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BEHAVIOR AND PERSISTENCE OF THIOCARBAMATE HERBICIDES IN SOILS UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

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Summary S-ethyl cyclohexylethylthiocarbamate (cycloate) and other thiocarbamates disappeared from the soil by vaporization, microbial breakdown, chemical breakdown and leaching. The rate of loss of surface applied cycloate from moist soil increased when the temperature was raised from 32 - 60°F, but further increases in temperature did not increase the rate of loss. Under similar soil conditions the rate of loss of vernolate increased between 35 - 100°F. Cycloate was lost by vaporization at a much slower rate than pebulate and EPTC after application to the soil surface. When cycloate was incorporated 3 inches deep in moist loam at 6 lb/ac and at a temperature of 70 - 80°F. 83% of the herbicide disappeared from the soil in 70 days. At 40°F only 32% loss occurred in 70 days. When cycloate was incorporated into dry soil only 9% loss occurred at 70 - 80°F in 70 days. Auto-claving the soils greatly increased the persistence of cycloate, indicating that microbial breakdown is important. Cycloate is quite resistant to leaching. In soil columns it leached slightly less than pebulate when both were leached with 8 inches of water. Increasing the clay and organic content of the soil caused a decrease in leaching.

INTRODUCTION

Several new thiocarbamate herbicides related to ethyl N,N-dipropylthiocarbamate (EPTC), have been introduced on the market in the past few years. These include S-propyl butylethylthiocarbamate (pebulate) for use in sugarbeets, tomatoes and tobacco, S-propyl dipropylthiocarbamate (vernolate) for use in soybeans and peanuts, S-ethyl-1-H-azepine-1-carbothioate (molinate) for rice, S-ethyl cyclohexylethylthiocarbamate (cycloate) for sugarbeets and spinach, and S-ethyl diisobutylthiocarbamate (butylate) for weed control in corn. Although considerable information has been published on the behavior and persistence of EPTC in soil under different environmental conditions, there is very little published information on the behavior of these other related thiocarbamate herbicides in soils. This study was conducted to determine how long these newer thiocarbamate herbicides persist in different types of soils under simulated summer and winter conditions. Since space does not permit reporting the results obtained with all six compounds, this report will be concerned mainly with cycloate along with some comparisons with related thiocarbamates.

METHODS, MATERIALS AND RESULTS

In a previous report by Gray (1965) it was shown by vapor trapping experiments that EPTC was lost rapidly by vaporization after application as a spray to moist soil, but not from dry soil. Using the same vapor trapping apparatus, the material coming off the soil was trapped after application of cycloate to moist soil. The trapped material was identified by gas chromatography as unchanged cycloate. Similarly, it was shown by gas chromatography of the trapped vapors that vernolate, pebulate, molinate and butylate were lost unchanged by vaporization from the moist soil.

In further tests, the cycloate lost by vaporization was collected in the traps and determined quantitatively using the colorimetric method reported by Batchelder

and Patchett (1960)for EPTC . The loss of cycloate was compared to that of pebulate and EPTC under the same conditions. Santa Cruz loamy sand containing 15% moisture was placed in 8 x 12 in. metal flats to a depth of 3 in. The liquid formulation of cycloate was diluted in water and applied to the wet soil surface at a rate of 3 lb/ac. The flat of soil was placed under the clear plastic chamber of the vapor trapping apparatus and the vapors were collected in acetone-dry ice traps for a 30 minute period. This procedure was repeated for both pebulate and EPTC. The test was repeated on three different days and in all cases the greenhouse temperatures ranged from 70 to 90F. The results summarized in Table 1 show that in the first 30 minutes, the loss of pebulate and EPTC was three to four times greater than the loss of cycloate.

Table 1

Comparison of the vapor loss of cycloate, pebulate and EPTC as determined by trapping the vapor after spraying on the surface of moist loamy sand at 3 lb/ac

	Vapor loss in first 30 minutes percent of applied			
Herbicide	Test 1	Test 2	Test 3	Avg.
cycloate	4.4	3.9	5.6	4.6
pebulate	16.0	12.3	16.6	15.0
EPTC	22.0	22.4	28.5	24.3

Another experiment was conducted by determing the amount of herbicide remaining in the soil rather than trapping the vapor. Pint samples of Santa Cruz loamy sand were placed into 8 x 5 in. aluminum pans so that the soil was $\frac{3}{4}$ to 1 in. deep. Cycloate diluted in water was sprayed on the wet soil surface at a rate of 3.2 lb/ac. The treated flats were placed in the greenhouse at 90F for two hours, and then the soil was subjected to steam distillation and the herbicide was determined quantitatively by the colorimetric method using the method reported previously by Gray and Weierich (1965) for studying the factors affecting the loss of EPTC from soils. Pebulate and EPTC were treated in the same way at the same time so that the environmental conditions were the same for each herbicide. A similar test was run for six hours. The results in Table 3 show again that cycloate was lost at a slower rate than pebulate and much slower than EPTC.

Table 2

Comparison of the vapor loss of cycloate, pebulate and EPTC by determining the amount remaining after spraying the herbicides on the surface of moist loamy sand at 3.2 lb/ac

	Vapor loss, percent of applied	
Herbicide	2 hours*	6 hours
cycloate	26	65
pebulate	53	75
EPTC	78	86

* Average of two tests. Soil moisture content was 16 - 17% and air temperature was 90F.

