sown crops, (Gt. Britain, 1960, Hakansson, 1963). 2,4-D and MCPA are of some value for reducing the build-up of bulbs in winter cereals, and 2,4-D esters can be used in grassland, but control is not complete and treatments need to be repeated over many years. There is a need for herbicides which will provide a more effective control both in cereals and in grassland, and a number of experiments are described here, in which a wide range of new herbicides were tested for this purpose.

METHODS AND MATERIALS

The *A. vineale* was collected from the field in April 1961, and grown on in stock pots outside. The type of bulb used in each experiment is described below. The nomenclature used is that of Richens (1947).

The soil for experiments 1, 4 and 5 was a Marlborough silty clay loam. For Experiments 2 and 3 it was made up into a compost with sand and peat (4:1:1). The spraying in each case was carried out with a laboratory spraying device comprising a Teejet E type nozzle travelling at a constant speed of 1.2 mph.

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Pre-sowing treatments: Experiment 1

For this experiment, the herbicides were sprayed on to soil in 3.5 in. diameter plastic pots. The soil was theh mixed thoroughly and returned to the pots. The resulting concentration in the soil was equivalent to an incorporation to a depth of 2.25 in. Two replicate pots were each sown with 4 aerial bulbils of *A. vineale*, 0.75 in. deep, on 28th November, 1961. Two further replicates were each sown with 5 seeds of wheat (var. Atle) at the same depth. The pots were placed in the greenhouse and watered from above as required. The fresh weights of above-ground parts of wheat were measured on 22nd December, 1961, and those of *A. vineale* on 29th January, 1962.

Post-emergence treatments: Experiments 2 to 5

For Experiments 2 and 3, "small plants" were established by planting 3-5 aerial bulbils per pot on 14th October, 1961. "Large plants" were grown from terminal or major offset bulbs, planted singly per pot on the same date. For Experiment 2 there were 3 replicate pots of the small plants, (8-12 plants per treatment present at the time of spraying), and one replicate (i.e. a single plant) of the larger material. For Experiment 3 there were 4 replicate pots of the small plants and 8 of the large plants.

The plants were maintained outdoors through the winter and were treated on two dates, at which time the stage of growth was as follows:-

(i) April 19th. (Experiment 3 only)

(a) Small plants - 2 green leaves about 2 in. high; no visible development of minor offset bulbs or scape.

(b) Large plants - 3-4 green leaves, 9-15 in. high; no visible development of minor offset bulbs or scape.

(ii) June 6th (Experiments 2 and 3)

(a) Small plants - up to 50% in some replicates had scapes up to 12 in. high; the remainder were mainly non-scapigerous, about 5 in. high; most with 2-3 minor offset bulbs, some mature and dormant, a few already sprouted.

(b) Large plants - 3-4 green leaves plus scape up to 30 in. high; most with major offset and 2-4 minor offset bulbs developing, some apparently mature.

Experiment 2 comprised 25 herbicides sprayed on 6th June, 1962, at 56 gal/ac, with 0.67% Tween 20 as a wetting agent. In Experiment 3, the esters of 2,4-D and its 4-fluoro analogue were compared at each of the two dates above. These were sprayed at 14 gal/ac without wetter. Each spraying was followed 24 hours later by heavy overhead watering.

Observations were made on deformity of the bulbil heads. Bulbils were also collected and stored, and in March 1962, the viability of 2x10-bulbil samples from all available heads was tested in petri dishes. Counts were also made of the number of shoots emerging in each pot in autumn 1962. At the final assessment in spring 1963, the fresh weights of the shoots of the small plants was measured and the offset bulbs were examined.

For Experiment 4, two types of plant were again used. Large plants were grown from major offset bulbs and smaller plants from terminal bulbs which were transplanted in October 1963, without any minor offsets attached. There were 2 replicate pots of the large plants and 4 of the smaller plants. Each pot contained a single plant. The plants were grown outdoors and were treated on two dates. The stage of growth at each date was as follows:

(i) April 23rd (a) Smaller plants - 3 green leaves, 6-8 in. high; some minor offset bulbs apparently mature, some dormant, others sprouted; scape not yet elongating.

(b) Large plants - 3-4 green leaves, 9-12 in. high; no well developed offset bulbs, nor any elongation of the scape.

(ii) May 12th (a) Smaller plants - 4 green leaves, 9-12 in. high; 2-3 minor offset bulbs, about 50% of which had sprouted; scape elongating, 2-3 in. long.

(b) Larger plants - 4-5 green leaves, up to 18 in. long; some immature minor offset bulbs; scape beginning to elongate, 2-3 in. long.

Most herbicides were applied at 56 gal/ac with 0.5% Tween 20 as a wetting agent, but MH was also applied without any wetter. Fenoprop was also applied by pipette direct to the soil. At the second date, amitrole was sprayed on to some plants placed at an angle of 35° from the vertical. Retention of the sprays was estimated for the treatments with and without wetter and for the plants sprayed at an angle. A 4% solution of tartrazine was sprayed and the concentration of dye in the washings from the plants was estimated colorimetrically on a photoelectric absorptiometer.

Assessments included observations, counts, weights and germination tests on aerial bulbils produced in the season of spraying, and counts of the shoots emerging from offset bulbs in the autumn. The experiment was harvested in two stages, half in January and the remainder in May, 1965. At each time, 2 replicates of the small and 1 replicate of the larger plants was examined, and the development of the offset bulbs recorded.

For Experiment 5, aerial bulbils were planted in January, 1965 and grown in the greenhouse until 8th April. Thereafter they were kept outside. There were 5 single-plant replications of each treatment, and 2 dates of spraying, at which times the stage of growth was as follows:-

(i) May 18th 2-3 green leaves, 6-9 in. high; 1-2 minor offset bulbs well developed but not yet mature.

(ii) May 28th 1-4 green leaves, 9-15 in. high; most with 1 mature minor offset bulb and 1-3 well developed but not yet mature.

Very few plants produced scapes in 1965.

The main treatments, with 8 herbicides, and including two formulations of fenoprop, were sprayed on 28th May, at 14 gal/ac without wetter. Additional treatments were fenoprop-potassium at 14 and 56 gal/ac plus 0.4% Tween 20. Only fenoprop ester was sprayed at the earlier date. Tartrazine was again used for measuring the retention of sprays at different volume rates, with and without wetter.

Assessments included counts of shoots emerging in autumn 1965 and observations on the height, vigour and production of scapes in 1966. The state of the minor offset bulbs was examined in 2 replicates on 27th April and in the remaining 3 replicates on 18th June, 1966.

Herbicides for which there is no approved common name, are referred to by code numbers as follows:-

BP-3	α-carbo(2,4-dichlorophenoxyethoxy)ethyl-N-phenylcarbamate
CP 31675	2-chloro-6-t-butyl-o-acetotoluidide
UC 22463	a mixture of 3,4- and 2,3-dichlorobenzyl-N-methylcarbamate
D-263	a mixture of 1,1-dimethyl-4,6-diisopropyl-5(and -7-)indanyl-ethyl ketone
IT 3233	9-hydroxy-(9)-carboxylic acid
IT 3456	2-chloro-9-hydroxy-(9)-carboxylic acid
2-Cl,4-FPA	2-chloro-4-fluorophenoxyacetic acid

RESULTS

Pre-sowing experiment

Treatments causing some or complete suppression of A. vineale for 9 weeks were metham-sodium at 100 and 200 lb/ac, and di-allate at 2 lb/ac. These treatments were lethal or very damaging to wheat. A number of other treatments reduced the vigour of the weed without seriously damaging the wheat. Chloramben 6 lb/ac, di-allate 1 lb/ac, tri-allate 2 lb/ac and naptalam 2 lb/ac were the best of these, but in the absence of any competition from the crop, the weed appeared to be recovering by the time of assessment. The remaining compounds, 2,4-D-amine, 2,3,6-TBA-sodium, dicamba-sodium, tricamba-sodium and diuron, showed neither selectivity in favour of wheat, nor any outstanding activity against A. vineale.