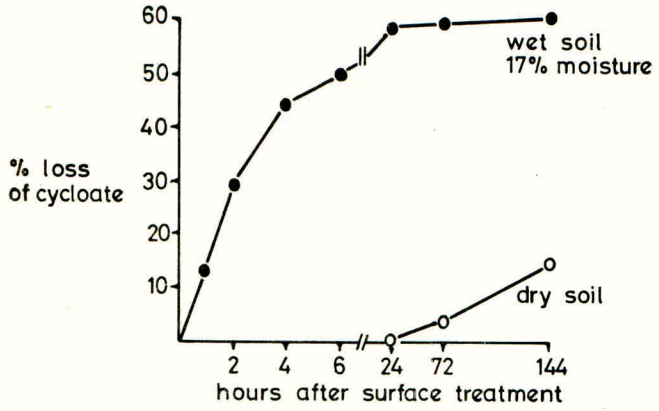
A large amount of the cycloate was lost in 6 hours even though the amount was less than with pebulate and EPTC.

Effect of soil moisture on the loss of cycloate after surface application

Using a number of the small aluminum pans, each containing one pint of soil containing 17.4% moisture or air dry soil containing 1% moisture, cycloate diluted in water was sprayed on the flats of soil at a rate of 3 lb/ac. The amount of herbicide remaining after various intervals of time was determined by the steam distillation-colorimetric method (Gray and Weierich 1965).

The results which are plotted in Figure 1 show that there was no detectable loss of cycloate from dry soil in 24 hours and very little loss after 3 or 6 days. The loss from the surface of the moist soil was almost 30% of the applied in just 2 hours after application. The rate of loss slowed down after 24 hours probably because the soil dried out and adsorbed the herbicide tightly preventing further loss.

Fig. 1
Loss of cycloate from wet and dry soils after application as a spray to the soil surface at 3 lb/ac



Effect of temperature and soil moisture on the loss of five thiocarbamates after surface application to soils

A number of small 8 x 5 inch alluminum flats were filled to a depth of 1 inch with 1 pint of Santa Cruz loamy sand containing 14% moisture. A similar number of flats were prepared the same way with air dry soil containing 1% moisture. The flats of soil were place in an environmental growth chamber where the air temperature was controlled at 32 F. One flat of moist soil and one flat of dry soil were sprayed with each herbicide diluted in water at 3 lb/ac. After 24 hours the soils were steam distilled and analyzed. The test was repeated at higher temperatures of 40, 50, 60, 70, 80 and 100 F. The results summarized in Table 3 show that increasing the air temperature from 32 F to 60 F caused an increase in loss of the herbicide in each case when applied to the moist soil surface. However, further increases in temperature to 80 and 100 F appeared to decrease the loss slightly in most cases. This may have been due to the soil drying out faster at the higher temperatures before the 24-hour period was up, thus preventing further loss due to the strong adsorption on dry soil.

Table 3

Effect of temperature and soil moisture on the loss of five thiocarbamates in 24 hours after spraying on the soil surface

Herbicide	% Moisture in Soil	Loss of herbicide in 24 hours, % of applied				
		Temperature in °F				
		32	40	60	80	100
EPTC	1	12.0	12.1	9.2	12.1	15.7
	14	62.4	67.0	81.0	80.8	75.3
vernolate	1	6.6	7.5	12.9	14.4	5.9
	14	53.4	57.1	77.1	73.2	63.9
molinate	1	8.3	11.5	-	-	12.2
	14	38.2	41.7	61.8	66.7	55.9
pebulate	1	3.0	7.5	13.2	8.7	4.7
	14	46.0	56.4	70.7	67.7	60.1
cycloate	1	-	1.0	10.5	0	8.5
	14	-	30.0	56.3	45.3	47.8

In each case the loss from dry soil was much less than from moist soil and the loss from the dry soil was not affected significantly by temperature. Previous findings with EPTC showed that most of the loss from dry soil occurred while the aqueous spray was evaporating from the soil in the first 10-15 minutes after application.

Of the five herbicides tested, cycloate was the least volatile followed by molinate, pebulate, vernolate and EPTC in order of increasing volatility.

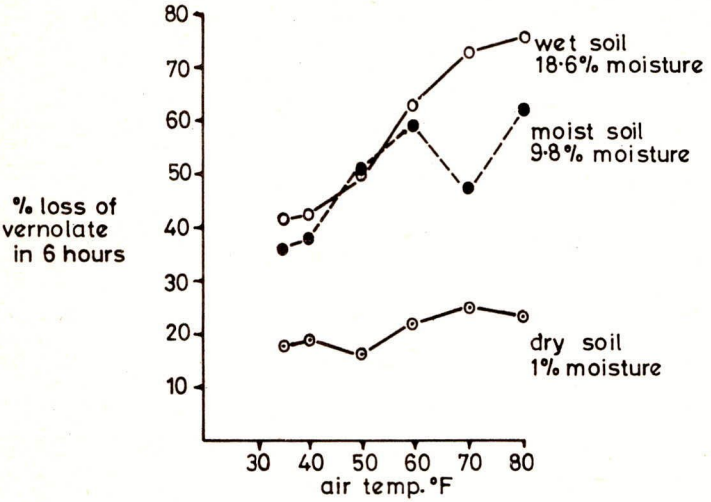
The effect of temperature and soil moisture content on the loss of vernolate after application to the soil surface was determined at three moisture levels. The same procedure described in the previous test was used except that the soils were analyzed 6 hours after application of the aqueous sprays to the soil surfaces. The results plotted in Figure 2 show that increasing the temperature in steps from 35 to 100 F caused a stepwise increase in loss of vernolate from the moist and wet soils. Increasing the temperature had very little effect on the loss of vernolate from dry soil. The effect of increasing the temperature was greater as the soil moisture content increased. The difference in the previous test and this one was probably due to the soil drying out at the high temperatures in 24 hours, but not in 6 hours.

Persistence of cycloate after incorporation in different soils at different temperatures and moisture levels

In the previous vaporization tests, the herbicides were applied to soil surfaces without incorporation. Since the recommended method of application for cycloate and the other thiocarbamate herbicides is to incorporate them 2 to 3 in. deep in the soil, the persistence tests were carried out by incorporating cycloate to a depth of 3 in. in soil contained in glass jars. One pint samples of dry Felton loamy sand were weighed out and mixed with water solution that contained enough cycloate to give 6 lb/ac. A small cement mixer was used for this incorporation. In a similar manner, pint samples of Sorrento clay loam were prepared, so that the final moisture content was 15.4%. The soil samples containing the herbicide were placed into one pint wide-mouth glass Mason jars so that each jar was filled to

Fig. 2

Effect of temperature and soil moisture on the loss of vernolate after application as a spray to the soil surface



a depth of 3 in. One set of jars of loamy sand and a set of the loam soil were placed in the greenhouse where the temperature was maintained at 70 - 80F to simulate summer conditions. Another similar set of jars was placed in an environmental plant growth chamber where the temperature was maintained at 40F to simulate late winter conditions. Both sets of jars were given additional water from time to time in order to keep the soil moist most of the time. Another set of soil samples was prepared by incorporating the cycloate into pint samples of dry Felton loamy sand and dry Sorrento loam. These dry soil samples were kept in the greenhouse at 70 - 80F and kept dry. At regular time intervals, two jars were removed for each treatment in the greenhouse and in the growth chamber and analyzed by the steam distillation-colorimetric method.

The average results plotted in Figure 3 and Figure 4 show that cycloate did not persist very long when incorporated into the two moist soils under simulated summer conditions at 70 - 80F, since 56% of the herbicide disappeared from the loamy sand and 83% disappeared from the loam in a period of 70 days. Cycloate was lost much faster at 70 - 80F than at 40F. Very little loss of cycloate occurred after incorporation in the dry soils that were kept dry for 98 days. Apparently cycloate is strongly adsorbed on dry soil similar to EPTC. The herbicide was applied at 6 lb/ac or approximately double the recommended rate in these tests. The persistence in soil would be expected to be less using cycloate at a lower rate of 3 or 4 lb/ac.

Similar persistence tests were conducted with vernolate, molinate and butylate where each was incorporated 3 in. deep at 6 lb/ac and kept in the glass jars. After 64 days in the moist soils at 70 - 80F, 93% of the vernolate disappeared from the loamy sand and 86% from the loam. At 40F the loss was 42% in the loamy sand and 39% in the loam. In the dry soil at 80F, only 14% disappeared in 64 days. In the moist loamy sand at 70 - 80F, 78% of the applied molinate disappeared in 64 days, and 40% disappeared at 40F. Butylate showed similar results. Cycloate disappeared in the cold moist soils at a slower rate than the other herbicides. With all herbicides

Fig. 3

Loss of cycloate after incorporation 3 inches deep
at 6 lb/ac in Felton loamy sand contained in open pint jars

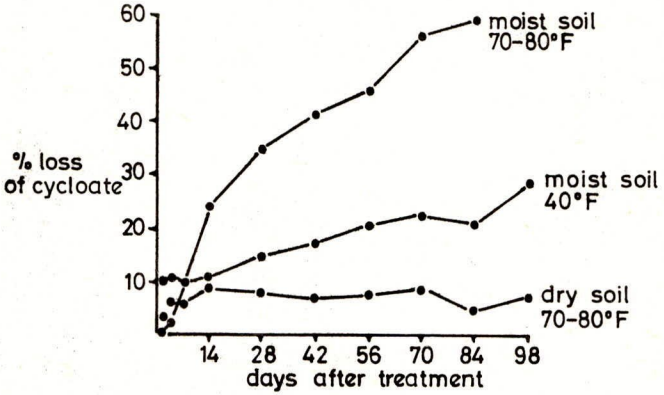
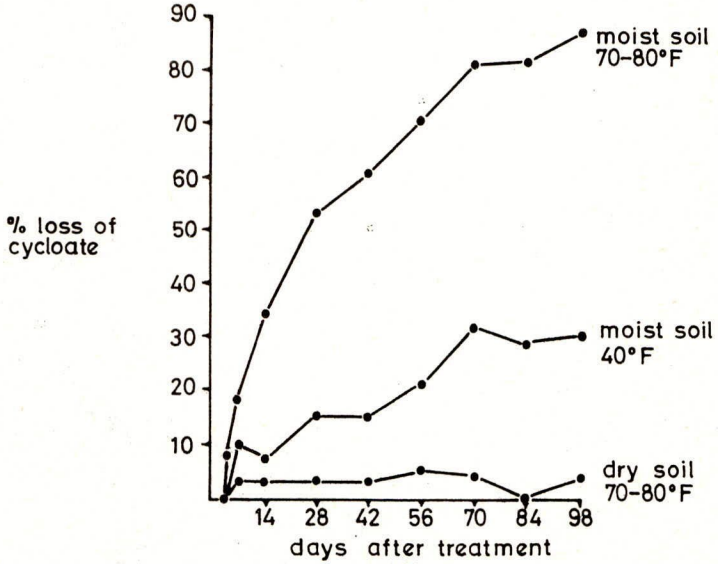