Post-emergence experiments

In Experiment 2, mortality of the small plants was not assessed precisely, but there was definitely some kill as a result of spraying paraquat 1 lb/ac, MH 4 lb/ac, 2,3,6-TBA and dicamba each at 1 lb/ac and dalapon at 16 lb/ac. There was more widespread mortality of the large plants, but this included some controls, presumably because of the severe winter of that year.

Plants which were not killed showed effects in various ways, (see Table 1). Firstly, the plants which produced scapes in the season of spraying showed various degrees of damage in the heads of aerial bulbils. The treatments which killed small plants also prevented the production of viable aerial bulbils, while some other herbicides also caused deformities and reduced viability. 2,3,6-TBA and dicamba were the most active in this respect. 2,4-D amine and MCPA, each at 2 lb/ac and 2,4-D ester at 1 lb/ac caused deformities but no loss of viability. 2-Cl,4-FPA ester was rather more active, causing deformities at 0.5 lb/ac and reduced viability at 1 lb/ac. Barban at 0.5 and 2 lb/ac caused marked abnormality of bulbils on the large plants, but had no corresponding effect on any of the small plants which produced scapes.

The phenoxypropionic acids did not cause any mortality or deformity, but did cause very early sprouting of the minor offset bulbs. Natural sprouting of these bulbs in the control pots occurred mostly in late autumn, whereas on plants treated with fenoprop at 4 lb/ac, it began in early August, and by 10th October represented 4 shoots per plant. There was a similar, but less marked tendency in the large plants. Fenac and all of the substituted benzoic acids other than chloramben, showed a similar tendency, as also did paraquat. Amitrole, MH and dalapon, however, caused a delay in sprouting rather than any acceleration.

Experiment 3 comprised a detailed comparison of 2,4-D and its 4-fluoro analogue, 2-Cl,4-FPA, which had previously shown greater activity than 2,4-D on cultivated onion. The 2-Cl,4-FPA caused more deformity of bulbil heads than 2,4-D and some reduction in viability at 0.5 lb/ac in this experiment - i.e. more active than in Experiment 2, possibly because of the lower volume spraying. The 2-Cl,4-FPA at 0.5 lb/ac sprayed in June also had a tendency to stimulate early sprouting of offset bulbs, which 2,4-D did not. There was appreciably greater effect of both

Table 1

The response of A. vineale to a range of herbicides applied as post-emergence sprays (Experiment 2.)

Herbicide	lb/ac	Effects on large plants grown from terminal bulbs (unreplicated): Bulbil deformity (+ or -)	Effects on large plants grown from terminal bulbs (unreplicated): Bulbil viability (%)	Effects on small plants grown from aerial bulbils (total 12 plants): Bulbil viability (%)	Effects on small plants grown from aerial bulbils (total 12 plants): Offset shoots emerged (10/62)	Effects on small plants grown from aerial bulbils (total 12 plants): Shoot fresh weights (%) (4/63)
paraquat-$(MeOSO_3^-)^2$	0.25	-	100	-	21	21
"	1	+	0	-	0	0
2,4-D-butyl	1	+	95	-	-)	(-
2-Cl,4-FPA-butyl	0.5	+	90	-	-)	(-
"	1	+	10	-	-) not	(-
2,4-D-amine	2	+	100	-	-) tested	(-
MCPA-amine	2	+	90	-	-)	(-
mecoprop-amine	4	-	-	100	14	87
dichlorprop-amine	2	-	100	100	23	149
"	4	-	-	95	29	124
fenoprop-amine	2	-	-	-	12	137
"	4	-	95	-	48	116
2,3-6-TBA-amine	0.25	+	50	-	19	93
"	1	+	0	-	5	16
dicamba-Na	0.25	+	-	-	10	85
"	1	+	0	0	4	2
tricamba-Na	0.5	+	-	100	11	122
"	2	+	50	16	15	57
chloramben-NH_4	2	+	90	-	4	119
"	8	+	65	95	8	87
fenac-Na	1	-	85	30	11	148
"	4	+	35	10	17	11
barban	0.5	+	100	100	2	100
"	2	+	-	100	1	110
dalapon-Na	4	+	100	30	0	54
"	16	+	0	0	0	14
MH-amine	1	+	100	95	0	44
"	4	+	-	35	0	3
amitrole	2	-	100	95	0	48
Control	0	-	100	100	0.25	100
L.S.D. (P=0.05)						51

Further treatments having negligible effect included:- 4-CPA-amine 2 lb/ac, 2,4,5-T-amine 2 lb/ac, naptalam-Na 4 lb/ac, BP-3 4 lb/ac, linuron 2 lb/ac, pyrazon 4 lb/ac, prometryne 2 lb/ac and lower doses of several of the above herbicides.

Table 2.

The response of *A. vineale*, established from terminal bulbs, to a range of post-emergence treatments, applied at two dates. (Experiment 4.)

Herbicide	lb/ac	Sprayed 23rd April 1964: Wt. of aerial bulbils (%)	Sprayed 23rd April 1964: Shoots per 4 plants (10/64)	Sprayed 23rd April 1964: Dormant offsets /2 plants (1/65)	Sprayed 12th May 1964: Wt. of aerial bulbils (%)	Sprayed 12th May 1964: Shoots per 4 plants (10/64)	Sprayed 12th May 1964: Dormant offsets /2 plants (1/65)
2,4-D-amine	1	94	3	5	82	3	5
"	2	82	3	7	58	2	1
"	4	66	5	6	64	5	1
2,4,5-T-K	1	85	5	3	105	3	12
"	2	90	4	5	99	4	4
"	4	89	5	2	90	6	2
mecoprop-amine	1	100	5	3	63	13	0
"	2	103	8	3	85	11	3
"	4	65	14	2	63	12	3
dichlorprop-K	1	100	5	3	63	13	0
"	2	85	12	6	70	12	1
"	4	61	15	0	43	20	0
fenoprop-K	1	111	6	8	85	8	0
"	2	97	9	0	65	17	0
"	4	65	20	1	35	21	0
fenoprop-K) to (	1	109	5	6	107	8	2
")soil(	2	120	10	4	106	13	3
")only(	4	65	15	2	84	17	1
dicamba-Na	0.25	65*	2	4	21*	9	0
"	0.5	5*	13	0	0*	19	0
"	1	0*	15	0	0*	12	0
picloram-K	0.15	6*	11	0	14*	13	0
"	0.3	0*	14	0	7*	10	0
"	0.6	0*	5	0	0*	4	0
MH-amine	1	86*	4	8	14*	1	7
"	4	0*	1	3	0*	0	0
MH-amine) no (	1	87	4	11	93	5	8
")wetter(	4	99	4	9	43	2	3
amitrole	1	48	4	5	76	4	8
"	2	21*	4	11	62	4	10
"	4	4*	4	10	56	4	9
amitrole)plus	1	8*	4	4	57	3	9
)NH_4-	3	3*	4	9	58	4	12
2 lb/ac)SCN	9	3*	5	8	50	4	7
CP 31675	2	33*	12	0	-	-	-
"	6	0*	3	0	-	-	-
Control	0	100 (5g/plant)	4.3	10.7	100 (4.8g/plant)	4.0	9.3

* viability of bulbils significantly reduced, ($P = 0.05$).

compounds when they were sprayed in June rather than in April.

Experiment 4 was carried out (a) to confirm the dormancy-shortening effect of fenoprop and other compounds, (b) to determine the influence of time of application, and (c) to test a few new herbicides. Two sizes of plants were treated, but as results were closely comparable on each set of plants, only those for the smaller plants are presented in Table 2.

The shortening of the dormant period was again caused by the phenoxypropionic acids and by dicamba and picloram, but not by 2,4-D or 2,4,5-T at rates up to 4 lb/ac. An examination of 2 replicates in January, 1965 showed that there were no minor offset bulbs remaining dormant in a number of these treatments, whereas the controls still had about 5 dormant offsets per plant. A further examination on the remaining replicates in May, however, showed that most offsets had by then sprouted in the controls also, there being not more than one per plant still dorment. It is not clear why the offsets show less persistent dormancy in pot experiments than is apparently common in the field.