Fig. 4

Loss of cycloate from Sorrento loam after incorporation
3 inches deep at 6 lb/ac in open pint jars



tested, there was very little loss after incorporating in dry soil even after 2 to 3 months in the dry condition at 70 - 80F. In general, the persistence of the thiocarbamate herbicides appeared to be of relatively short duration when moisture was present in the soils.

Butylate, cycloate, molinate and vernolate disappeared much faster from non-autoclaved soil than from autoclaved soil, indicating that microbial decomposition plays an important role in removing these compounds from the soil. Some cycloate disappeared from the autoclaved soil indicating that some chemical degradation, probably by hydrolysis, also occurred. The breakdown products of cycloate in the soil will be the subject of another report.

Effect of soil type on leaching of cycloate

Glass columns were assembled by taping together eleven sections of glass tubing which were 3 in. long and 1.69 in. in diameter. The glass columns were packed with air dry screened Santa Cruz loamy sand, Coyote sandy loam, Sorrento loam and Bowers clay. In each column, cycloate at a rate of 10 lb/ac was incorporated into the upper 2 in. of soil. Eight in. of water was then applied in two 4 in. increments to the column. A small wad of glass wool was placed on the top of the soil in order to prevent disturbing the soil when adding the water. The columns were allowed to leach overnight for 16 hours, and then the 3 in. sections were separated and analyzed by the steam distillation-colorimetric method.

The leaching results shown in Table 4 show that cycloate was relatively resistant to leaching. Increasing the clay and organic matter content of the soil caused a decrease in the amount of leaching.

Table 4

Distribution of cycloate in soil columns after incorporating it in the top 2 in. of soil at 10 lb/ac and leaching with 8 in. of water

Sections of Soil Column inches	Cycloate found, lb/ac			
	Santa Cruz Loamy sand	Coyote Sandy loam	Sorrento loam	Bower's Clay
0 - 3	0.64	3.50	7.85	9.54
3 - 6	7.30	6.08	1.15	0.34
6 - 9	0.90	0	0	0
9 -12	0	0	0	0
12 -15	0	0	0	0
Soil Composition				
% Clay	5.0	9.0	20.0	33.2
% Organic matter	4.6	0.8	5.6	11.6
Depth of water penetration in inches	30	30	24	21

Cycloate leached less than the other thiocarbamate herbicides as reported by Gray and Weierich (1968) indicating that it should be more effective in high rainfall areas than the other thiocarbamate herbicides. To test this further, another experiment was run in which cycloate and pebulate were leached in Santa Cruz loamy sand in glass columns at the same time under the same conditions. The results in Table 5 show that cycloate was slightly more resistant to leaching than pebulate.

Table 5

Distribution of cycloate and pebulate in columns of Santa Cruz loamy sand after incorporating in the top 2 in. of soil at 10 lb/ac and leaching with 8 in. of water

Section of soil column, inches*	lb/ac of herbicide found	
	Cycloate	Pebulate
0- 3	0.75	0.26
3- 6	5.96	5.90
6- 9	2.86	3.90
9-12	0	0
12-15	0	0

* Water moved 30 in. down the column

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SOME INVESTIGATIONS INTO THE EFFECTS OF ENVIRONMENT ON THE ACTIVITY OF THE HYDROXYBENZONITRILES

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Summary Greenhouse experiments have shown that ioxynil-Na was much more active on several weed species when plants were kept in a humid chamber (R.H. near 100%) after spraying. Only 24-48 hrs. in the chamber were necessary to increase activity very significantly. Temperatures in the chamber were higher than ambient, and it is not yet known whether the increase in activity was due to this factor or to the high humidity. Plant moisture status had little effect on the activity of ioxynil-Na, except that plants kept near wilting point were somewhat more resistant than those watered normally.

In outdoor pot experiments, solar radiation after spraying was significantly negatively correlated with herbicidal activity of bromoxynil-K. Temperature effects were not significant. It appears from recent (unanalysed) results that high post-spraying humidity increases activity. Environmental effects on the activity of bromoxynil ester seem to be small, and of no practical importance.