The phenoxyacetic and -propionic acids caused some reduction in weight of aerial bulbils at 4 lb/ac, but did not influence viability. Dicamba and picloram were much more active in this respect and MH, amitrole and CP 31675 also had severe effects.

Complete kill of the major offset bulb and hence elimination of the parent plant was only achieved with picloram 0.6 lb/ac and MH 4 lb/ac, though some significant mortality also occurred with amitrole.

Effects from the growth regulator herbicides and from MH were generally more pronounced at the later date of spraying, whilst those of amitrole were distinctly greater at the earlier date.

The addition of ammonium thiocyanate at 1,3 or 9 lb/ac to amitrole at 2 lb/ac increased the degree of damage to the bulbil heads and also caused more distinct albinism in the regrowth when a special assessment was made in December, 1964. Barban at 2 lb/ac had much less effect than it had in Experiment 2. CP 31675 was in limited supply and was only tested at the earlier date. Both doses caused the scape to become twisted and dark green, and aerial bulbils were much reduced at 2 lb/ac. The regrowth from the major offset bulbs was very much retarded and one was killed at 6 lb/ac. The minor offsets sprouted early, but were otherwise normal. Dichlobenil was substituted at the later date, but was ineffective at 4 lb/ac.

The retention measurements showed that, when sprayed at 56 gal/ac, without wetter, at the earlier date, the smaller plants retained 0.017 ml/plant, and the large plants 0.06 ml/plant. With the addition of 0.5% Tween 20, these amounts were increased by 12% in each case. The increase in retention seems unlikely to account for the difference in the activity of MH when sprayed with and without wetter, and presumably differential penetration may be involved. At the later spraying, the smaller plants retained 0.04 ml/plant when placed in the usual vertical position. When held at 35° from the vertical, retention was increased by 38%, and there was a corresponding small increase in the activity of 1 lb/ac amitrole sprayed in this way.

The aims of Experiment 5 were (a) to obtain further information on the optimum formulation and time of application of fenoprop for influencing the dormancy of the offset bulbs, (b) to see if equal effects could be obtained with lower doses of picloram and dicamba, and (c) to test the effect of 3 new compounds.

The tartrazine measurements showed that spraying at 14 gal/ac without wetter resulted in the retention of 0.0076 ml/plant. With 0.4% Tween 20, it was increased by only 8%. At 56 gal/ac plus wetter, 0.02 ml/plant was retained (cf. Experiment 4). Allowing for the different concentrations of the spray solutions, retention of the herbicide was 70% greater with the lower volume spray. The presence of wetting agent, or the use of ester instead of the potassium salt did not make any apparent difference to the performance of fenoprop, and there was only a small advantage from low volume spraying. The later date of spraying, however, again gave somewhat better results.

The counts of old minor offset bulbs remaining dormant in spring, 1966, showed that sprouting was virtually complete with all formulations of fenoprop at 1-4 lb/ac and with picloram-potassium at 0.06-0.25 lb/ac and dicamba-amine at 0.12-0.5 lb/ac, but was scarcely influenced by 2,4-D amine at 1 lb/ac. D-263 at 4 lb/ac and UC 22463 at 8 lb/ac had no noticeable effects at all.

Most plants did not produce scapes in 1965, and died back naturally within a few weeks after spraying. Fenoprop at 2 and 4 lb/ac and dicamba 0.5 lb/ac caused partial kill of the terminal bulbs, but the most severe effects were caused by picloram, IT 3233 and IT 3456. Picloram killed the majority of the parent bulbs at 0.12 and 0.25 lb/ac. The fluorenol compounds achieved little kill, but IT 3233 at 4 lb/ac and IT 3456 at 1 lb/ac each caused severe deformity in the regrowth, suppression of scape production in 1966, and also abnormalities in the new offset bulbs being produced in the spring of 1966.

DISCUSSION

A.vineale has a somewhat complex growth cycle (see Richens, 1947). Briefly, it emerges from bulbs in the autumn and grows slowly through the winter. In the spring, all plants produce minor offset bulbs below ground. Larger plants produce a scape which bears flowers and/or aerial bulbils. The main axis of the plant dies after producing a scape and is replaced by a major offset bulb. Smaller plants die down in July without producing a scape but the main axis survives as a terminal bulb. The aerial bulbils, major offsets and terminal bulbs have a brief dormant period before resprouting in the autumn. The minor offsets, however, may remain dormant for several years.

When spring-sown crops are grown, it is possible to keep the weed under control by suitable autumn and spring cultivations. In winter-sown cereals, however, it sprouts at the same time as the crop and is able to complete its growth cycle undisturbed. In this discussion it is intended to consider how herbicides may be used to reduce the problem of A. vineale where winter cereals have to be grown.

Ideally, perhaps the weed should be controlled in the autumn by a pre-emergence or early post-emergence treatment. In the one experiment with pre-sowing treatments described here, metham gave good control but is impractical on a farm scale. Di-allate, tri-allate, chloramben and naptalam showed partial selectivity but their usefulness has not been checked in the field. Only a limited number of herbicides has been tested and it is possible that more selective treatments could be found. It is hoped to include A. vineale in more routine selectivity experiments in future.

Post-emergence treatments have not been applied to newly emerged plants in the autumn, although this is a possible method of control. The pot experiments have all been carried out on well-established plants in spring and early summer in order to simulate the normal time for spraying herbicides in cereals, and to make comparisons with MCPA and 2,4-D.

(i) Kill

Herbicides which were found capable of killing the terminal or major offset bulbs and so preventing regrowth direct from the parent plant included paraquat 1 lb/ac, fenoprop 4 lb/ac, 2,3,6-TBA 1 lb/ac, dicamba 0.5-2 lb/ac, picloram 0.12-0.6 lb/ac, MH 4 lb/ac, amitrole 4 lb/ac (or 2 lb/ac plus ammonium thiocyanate) and IT 3456 1-4 lb/ac. Unfortunately only fenoprop would be at all selective in a cereal, and this caused kill of small plants in only one experiment. 2,3,6-TBA has been suggested for spot treatments (Davis et al. 1962) and, together with dicamba and picloram, could be used in pasture - but only at the expense of clovers. Selective eradication in cereals does not appear feasible with the compounds tested so far.

(ii) Aerial bulbils

Other than the treatments listed above which killed the parent plants, only 2,3,6-TBA 1 lb/ac, dalapon 16 lb/ac and CP 31675 6 lb/ac completely prevented production of viable bulbils. Treatments causing gross deformities and much reduced viability included the 4-fluoro analogue of 2,4-D at 1 lb/ac, 2,3,6-TBA 1 lb/ac, dicamba 0.25 lb/ac, tricamba 0.5-2 lb/ac, fenac 4 lb/ac and MH 1 lb/ac. MCPA and 2,4-D amines at 2 lb/ac and 2,4-D ester at 1 lb/ac caused some deformities of the scape and bulbils. This deformity can reduce the number of bulbils harvested with the cereal grain, by causing the scape to bend down below the level of the cutter bar, but in these experiments the viability of the bulbils was unaffected. The phenoxypropionic acids at 4 lb/ac caused no deformity and only moderate reductions in bulbil production. Treatments of possible practical interest in cereals would appear to be low doses of 2,3,6-TBA, dicamba and picloram.

(iii) Minor offset bulbs

2,3,6-TBA 1 lb/ac, picloram 0.6 lb/ac and MH 4 lb/ac killed all minor offset bulbs as well as the parent plant, but all other treatments allowed some survival. Any surviving dormant bulbs represent a potential infestation of subsequent crops. Many of the treatments, however, caused a shortening of the dormant period, such that most minor offset bulbs sprouted in late summer or early autumn. The phenoxypropionic acids and picloram were especially active in this respect, while the effect was also apparent with 2,3,6-TBA, fenac, dicamba, paraquat, CP 31675 and the 4-fluoro analogue of 2,4-D. Hakansson (1963) observed this effect with MCPA and commented on its potential value, but it does not appear to be as consistent with either 2,4-D or MCPA as with these various newer compounds. Hakansson (1963) and Davis et al. (1965) have described morphological differences in minor offsets after treatment with 2,4-D and 2,3,6-TBA which might explain the effect, but Hakansson also reports that a shortened dormancy period can result from spring cultivations. The fact that it can also be caused by paraquat suggests that it may be the result of a relatively non-specific effect, such that the outer scales fail to attain their full degree of impermeability, upon which dormancy is believed to be largely based.

The practical implications of this shortened dormancy are that at least the latest crop of minor offset bulbs may come into growth early enough in the autumn to be destroyed by cultivations prior to sowing a winter cereal. It is suggested that where winter cereals have to be grown in infested land, one or other of the above herbicides should give a more satisfactory reduction in carry-over of dormant offset bulbs than 2,4-D or MCPA. Dichlorprop and fenoprop are the most likely to be safe, but dicamba, picloram or 2,3,6-TBA would have more effects on the scapes and aerial bulbils, and could be useful as additions or alternatives to the phenoxypropionic acids. Further work is required to confirm these findings in the field and to establish optimum doses, timing and methods of application.

The assessments made in these experiments did not permit any firm conclusions concerning the effects of herbicides on the dormancy of bulb types other than the minor offsets.

Time of application

Hakansson (1963) reports that the optimum time for application of 2,4-D and MCPA on A. vineale is when the scape has begun to elongate, or when non-scapigerous plants are in a correspondingly late stage of development. In these experiments results with all the growth regulating herbicides (including effects on dormancy of offset bulbs) were consistently better when sprayed later rather than earlier, over the range from April 19th to June 6th, but the timing did not appear to be critical. MH also gave better results in May than in April, but amitrole was better with earlier spraying.

Formulation and application method

Reducing the volume rate and spraying plants at an angle each increased the retention of herbicide substantially. The addition of a wetting agent only increased retention slightly, but markedly increased the activity of MH. The ester form of 2,4-D was more active than the amine salt, but neither wetting agent nor the use of ester instead of the potassium salt increased the activity of fenoprop. Fenoprop applied on the soil around the plants had almost as much effect as a foliar spray. Picloram would probably also be active in this way, and selectivity might be improved as the substantially greater retention by the foliage of the crop would then be avoided.

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THE CONTROL OF PERENNIAL AND ANNUAL GRASSES AND ANNUAL BROAD LEAVED WEEDS IN POTATOES WITH PRE-EMERGENCE APPLICATIONS OF EPTC

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Summary Following successful use in the U.S.A., trials were carried out in the U.K. to evaluate EPTC as a selective herbicide in potatoes. Results show that EPTC gives efficient control of Agropyron repens and Agrostis spp. at 4lb/ac a.i., as well as annual grass weeds, and has a high degree of selectivity in potatoes. In addition 4lb /ac a.i. will give adequate control of Stellaria media, Chenopodium album, Lamium amplexicaule, Fumaria officinalis and Veronica spp. while that of P. aviculare is usually poor. Capsella bursa-pastoris, Senecio vulgaris and Matricaria spp. are resistant to a dose of 4lb/ac a.i. Best control of broad leaved weeds was obtained when application was made immediately prior to planting. EPTC has been found to be less active on soils of a high organic matter content.

INTRODUCTION

Commercial use in the U.S.A. EPTC (S-ethyl NN dipropylthiolcarbamate) has been marketed as EPTAM* in the U.S.A. for several years, for use as a selective herbicide, which when applied and incorporated into the soil at rates of 2 to 6lb/ac a.i., has provided effective pre-emergence control of Sorghum halepense, Cyperus spp, Agropyron repens and all annual grasses growing from seed. Broad leaved weeds such as Stellaria media, Lamium amplexicaule, Chenopodium album, have been controlled if application was made when conditions were favourable for germination.

In the U.S.A. EPTC is registered for use in a wide variety of crops including alfalfa, beans (snap and dry), carrots, clovers, corn (field and sweet), cotton, potatoes (Irish and sweet), and sugar beet (Anon 1965).

Characteristics of EPTC EPTC is relatively non-toxic and has an acute LD-50 in rats, of 1,630 mg/kg and an acute dermal LD-50 in rabbits of about 10,000 mg/kg (Anon 1965).

EPTC is a volatile chemical, which if applied to the soil surface without incorporation, particularly in warm conditions, can result in loss of chemical with resultant poor weed control. (Gray and Weierich 1965).

For optimum weed control under normal U.K. soil and climatic conditions, EPTC must be mechanically incorporated into the soil to a depth of 4 to 6 inches immediately after application. The best method of chemical incorporation has been found to be by rotavation (Holroyd 1964), the authors have also found cross harrowing with discs to be effective.

* Registered trademark of Stauffer Chemical Company, New York, U.S.A.

If EPTC is applied to extremely dry soil, during dry climatic conditions, incorporation by overhead irrigation following application has been found to be satisfactory, as has metering EPTC into the irrigation water for flood irrigated crops, such as citrus and deciduous orchards. (Anon 1965).

Other workers in the U.K. have demonstrated the tolerance of potatoes to rates of up to 6lb/ac a.i. (Anon (a) 1965) and in Canada up to 10lb/ac a.i. has been used safely (Everett 1964).

In 1964 it was decided to evaluate the possible uses of EPTC as a selective herbicide in potatoes in the U.K. with particular reference to the control of A. repens.

METHOD AND MATERIALS

EPTC: S-ethyl NN dipropylthioloarbamate - as an emulsifiable concentrate containing 72% a.i. w/v.

Two types of trial were carried out; the first being replicated small plot trials giving mainly weed response, and the second larger grower trials, to assess the effect on crop yields.

These trials were carried out in different areas of the country to give three different soil types - light sandy and medium to heavy loams, and highly organic soils.

Materials on small plot trials were applied through a Van der Weij sprayer (modified to give finite rates) at 50 g.p.a. or through an Oxford Precision sprayer at 30 g.p.a. On the grower trials standard farm sprayers were used.

1964 Trial

A small plot trial was carried out using 4lb/ac a.i. and 8lb/ac a.i. to determine the possibility of controlling A. repens in a potato crop. The chemical was sprayed onto the soil and immediately rotavated in to a depth of 4-6 inches. The potatoes were planted 3 weeks after application.

1965 Trials

Unfortunately the 8lb/ac a.i. dose rate had to be ruled out on economic grounds so it was decided to continue with the 4lb/ac a.i. rate for the control of A. repens in potatoes. A dose of 3lb/ac a.i. was used where the rhizomes of A. repens were chopped up by discing or rotavation 2-3 weeks before application. It was hoped that the chopping up of the rhizomes would stimulate the growth of the maximum possible number of dormant buds, as it has been shown that the action of EPTC is dependent on uptake via the shoot, prior to emergence (Appleby et.al 1965) (Parker 1966). Twelve grower trials were carried out using EPTC at 3lb/ac a.i. on chopped up A. repens rhizomes, potatoes were planted from 2hours to 14 days after application. In one case the EPTC was applied to the potato ridges post-planting, the ridges were harrowed down and then re-ridged up again.

In addition a small plot trial carried out on sown plots of perennial and annual grass weeds comparing EPTC 2lb and 4lb/ac a.i. and another on fallow arable land to determine the degree of control of A. repens, Agrostis gigantea and Avena fatua. Incorporation was by rotavation to a depth of 4-6 inches.

1966 Trials

Seven grower trials on potatoes using EPTC at 4lb/ac a.i. were carried out on mineral soils. Incorporation was to a depth of 5-6 inches by rotavation or disc harrowing.

RESULTS

1964 Trial

Results showed that a dose of 4lb/ac a.i. gave 70% control of A. repens while 8lb/ac a.i. gave 84% control. The 8lb/ac a.i. rate was tolerated by King Edward potatoes planted three weeks after application.

1965 Trials

Any improvement in the germination of the dormant shoots was probably outweighed by the drop in dosage. Control of A. repens was variable - the average figure for the 12 grower trials was only 59% control. The results appear in Table 1. Broad leaved weed control was also variable, although adequate control of some species such as Veronica spp, Chenopodium album and Stellaria media was obtained.

Table 1.