It is suggested that the data support the hypothesis that, in the case of the hydroxybenzonitrile salts, the main influence of environment is on herbicidal entry into the plant.

INTRODUCTION

During the past four years, the hydroxybenzonitrile herbicides ioxynil and bromoxynil have undergone field trials in a wide range of crops in many countries, with climates varying from the cool temperate to the sub-tropical. The vast majority of the results have shown that these herbicides satisfactorily control a large number of broad-leaved weed species in cereal, sugar cane and onion crops, in particular. There have, however, been scattered but persistent reports that on occasions (when apparently formulation and spraying techniques were satisfactory) weed control has been incomplete. Experiments have therefore been conducted over the past two years at Ongar in an attempt to discover whether environmental conditions at or near the time of spraying do materially affect the herbicidal activity of ioxynil and bromoxynil. As field experience suggested that instances of poor weed control were generally connected with the use of aqueous salt formulations, attention has been concentrated on these formulations.

Apart from greenhouse studies, there are two main alternative methods available for investigating plant/herbicide responses to climatic variations - controlled environments, and the utilisation of natural variations. Growth chambers are particularly useful for evaluating (a) the effects of a specified environment over fairly long periods pre- or post-spraying; and (b) the separate effects of such factors as temperature, radiation and humidity. On the other hand, growth chambers have two important defects for this type of investigation. First, they cannot at present achieve radiation levels as high as those occurring naturally: most growth chambers cannot give

more than 0.2 cals cm^{-2} min^{-1}, or about 200 cals cm^{-2} over a 16-hour photoperiod. On the other hand, daily totals of 600-700 cals cm^{-2}, with short-term peaks of rather more than 1 cal cm^{-2} min^{-1}, are not uncommon outside in summer. While only about half the total amount of solar radiation is photosynthetically useful, other parts of the spectrum (particularly the ultra-violet) have important formative effects on plants. Secondly the "hardening" effects of natural fluctuations in climate (e.g. of wind on cuticle thickening and cracking) are also difficult or impossible to simulate in growth chambers.

It was decided, therefore, initially to determine what range of herbicidal activity could be observed on plants grown outdoors, when other factors such as plant growth-stage, method of spraying, and soil moisture-content, were (as far as possible) held constant, and to attempt to correlate any observed differences with records of the weather near the dates of spraying.

MATERIALS AND METHODS

1. Greenhouse experiments. A number of weed species were used, employing usually 5 x 4-plant replicates in randomised blocks. Plants were sprayed at the 'young plant' stage of growth, with ioxynil Na-salt at a number of dose-rates in a volume of 20 gal/ac, using a laboratory sprayer with a commercial Tee-jet nozzle travelling at 1.6 m.p.h. Experiments investigated the effect of (a) high soil-moisture deficits throughout the life of the plants: This was achieved by bringing the pot soil to field-capacity at intervals of 1 day (low deficit), 2 days (moderate deficit) or 3 days (high deficit treatment); and (b) high atmospheric humidity for varying periods before and after spraying: this was achieved by placing the plants as required in a large polyethylene chamber.

2. Outdoor pot experiments. Successive weekly batches of plants were grown outdoors, and sprayed on 23 occasions in 1967, and 19 occasions in 1968, in each case between May and September. The species used were Polygonum lapathifolium and P. convolvulus; they were sprayed at the 3- and 4-leaf stages, and the 2- and 3-leaf stages, respectively, in 1967. This year only P. lapathifolium at the 4-leaf stage was used. The herbicides applied were: in 1967, bromoxynil K-salt in 20 gal/ac; in 1968, bromoxynil K-salt and octanoyl ester, in 5 and 20 gal/ac. Seven progressive dilutions, and 2 x 3-plant replicates were used in each experiment. Herbicidal activity was correlated with climatic data collected close to the experimental area. Records were obtained of: solar radiation (Kipp solarimeter), aspirated air temperature (resistance thermometer), relative humidity (1967 - 9 a.m. and 3 p.m. spot readings with Assmann hygrometer; 1968 - continuous records from aspirated wet-bulb resistance thermometer), and wind speed (1968 only, Sheppard sensitive anemometer). Output signals from these instruments were transmitted to a Kent multi-channel integrator, which automatically recorded data from each instrument during two 1-minute sampling periods in every 10 minute cycle throughout the experimental season. The 10-minute totals were printed on Sodeco counters. Data for the whole and/or various portions of the day of spraying, the two days before and the two days after, for each experiment were submitted to multiple regression analysis.

In all the experiments reported here, herbicidal activity is expressed as (percentage) reduction in fresh weight compared with unsprayed controls, assessed 13-14 days after spraying, by which time mortality was complete.

RESULTS

1. Greenhouse experiments. (a) Effect of soil-moisture deficits. Experiments on several species showed little effect on herbicidal activity of

moderate deficits, though the rate of plant growth was in some cases considerably altered. When the interval between waterings was increased to the point at which incipient wilting occurred in some plants towards the end of the interval, herbicidal activity was markedly reduced. This is illustrated by results for Galium aparine: small 'droughty' plants were much more resistant to ioxynil than normal plants (Table 1).