1965 Trial Data and Results

Site No.	Location	Soil Type	% organic matter	Method incorp.	% control A. repens.
1.	Norfolk	sandy loam	2.1	Rotavated	70
2.	Worcs	sandy loam	3.0	Springtines	80
3.	Yorks	medium loam	3.6	Rotavated	70
4.	Angus	medium loam	4.1	Springtines	15
5.	Beds.	sandy loam	4.8	Springtines	70
6.	Lincs.	heavy loam	5.7	Disc harrowed	60
7.	Norfolk	sandy loam	6.8	Disc harrowed	60
8.	Yorks	silt loam	7.1	Rotavated	70
9.	Norfolk	heavy loam	10.0	Rotavated	30
10.	Cambs.	skirt fen	12.8	Disc harrowed	10
11.	Lincs.	organic silt	21.9	Disc harrowed	70
12.	Norfolk	organic	28.0	Rotavated	not present
				mean 11 sites.	59%

The failure at site 10 can be explained by the two week delay between application and incorporation. Site 4 was sprayed in very hot, dry weather and there was a delay of one hour between application and incorporation, which may account for the poor control of A. repens.

The high organic matter at site 9 may explain the poor control of A. repens but site 11 gave a good result where the organic matter was higher. At site 12 there was no A. repens but Phragmites communis which was present, was not controlled again probably due to the high organic matter. There was no effect on potato haulm vigour or any yield depression at any site.

Tables 2, 3 and 4 show the results from small plot trials.

Table 2.
% control of annual and perennial grass spp. on loam soil 2 months after treatment.

EPTC	Poa annua	Poa trivialis	Agrostis tenuis	Agrostis stolonifera	Lolium perenne	Mean % control
2lb/ac a.i.	81	83	61	78	42	69
4lb/ac a.i.	89	87	97	93	81	89
No. shoots on untreated plots (60ft x 6ins.sample)	130	152	141	162	125	

Table 3.
% control of annual broad leaved weeds on sandy loam soil 6 weeks after treatment

EPTC	Fumaria officinalis	Matricaria spp.	Polygonum aviculare	Senecio vulgaris	Veronica spp.	Lamium amplexicaule	Capsella bursa-pastoris	Urtica urens	Stellaria media	Chenopodium album	Mean % Weed control
2lb/ac a.i.	31	0	37	20	89	78	0	0	80	88	42
4lb/ac a.i.	93	63	42	37	97	97	33	61	95	96	71
Untreated No weeds/12^2	83	121	19	158	99	116	270	210	83	74	-

Table 4.
% control of A. repèns A. gigantea and Avena fatua on a fallow loam

EPTC	A. repens/ A. gigantea	Avena fatua.
2lb/ac a.i.	32	17
4lb/ac a.i.	81	65
Untreated no. shoots/$10yds^2$	562	212

1966 Trials

Table 5 shows site details and results from six of the seven grower trials carried out, information was not obtained from the seventh trial, due to foot and mouth disease.

Table 5.

Site No.	Location	Soil Type	Method of incorporation	% control of A. repens
1.	Herts.	loam	rotavated	77
2.	Herts.	loam	rotavated	81
3.	Worcs.	loamy sand	rotavated	98
4.	Norfolk	medium loam	planter ridger	84
5.	Yorks.	silt loam	triple K harrowed	79
6.	Hants.	loam	rotavated	90
			mean	85

No phytotoxicity has been observed to potatoes that have been planted in soil treated with EPTC. The following varieties of potato have been tested - King Edward, Majestic, Arran Pilot, Record and Dr. McIntosh.

The control of A. repens by EPTC at 4lb/ac a.i. was about 80% while that of annual grasses was nearer 90%, annual broad leaved weed control was about 70%. The following is a suggested order of susceptibility for the broad leaved weeds that have occurred in our trials.

Susceptible:	*C. album* *S. media* *Veronica spp.* *F. officinalis* *L. amplexicaule* *Galeopsis tetrahit*
Moderately susceptible:	*P. aviculare* *P. persicaria* *U. urens*
Moderately resistant:	*Matricaria spp.* *P. convolvulus*
Resistant:	*S. vulgaris* *C. bursa-pastoris* *Solanum nigrum* *Sonchus spp.*

DISCUSSION

While weed control on most mineral soils is satisfactory, that on soils containing more than 10% organic matter is variable and usually unsatisfactory.

Incorporation of EPTC into the soil immediately following application is vitally important for efficient weed control Work on factors affecting the vapour loss of EPTC from soils has shown that the most important factor is soil moisture. During the first 15 minutes after spraying on the soil surface, 20% of the applied EPTC disappeared from dry soil, 27% from moist soil and 44% from wet soil. The loss was 23, 49 and 69% after one day. (Gray and Weierich 1965). These figures help explain some of the poor results obtained where incorporation was delayed.

Provided incorporation is efficient and follows immediately after application the time lapse before planting does not affect the control of A. repens; but it does affect the control of broad leaved weeds. Optimum broad leaved weed control occurs when planting immediately follows application, poor control results if planting is delayed 2 or more weeks after application (authors experience and unpublished results elsewhere). The reason is that EPTC has a relatively short persistence in the soil after incorporation. A preliminary investigation has shown that on a mineral soil sprayed with EPTC 4lb/ac a.i. and immediately rotavated in, 66 ppm were detected from a 2 in. soil core taken on the same day, 18 ppm 7 days after, 12.4ppm 14 days and 7.4ppm 28 days after application. The lower levels allow the germination of certain resistant and moderately resistant weed species.

From the results it is difficult to determine the best method for the incorporation of EPTC. Rotavation has been suggested as the best method (Holroyd 1964). The authors have concluded that most types of harrow have given satisfactory results provided a high forward speed is maintained and that depth of incorporation is 4 to 6 inches. Cross harrowing removes any risk of streaky incorporation.

Chopping up of rhizomes of A. repens, 2-3 weeks prior to application of EPTC probably increases the level of control, provided good growing conditions allow the germination of dormant buds.

So far residues of EPTC in potatoes have been of an acceptably low level.

EPTC shows certain advantages over two of the chemicals dalapon-Na and amitrole, currently used for control of A. repens and other perennial grasses in arable land. Both these chemicals have to be applied to the foliage of actively growing A. repens and then at least two weeks must elapse before ploughing. The accomplishment of this operation is often difficult or even impossible in Northern areas where, between harvest and onset of frost, there is only a short interval in which it is possible to apply the herbicide to actively growing foliage. Dalapon-Na can also be applied to potatoes before emergence for the control of grasses which have sufficient foliage to receive an effective dose of the spray but this combination of circumstances is not readily obtained. EPTC has the advantage of being soil applied immediately before potato planting and being non-dependent on the presence of foliage of A. repens.

It is thought that while the use of EPTC at 4lb/ac a.i. will not give complete control of perennial grass weeds, its use will give control sufficient to enable an economic potato crop to be grown.

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THE CONTROL OF PERENNIAL GRASSES BEFORE AND DURING THE PRODUCTION OF POTATOES

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Summary The results of three experiments carried out in 1965-66 are reported. In two experiments where no crop was grown, autumn treatments applied to Agropyron repens and Agrostis gigantea in cereal stubble showed that two rotary cultivations gave a very substantial reduction in shoot numbers in the following year. Amitrole T at 5 lb/ac also caused a marked reduction in shoot numbers but to a lesser extent. In the third experiment, spring treatments of TCA, dalapon and linuron were applied before seedbed preparation to plots containing the same grasses as above; these plots were then split for EPTC mixed in prior to potato planting, dalapon or linuron applied before emergence, and cultivation as required. TCA and EPTC were outstanding in controlling the grasses and the latter herbicide also gave a control of broad-leaved weeds comparable with linuron which in turn gave the poorest control of grasses. Such weed competition as occurred appeared to be caused by the broad-leaved weeds and not by the grasses because the highest potato yields resulted from the use of EPTC or linuron and not from TCA which gave the best grass control. Cultivation resulted in mediocre weed control and a low yield.

INTRODUCTION

In rotations involving a major proportion of cereal crops, the most troublesome perennial grasses are Agropyron repens and Agrostis gigantea: where potatoes are included in such rotations it may be expected that these two will infest the crop. The past five years have seen considerable activity in the development and marketing of herbicides for use in the potato crop. However the chemicals, with the exception of paraquat, are not capable of providing a satisfactory control of perennial grass weeds. Paraquat has on many occasions provided excellent control, but its success relies on obtaining a good emergence of the grass before the potatoes; failure to do so, can lead to poor control. For this reason paraquat, useful though it is, cannot be considered to provide the full answer.

As part of a wider investigation on potatoes, the Weed Research Organisation carried out three experiments on perennial grasses during 1965-66. Two, which were similar in design, examined the possibility of control after cereal harvest in the autumn of the year prior to potato planting; while the third compared treatments in their ability to control the grasses in the potatoes.

METHOD AND MATERIALS

Experiments AA.29.65 (Chipping Norton) and AA.30.65 (Stanton St. John).

Both experiments started on stubble after the harvesting of a cereal crop. The Chipping Norton Site contained approximately equal quantities of A. repens and A. gigantea; while that at Stanton St. John contained only A. repens. In both experiments the statistical design was split plots in randomised blocks. Each block was replicated 4 times. The split plot treatments applied in the autumn were:-

1. Rotary cultivation twice (with two weeks' interval)
2. 5 lb/ac amitrole-T.
3. None

These plots were split further for nitrogen (75 units/ac) or no nitrogen applied prior to the stubble treatments above. During the winter the main treatments of mouldboard versus chisel ploughing were super imposed. The main plots were 15 yd x 15 yd, sub-plots 5 yd x 15 yd and sub-sub-plots 5 yd x 7.5 yd. The nitrogen as sulphate of ammonia was applied by hand on 17.9.65 at Stanton St. John. Rotary cultivation was carried out by a medium sized tractor moving at 1 m.p.h. and with a rotor speed of 180 r.p.m.; the depth of work was to 6 in. and the average rhizome length after the first cultivation appeared to be 7 - 8 in. The cultivations were carried out on 20.9.65 and 5.10.65 at Stanton St. John. Amitrole-T as Weedazol T.L. was applied from a Land Rover sprayer (Fryer and Elliott, 1954) on 14.10.65 at Stanton St. John. At Chipping Norton the sequence of events was the same but a fortnight later than at Stanton St. John.

In 1966 the land was not disturbed or planted to a crop, so as to allow assessment of the emergence of grass shoots.

Experiment AA.28.65 (Begbroke Hill).

This experiment was carried out on land which had grown wheat in 1964 and was to be planted to potatoes (var. King Edward) in the spring of 1965. The soil was a sandy loam and was known to contain *A. repens*, *A. gigantea*, *Fumaria officinalis*, *Raphanus raphanistrum* and other weeds. The experiment was a randomised block, split-plot design with 4 replicates. The main plots were 30 ft x 65 ft and the sub-plots were 30 ft x 13 ft (6 rows of potatoes, 26 in. apart).

The land was mouldboard ploughed in autumn 1964, disc harrowed in February, and rolled in March 1965 to obtain a reasonably level surface. Treatments C (TCA) and D (dalapon) were applied on 2.3.65 and 1.4.65 respectively. On 24.4.65 the whole area was cross-ploughed and treatment C (linuron) was applied on 28.4.65. On 29.4.65, EPTC (treatment 1) was applied and mixed in by rotary cultivation immediately. The potatoes were planted and ridged on 29.4.65. No further soil disturbance occurred except on the cultivation plots (treatment 5) which received two passes of a rigid tined cultivator and final ridging.

Main treatments:

A. 5 lb/ac dalapon sodium + a wetting agent.
B. 1 lb/ac linuron as a 50% wettable powder.
C. 30 lb/ac TCA sodium.
D. No herbicide.

Sub-treatments:

1. 6 lb/ac EPTC emulsifiable concentrate.
2. 5 lb/ac dalapon sodium + a wetting agent.
3. 1 lb/ac paraquat + a wetting agent.
4. 1 lb/ac linuron as a 50% wettable powder.
5. Cultivation.

In all cases the chemicals were standard proprietary herbicides.

The whole area was sprayed for blight as required, and the potato haulm was burnt off on 6.9.65. Harvesting started on 21.10.65. The herbicide treatments were applied at medium volume from a tractor mounted sprayer, specially built for experimental applications.

During the life of the crop assessments were made of weed performance.

RESULTS

Experiment AA.29.65. and AA.30.65

After the ploughing treatments had been carried out in mid-January 1966, the two sites were left undisturbed and unplanted. Although this treatment was artificial in that a farmer would be unlikely to be so lax, the intention was to provide all the live grass rhizomes with ample opportunity to produce shoots. The growth of grass on the various plots in spring and summer 1966 may thus be regarded as worse than would occur in practice if the land was planted to potatoes or a cereal. Assessments were made at regular intervals at the two sites, and a similar pattern of effects was seen; these are illustrated by the shoot counts made in June and presented in Table 1.

Table 1

The effect of treatments on A.repens and A.gigantea (AA.29.65) and A. repens (AA.30.65) Means for each treatment

			AA.29.65. on 24.6.66.		AA.30.65. on 13.6.66.	
Nitrogen	Autumn Treatment	Ploughing	Shoots/ft^2	leaves/shoot	Shoots/ft^2	leaves/shoot
+	rotary	m/board	4.1	3.6	0.4	2.7
-	rotary	m/board	6.2	3.4	0.3	1.2
+	rotary	chisel	5.9	3.6	0.4	2.5
-	rotary	chisel	6.4	3.4	0.2	3.5
+	amitrole	m/board	10.6	3.7	1.5	2.9
-	amitrole	m/board	15.7	3.6	3.4	2.9
+	amitrole	chisel	10.3	2.9	1.9	2.9
-	amitrole	chisel	13.2	3.7	1.8	3.1
+	none	m/board	63.3	4.0	11.8	2.8
-	none	m/board	58.0	3.8	11.7	3.1
+	none	chisel	85.8	3.9	14.8	3.3
-	none	chisel	55.3	4.0	13.8	3.1

The figures for AA.30.65. are means of four replicates, those for AA.29.65. are based on two replicates. Observations on 3.5.66 and 4.7.66 showed that the trends of effect were similar in all replicates of AA.29.66.

The most striking outcome of the treatments is the substantial reduction in grass shoots caused by rotary cultivations in the autumn: at both sites the shoot density was on average less than a tenth of that on the plots that received no autumn treatment. Although much reduced in numbers, the shoots that did emerge on the rotary cultivated plots were healthy and, in June, were not different in stage of growth from those on the untreated controls. Amitrole-T caused a marked reduction in the numbers of shoots but at both sites the chemical was less effective than rotary cultivation. The first shoots to emerge on the amitrole-T plots were purple but the effect was transitory and subsequent growth was normal. The type of ploughing appeared to have little effect on the outcome. The application of nitrogen in the autumn did not cause differences comparable with rotary cultivation or amitrole-T. But the figures provide some suggestion, particularly in AA.29.66, that the addition of nitrogen may have assisted in the control provided by these two. The possible interaction might merit further investigation.

Experiment AA.28.65.

From the start of the experiment in early March until potato emergence in late May, the plots were subjected to the various treatments and it was not possible to carry out comparative assessments. After potato emergence the only treatment still being applied was that of cultivation. On 13th June, 23 days after the application of the last herbicide treatments and 17 days after the last cultivation, assessment of perennial grass shoots was carried out on all plots by throwing 20 quadrats on each face of 4 rows per plot.