Table 1

Effect of ioxynil on Galium aparine grown under various watering regimes

Ioxynil rate (oz/ac)	Mean fresh wt/plant (g) Interval between waterings			Percent fresh wt reduction Interval between waterings		
	1 day	2 days	3 days	1 day	2 days	3 days
0	1.90	1.48	0.82	-	-	-
1	1.44	1.30	0.77	24	13	6
2	1.09	0.85	0.79	43	43	3
4	0.75	0.66	0.58	61	56	29
8	0.55	0.46	0.61	71	69	26

(b) Effect of high atmospheric humidity. In these experiments, plants placed in a large polyethylene chamber (R.H. 96-100%) for varying periods were compared with others standing in the open greenhouse (R.H. 40-50% during the day). Mean maximum daily temperatures were also higher in the chamber than in the greenhouse (23.0°C as against 16.3°C, in one experiment). In experiments with Lapsana communis and Polygonum convolvulus, placing the plants in the chamber for 6 days, 1 day or 2 hours before spraying had no significant effect on ioxynil activity, though all three treatments tended slightly to depress herbicidal effects. Activity was strikingly increased, however, when plants were placed in the chamber after spraying. The largest increases were produced by leaving the plants in the chamber for 24-48 hours after spraying: longer periods had little additional effect. Adding a humectant to the spray solution had very little effect on plants either in the open greenhouse or in the chamber.

The results for Chenopodium album, a species notoriously resistant to wetting, are of interest (Table 2). All plants were grown in the open greenhouse pre-spraying, and ioxynil was sprayed at 2, 4, 8, 12 and 16 oz/ac.

Table 2

Effect of various post-spraying humidity regimes and spray additives on the activity of ioxynil Na-salt on Chenopodium album

	Treatment	Total fresh wt (g)[1] (average of all ioxynil rates)	
1.	Dry[2]	23.8	a
2.	Dry 24 hr, humid[3] 27 hr, than dry	16.9	b
3.	Dry 8 hr, humid 21 hr, then dry	16.0	b
4.	Humid 8 hr, then dry	16.8	b
5.	Humid 24 hr, then dry	15.3	b
6.	Humid until end of experiment	11.2	c
7.	Dry; 10% dipropylene glycol in spray solution	0.4	d
8.	Dry; 0.1% Ethylan CP in spray solution	Nil	d

1. Treatments followed by different suffix letters are significantly different ($P<0.05$, Duncan's multiple range test).

2. Dry = in open greenhouse.
3. Humid = in polyethylene chamber.

Placing the plants in the humid chamber for a period increased ioxynil activity (even when this treatment was delayed for 24 hrs. after spraying), but to a far smaller degree than with the previous species, which are readily wetted. Even after two weeks in the humid chamber mortality reached 95% only at 16 oz/ac ioxynil; on the other hand, 2 oz/ac ioxynil plus 0.1% surfactant gave 100% mortality. With this species, too, the humectant additive was far more effective than the humid chamber treatments.

2. Outdoor pot experiments. (a) 1967. Activity (expressed as the dose giving 90% fresh wt reductions - ED90) was found to vary over quite a wide range - e.g. from 1.5 to 22 oz/ac bromoxynil K-salt, for the 4-leaf P. lapathifolium. P. convolvulus was more easily controlled, and the younger plants of both species were controlled at lower doses than the older. The results, which are summarised in Table 3, agree well with field experience; practical interest, of course, is centred on the occasions on which control was not achieved at a dose of 8 oz/ac.

Table 3

Summary of 1967 outdoor experimental results - activity of bromoxynil K-salt

Species	Growth stage	Mean ED90 (oz/ac)	No. of occasions on which ED90 was:- <4oz/ac	5-8oz/ac	>8oz/ac	Total
P. lapathifolium	4-leaf	4.1	15	3	5	23
	3-leaf	2.5	-	-	-	-
P. convolvulus	3-leaf	3.3	16	5	2	23
	2-leaf	1.7	-	-	-	-

Preliminary statistical analysis showed that none of the climatic data for the two hours before or after spraying were significantly correlated with activity. When both species and growth stages were analysed together (using the mean ED90 values quoted in Table 3 as covariates, to allow for differences in susceptibility between species and growth stages), no climatic variables were significantly correlated with activity. However, when each species and growth stage was analysed separately, it was found that (except for the smaller P. convolvulus), solar radiation was negatively correlated with activity, while neither temperature nor the available humidity data were significantly correlated. For P. lapathifolium, the smallest residual error was given by the linear regression of the logarithm of ED90 on the total solar radiation for the post-spraying period of the day of spraying plus the following day ('Day 0 post-spraying' plus 'Day 1'). The slope is such that an increase of 100 cals cm^{-2} will increase the ED90 dose by about 30% (Fig. 1). The considerable scatter of the individual results, however, suggests that some other factor or factors are involved.

(b) 1968. In this rather dismal summer, solar radiation levels have been considerably lower than in 1967. Activity levels have been higher, and no ED90 values above 8oz/ac have been recorded (Table 4). 1968 results with bromoxynil K-salt appear to fit the 1967 solar radiation regression well, but statistical analysis has not yet been completed. Bromoxynil octanoyl ester performed more consistently than the salt, confirming field experience, and for practical purposes does not appear to be affected by weather conditions. Judging by scatter diagrams, both salt and ester appear to be more active when humid conditions follow spraying. Activity of both salt and ester was unaffected by volume rate of application (5 and 20 gal/ac).