Table 2

Numbers of perennial grass shoots in 160-6 in. quadrats per plot on 13.6.65. Means for each treatment

During and after seedbed preparation		Before seedbed preparation: Dalapon	Linuron	TCA	No herbicide	Overall Mean
Pre-planting	EPTC	81.7	54.5	7.5	120.8	66.2
Pre-emergence	Dalapon	70.7	63.3	2.5	105.2	60.6
"	Paraquat	98.5	46.7	7.2	109.6	65.4
"	Linuron	81.3	65.2	7.5	101.7	64.0
as required	Cultivation	117.1	67.8	7.5	70.6	65.9
overall mean		89.9	59.7	6.5	101.6	

At P = 0.05, Sig. diff. between means of treatments before seedbed preparation = 46.9.
" , No Sig. diff. " " " " during and after seedbed preparation

The treatments produced a variety of effects on the perennial grass. TCA applied in March was outstanding in reducing shoot numbers, regardless of the treatment that followed. Dalapon was not so successful, a result that would tend to confirm past experience that the early spring is not the best time to apply the chemical. Linuron as a pre-treatment reduced the number of shoots visible in June, and particularly when followed by paraquat applied pre-emergence. There were most shoots at this time (13th June) on the plots treated only with EPTC but later assessments (see Table 3) showed that the performance of this chemical improved as the season advanced. Between the three pre-emergence herbicides, there were only small differences in number of shoots in June.

The late season assessments in August and September may be seen in table 3. The excellent grass control provided by TCA continued throughout the life of the crop, but early treatments of dalapon and linuron reduced the perennial grasses only a little as compared with no herbicide before seedbed preparation. By the end of the season, the EPTC plots had very little perennial grass present. The poorest controls were provided by linuron pre-emergence and by cultivation.

Table 3

Scores for presence and vigour of broad-leaved weeds on 31.8.65.

and of perennial grasses on 29.9.65.

0 = absence 10 = abundance on the most densely infested plot*
Means for each treatment

The broad-leaved weeds

During and after seedbed preparation		Before seedbed preparation: Dalapon	Linuron	TCA	No herbicide	Overall Mean
		Broad-leaved weeds				
Pre-planting	EPTC	2.0	1.7	1.5	2.7	2.0
Pre-emergence	Dalapon	8.0	7.0	6.5	7.7	7.3
"	Paraquat	3.5	2.7	2.0	3.2	2.9
"	Linuron	1.5	1.7	1.2	1.7	1.5
as required	Cultivation	4.5	4.7	4.7	6.5	5.1
overall mean		3.9	3.6	3.2	4.4	
		Perennial grasses				
As above	EPTC	0.2	0.5	0.0	0.5	0.3
"	Dalapon	1.7	1.2	0.0	0.2	0.8
"	Paraquat	1.7	2.7	0.0	5.0	2.4
"	Linuron	3.7	6.7	0.0	8.7	4.8
"	Cultivation	3.5	3.2	0.5	6.0	3.3
overall mean		2.2	2.9	0.1	4.1	

* The broad-leaved weeds were Stellaria media, Chenopodium album, Polygonum convolvulus, Fumaria officinalis, Papaver rhoeas, Aethusa cynapium. The perennial grass infestation amounted to 5-10 shoots/ft^2 on the densest plot.

The effects of the various treatments on the broad-leaved weeds were different from those on the perennial grasses. On the whole the treatments prior to seedbed preparation had little effect on the broad-leaved weeds. Of the treatments applied to the crop, EPTC and linuron provided outstanding control while dalapon applied pre-emergence was the worst treatment. Paraquat provided a fair control and cultivation a rather poor control.

Table 4

Weight of all tubers harvested on 21.10.65

Yields from 4 central rows of each plot, converted to tons/ac
Means for each treatment

During and after seedbed preparation		Before seedbed preparation: Dalapon	Linuron	TCA	No herbicide	Overall Mean
Pre-planting	EPTC	19.9	18.9	19.2	18.6	19.1
Pre-emergence	Dalapon	17.1	17.3	17.9	16.3	17.1
"	Paraquat	19.3	17.9	18.6	18.5	18.5
"	Linuron	19.0	18.3	18.3	19.3	18.7
as required	Cultivation	18.1	17.8	17.0	17.2	17.5
overall mean		18.7	18.0	18.2	18.0	

At P = 0.05, No Sig. diff. between means of treatments before seedbed preparation.
" " , Sig. diff. " " " " during and after seedbed preparation = 0.78.

The potatoes were harvested in the third week of October, and were subsequently separated into six different sizes. As the effects of the treatments on quantity of saleable tubers were the same as those on the total yield, only the latter has been included in Table 4. The results show that the treatments prior to seedbed preparation had no overall effect on yield. TCA which caused a substantial reduction in perennial grasses throughout the season, was associated with a yield not different overall to that of the plots that received 'no herbicide', the treatment that provided the worst control. In contrast, the yields followed the trends of broad-leaved weed control, in that EPTC and linuron gave the best broad-leaved weed control and also the highest yields, while dalapon and cultivation gave the worst control and the lowest yield.

DISCUSSION

In interpreting the results of the three experiments, it is necessary to bear in mind the weather pattern at the time. From June onwards 1965 was damp and warm. Good growth occurred, and no irrigation was required on the potato crop. October and November were mild and open with sufficient soil moisture to allow growth but not too much to hinder cultivation. The spring of 1966 was cool and late but with ample soil moisture from torrential rain in April.

The rotary cultivation in experiments AA.29. and 30.65. was carried out in soil conditions very suitable for the stimulation of the dormant buds on the grass rhizomes. Had the soils been drier or wetter such satisfactory results might not have occurred. Nevertheless techniques of autumn stubble cultivation would appear to merit further investigation. The substantial but incomplete kill provided by amitrole-T appears to be consistent with the general experience with this chemical. Unfortunately it was not possible to assess A. repens and A. gigantea separately in experiment AA.29.

TCA is a herbicide which has not attracted research interest in recent years, mainly because its use for perennial grass control involves difficulty in the timing of cultivations in the autumn. The present recommendation requires an interval of two months between application and the planting of potatoes (British Weed Control Handbook 1965). The interval in experiment AA.28.65. fell short of the recommendation by three days, but there would have been no difficulty in applying the herbicide in February. In view of the excellent grass control provided by TCA throughout the life of the potato crop, and its apparent lack of adverse effect on yield, further investigation would seem worthwhile. EPTC was rather slow to work on the grasses as is shown by the counts on 13th June, (Table 2) but eventually a good control was obtained which was apparent in the assessments later in the season; this chemical gave a good control of broad-leaved weeds and the highest yield of potatoes. The cultivation treatment proved inadequate to control either the grasses or the broad-leaved weeds, a failure which was to some extent due to the wet summer, in a drier season a better control might have been obtained.

The yields of potatoes appear to have followed closely the trends in broad-leaved weed control, and not to be associated with the control of grasses. It seems logical to conclude that the crop in AA.28.65. was sensitive to competition from the broad-leaved weeds but not from the grasses, which in early summer amounted to a mean maximum of 3 shoots/ft^2 on the ridge faces.

These three experiments were part of a programme concerned with the control of grasses in potatoes, in which possible activities in the autumn and spring were studied independently. Some interesting pointers to future experimentation have been produced which will be followed up in due course.

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CHEMICAL CONTROL OF PERENNIAL GRASS WEEDS IN CEREAL STUBBLES

N.A.A.S. (SOUTH WEST REGION) EXPERIMENTS 1964-65

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Summary

A series of trials testing Paraquat at three dose rates, Dalapon and Aminotriazole at standard dose rates were laid down on cereal stubbles in the autumn of 1964.

Estimates of crop scorch 10 days after application showed that Paraquat at all levels gave a complete scorch which aided ploughing. Dalapon and Aminotriazole produced very little scorch.

Assessments of ground covered by creeping grass weeds in the following stubble (1965) showed that all treatments had reduced the infestation by about 50% at most sites.

Cereal yields were recorded at two centres and these indicated that there was no correlation between yield and the weed grass infestation present at harvest.

INTRODUCTION

With the intensification of cereal growing in the South West Region perennial grass weeds present the most serious weed control problem in arable crops. Whilst cultivations may give good control if the weather is dry it is quite clear that reliable chemical control must be the ultimate aim.

The advent of paraquat caused considerable interest as a means of cleaning stubbles and in the autumn of 1964 the N.A.A.S. in the S.W. Region put down a series of eleven spray trials extending from Wiltshire to Cornwall.