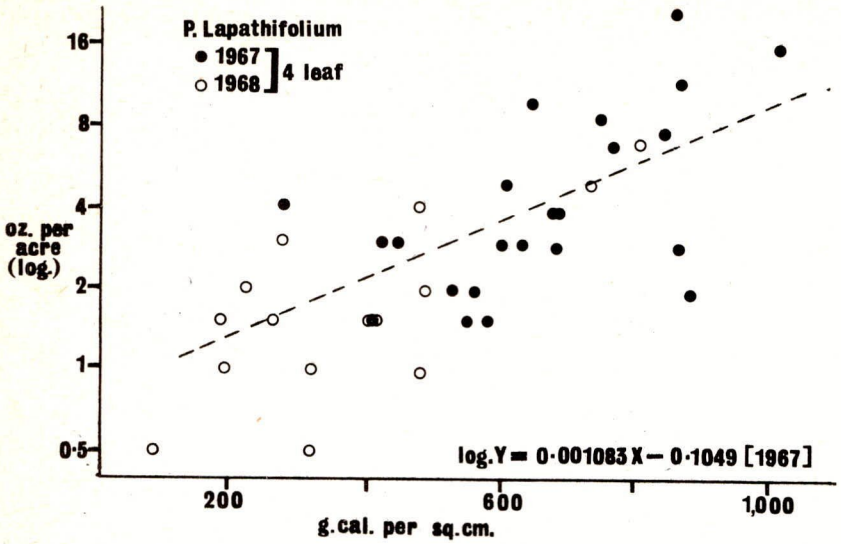

Fig. 1 Regression of log. dose bromoxynil salt on Solar Radiation (Day 0 post spray + Day 1)

Table 4

Summary of 1968 outdoor experimental results - activity of bromoxynil K-salt and octanoyl ester on 4-leaf P. lapathifolium

Bromoxynil formulation	Mean ED90 (oz/ac)	Number of occasions on which ED90 was:- <4oz/ac	5-8oz/ac	>8oz/ac	Total
K-salt	1.45	13	2	0	15
Octanoyl Ester	1.00	18	0	0	18

DISCUSSION

Until analysis of all the results has been completed, it would not be wise to be too dogmatic about interpretation. However, it appears from both the greenhouse (humidity chamber) and outdoor experiments that environmental conditions in the 24-48 hrs. after spraying are important in determining the final effect of ioxynil and bromoxynil salts. The most important effects seem to be that of solar radiation in decreasing activity, and that of relative humidity in increasing activity. The greenhouse results are in most respects very similar to those of Foy et al. (in Freed and Morris, 1967), working with dalapon on johnsongrass. It seems reasonable to infer that the environmental conditions are exerting their effect mainly by influencing the stomatal element of herbicide entry into the plant. On the other hand, it seems that the long-term (morphogenetic or physiological) climatic effects on plants' susceptibility or resistance to these herbicides are of little importance.

The 1968 results support field evidence that the activity of ester

formulations of the hydroxybenzonitriles are not greatly affected by environmental conditions, and this fact also suggests that the above interpretation is correct.

Acknowledgements

It is a pleasure to acknowledge the assistance of Mr. C.J. Hibbitt throughout this work. I am grateful to Mr. W. Laycock for his expertise with the electronic recording equipment, and to Prof. J.F. Scott for undertaking the computer analyses.

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THE EFFECT OF ENVIRONMENT ON THE ACTIVITY OF BIPYRIDYLIUM HERBICIDES

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Summary The activity of diquat and paraquat is influenced by many environmental factors which include light quality and time of day of treatment. Periods of darkness, reduced light intensities, the humidity of the air and soil influence their uptake and movement in plants. Experiments with potatoes have shown that low light intensity, drought and high foliar humidity increase the downward translocation of diquat and may interact to cause abnormally high residues and damage in the tubers. Paraquat is more active on rhizome buds of Agropyron repens from foliar applications in similar environments. The effect of periods of darkness or reduced light intensity on haulm desiccation by diquat and residues in the tubers is described. Results from greenhouse studies are confirmed because in practice, evening treatments of diquat or paraquat are much more effective in the control of perennial grasses in the tropics.

INTRODUCTION

A number of factors influence the activity of bipyridylium herbicides. Diquat and paraquat are not active per se but must be reduced by plants to their free radicals during photosynthesis. (Homer, Mees and Tomlinson (1960)). Light is therefore essential for producing rapid damage to plant tissue. The herbicides are moved mainly in the xylem and hence their distribution within a plant is linked with water movement and factors such as atmospheric and soil humidity are also important. Downward movement occurs in the plant by reverse xylem flow which results from rapid damage to leaf tissue.

METHODS, MATERIALS AND RESULTS

Environment in glasshouse experiments

The effect of light on the activity of diquat and paraquat is complex. Brian (1967b) has shown that their activity is influenced by the light quality before treatment. Tomatoes receiving 3 to 6 hr. red light before treatment with a dark period after treatment were much more resistant than those receiving corresponding periods of blue light.