The treatments involved, compared paraquat at three dose rates ($\frac{1}{2}$, $\frac{3}{4}$ and 1 lb. a.i./acre) with no herbicide at two centres and paraquat at two dose rates ($\frac{3}{4}$ and 1 lb. a.i./acre) with Dalapon and Aminotriazole and no herbicide at the remaining centres. There were three replications at each centre.

The autumn of 1964 was dry and vigour of growth varied from site to site although the sites in Cornwall were the most vigorous.

An estimate of the percentage ground covered by creeping grass weeds was made just before spraying and the proportionate infestation of each species assessed. Assessments of scorch were made approximately ten days after treatment and the percentage ground covered by grass weeds was assessed after the 1965 harvest. Cereal yields were taken at two centres.

RESULTS

1. There was a large variation in the distribution of weed grass species from centre to centre. In Cornwall one site was 90% Agrostis stolonifera, whereas the other was 100% Agrostis gigantea. In Wiltshire Agrostis species and Agropyron repens occurred in mixed populations. On balance the main problem seemed to be Agrostis species. (See table 1).

TABLE 1. SITES AND % GROUND COVER BEFORE TREATMENT

Site	Agrostis gigantea	Agrostis stolonifera	Agropyron repens	Poa spp	Total
Devon - N. Tawton	5	95	-	-	100
Devon - Totnes	-	-	40	-	40
Devon - Winkleigh	-	80	-	-	80
Cornwall - Truro	90-100	-	-	-	90-100
Cornwall - Nancolleth	25	7	-	15	47
Cornwall - St. Germans	-	90-95	under 5	under 5 (patchy)	95-100
Wilts. - Salisbury	20.5	-	17.5	4	42
Wilts. - Swindon	Agrostis spp. 62		-	-	62
Wilts. - Pewsey	25	-	25	-	50
Dorset	Agrostis spp. 60		30	-	90
Somerset - Bridgwater	-	6-7	16-17	-	23

2. Estimates of the degree of scorch were made at all sites 10 days after applying the herbicides.

In all cases paraquat at $\frac{1}{2}$, $\frac{3}{4}$ and 1 lb./ac had destroyed 80-100% of the leaf area whilst dalapon and aminotriazole had very little effect at this time.

3. Paraquat reduced the infestation of grass weeds surviving in the succeeding stubble with varying success, the $\frac{3}{4}$ and 1 lb. a.i./ac rates being the most effective.

Dalapon and aminotriazole gave variable control but on balance were slightly more effective than the 1 lb./ac dose of paraquat.

There was a tendency at all centres for grass growth to restart as soon as the cereal crop commenced ripening. Hence after harvest there was a fairly uniform spread of weed grasses in the succeeding stubble.

In Cornwall there was a suggestion that surviving weed grasses arose largely from shed seed. (See table 2).

TABLE 2. % GROUND COVER OF CREEPING GRASS WEEDS AFTER HARVEST (1965)

Site	Paraquat 1 lb a.i./ acre	Paraquat $\frac{3}{4}$ lb a.i./ acre	Paraquat $\frac{1}{2}$ lb a.i./ acre	Dalapon	Aminotriazole	Control
Devon - N. Tawton	10.5	7	-	15.5	9	30
Devon - Totnes	4	3	-	1	1	8
Devon - Winkleigh	37	62	-	38	52	76
Wilts. - Salisbury	34.2	30.6	-	14.3	22.6	40.3
Wilts. - Swindon	34	25.8	-	30	29	50
Wilts. - Pewsey	32	33.3	-	38.6	20.7	24.6
Cornwall - Truro	33	36	46	-	-	90
Cornwall - Nancolleth	31	31	37.7	-	-	61
Dorset	No differences recorded all plots				90	

4. Cereal yields were recorded at two sites and these are presented in table 3.

At the Winkleigh site there was little effect on yield but yields were slightly lower on the plots treated with herbicide than on the control plots.

At Pewsey much more marked differences were recorded and the highest yields were obtained from the treated plots.

The plots treated with dalapon and aminotriazole gave a 35% yield increase over the untreated controls.

TABLE 3. GRAIN YIELDS (1965 HARVEST)

Treatment	Yield at 15% Moisture	
	Wiltshire (Pewsey)	Devon (Winkleigh)
Control	18.1 cwt/acre	20.3 cwt/acre
Paraquat at 1 lb a.i./acre	22.3	19.6
Paraquat at $\frac{3}{4}$ lb a.i./acre	21.4	19.4
Dalapon	24.5	18.9
Aminotriazole	24.6	18.2

(Results not statistically analysed)

DISCUSSION

The results indicate that Agrostis spp are the main problem in the South West Region and that chemicals will give a partial control of these weeds. Clearly the quality and date of ploughing will have considerable bearing on the degree of control obtained but there is evidence to show that increased yield arises from the reduced competition which the grasses are able to exert on the cereal crop in the spring and early summer following treatment. The assessment of weed grasses surviving in the stubble following treatment could well be misleading and it seems essential to record not only yield of cereal but also the degree and vigour of weed grass survival in the early stages of crop growth.

Similar work continued during 1965-6 although a further treatment was added at one centre using a low dose of Dalapon followed by a low dose of Paraquat.

Results of the 1966 harvest are not yet to hand but preliminary reports indicate a similar pattern to 1965.

The work is continuing during 1966-7.

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A NOTE ON THE RESPONSE OF SPRING CEREALS TO THE CONTROL OF COUCH GRASS BY DALAPON AND AMINOTRIAZOLE

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A number of experiments, running from about 1958 to 1962, were carried out by the N.A.A.S. to see how effective dalapon and aminotriazole were in killing couch. The treatments were applied to cereal stubbles in autumn and the effect assessed about a year after treatment in the stubbles of spring-sown cereal crops. Many of these experiments were reported at the Fifth British Weed Control Conference (Evans 1960) and the conclusion was that herbicides are not very reliable as a means of giving a long-term control of couch.

Yield increases due to spraying were however frequently obtained. The average increase was 8 per cent (range -8 to +34 per cent), which may represent an extra average return of about 50 shillings an acre (based on a crop of 30 cwt per acre and the price of grain of 20 shillings per cwt). The cost of herbicide treatment at the normally recommended dose can be from 80 to 120 shillings per acre. Increases in yield of 14 to 20 per cent are required to cover these costs and such yield responses were obtained in only a minority of experiments. Thus there may often be no short-term financial benefit from using the herbicides and an effect lasting over two or three years may be required in order that the treatment shall "pay off". There are of course other possible benefits than the direct effect on yield, such as cleaner harvesting conditions, and the restriction of disease such as "take-all" which can be carried by couch. Nevertheless the uncertainty of long-term control from the herbicides can make their use controversial.

Table I shows that there was no correlation between yields of corn and the degree of control of couch. The amount of couch in the crop was assessed after the crop had been harvested; but the important factor might be competition with the crop in its early growth stages.

Table I.

Yield of spring cereals following the use of a herbicide to control couch

Per cent control (as measured in the stubble of the crop following treatment)	No. of cases	Mean yield as per cent of untreated crop
90 - 100	3	104
80 - 89	2	112
70 - 79	7	105
60 - 69	8	113
50 - 59	5	114
40 - 49	8	109
< 39	6	117
	39	Mean (weighted) 108

We know from data on broad-leaved weed control that it is the early competition which is important: and the assessment of couch in the stubble need be no reflection of the intensity of competition exerted by the couch in spring.

The experimental results show (a) the difficulty of getting a reliably good long-term control and (b) the relative ease of getting improved yields from partial couch control. This suggests that the best line of approach might be to not attempt eradication but to aim simply at suppression during the spring months when the cereal crop is establishing itself. This implies perhaps, as with annual weeds, annual treatment. It means also farming in the continual presence of the weed which may not be satisfactory if this means a higher level of "take-all" incidence. However, from the point of view of developing a herbicide treatment it represents a target which is likely to be more easily reached than the target of a herbicide which will give a virtually complete kill of the weed.

This re-examination of the N.A.A.S. trials also stresses the need for studying the interaction of crop and weed under the various treatments throughout the life of the crop if the effects of weed control are to be properly understood.

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