Activity is also influenced both by the time of day of treatment and the light intensity as seen in Table 1. (Brian 1967b). The bright or dull day preceded the day of treatment. Similar results were obtained when only 6 hr darkness after treatment was used. Table 1 indicates that when darkness follows treatment, afternoon spraying was much less effective when it followed a bright day. Activity was independent of the timing of treatment after a dull day.

Periods of reduced light intensity or darkness before or after spraying also increase activity.

TABLE 1

"Bright day" and 'dull day' tomatoes sprayed at various times of day in July with 0·025% diquat. 72 hr darkness after treatment

Time of treatment (hr)	Biological Activity (Max = 50) Bright day (20,000 lux)	Dull day (5,000 lux)
9·00	46	45
11·00	33	44
13·00	16	44
16·30	19	47

Standard error (treatment mean) = ± 0·28

Table 2 shows the effect of 3 days reduced light intensity before treatment. (Brian 1967b).

TABLE 2

Light intensity for 3 days (12 hr/day) before treatment and the activity of 0·02% diquat and 0·04% paraquat on tomatoes. 6 hr darkness after treatment and mean of 3 experiments

Light intensity (lux)	Biological Activity (Max = 50) Diquat	Paraquat
16,000	18	13
10,000	22	10
6,500	23	19
3,500	34	19
1,200	38	28
Darkness	45	37

Standard error (treatment mean) : diquat ± 0·77 paraquat ± 0·41

Activity of diquat and paraquat both increase when treatment follows a period of low light intensity (< 6,500 lux for diquat and < 3,500 for paraquat).

Darkness greatly increases activity but only when part of the dark period follows the diquat or paraquat treatment (Brian 1967a). Results in Table 3 show that dark periods following treatment increase uptake.

TABLE 3

The effect of darkness after treatment on the uptake of diquat into tomato using 0·03% diquat spray

Dark treatment (hr)	Uptake (ug/g)
L/0D	13
L/2D	17
L/4D	23
L/8D	21
L/48D	24

Uptake was doubled by as little as 4 hr. darkness.

Movement may also be increased by modifying the water stress in plants. Thus the downward movement of paraquat is increased when plants are sprayed in a moist atmosphere combined with dry soil conditions. Least movement occurs when the soil is wet. These conclusions are based on autoradiographic evidence and experiments where the uptake and movement in wheat were measured, after immersing part of an adult leaf in paraquat solutions. Results for 90% RH air/dry soil and 70% RH air/wet soil are given in Table 4 (Brian 1966).

TABLE 4

The effect of air and soil humidity on the uptake and movement of paraquat in wheat

(WHC = water-holding capacity)

90% relative humidity				70% relative humidity			
Soil moisture (% WHC)	Uptake (µg)	% movement	Activity	Soil moisture (% WHC)	Uptake (µg)	% movement	Activity
30	82	32	38	30	176	8	31
100	176	17	31	100	175	1	7

A progressive fall in % movement occurs as water stress decreases using high air humidity with dry soil to the conditions of least stress - reduced air humidity and wet soil. In these conditions both movement and activity were very low.

Movement may also be increased by reducing soil temperature. In preliminary experiments in which plastic pots containing cocksfoot plants (Dactylis glomerata) were cooled to 0°C, the movement and activity of paraquat were increased. It is concluded that root pressure is reduced at 0°C and this increases the water stress with consequent increase in movement.

A similar combination of factors has also markedly enhanced the activity of paraquat on Agropyron repens. The foliage of 10 week old pot-grown plants having a well developed rhizome was dipped for 2 seconds into a solution of 1,000 p.p.m. paraquat. Two weeks later when the tops were completely desiccated the rhizome was sectioned into single node pieces and planted. For plants which were turgid at the time of treatment and received illumination (1,000 f.c) and a relatively low humidity (60%) for 24 hours following dipping, the germination of rhizome buds (as % controls) 6 weeks after transplanting was 57%. In the case of plants which were drought-stressed to the point of visible wilt at the time of treatment and were subjected to darkness and a high atmospheric humidity (90%) the germination of buds was reduced to zero. These results are analogous to those derived by Robbins, Crafts and Raynor (1953) from work on Convolvulus arvensis with sodium arsenite, also a quick acting xylem mobile herbicide, and indicate the possibility of a more deep-seated herbicidal effect from the bipyridyls under dry soil conditions provided the aerial environment permits adequate uptake.

In contrast it may be necessary to avoid abnormally high downward movement of bipyridyls when used for crop desiccation. The use of diquat for potato haulm destruction is an important example.

When potato tops are killed with diquat the residues normally found in tubers are only 0·01-0·02 p.p.m. of the fresh weight. However, under an environmental moisture status conducive to a reversal of the transpiration stream much higher concentrations of diquat may be associated with a zone of necrotic tissue in the tuber at the point of stolon attachment (Headford and Douglas, 1967). This condition, known as stem-end rot, is uncommon and has occurred in the field only in

abnormally dry seasons. The condition may be readily reproduced under glasshouse conditions and is significant only when a severe soil moisture stress is combined with a high atmospheric humidity. This is illustrated in Table 5 by the results obtained from two pot experiments in which potato plants were sprayed with the equivalent of 1 lb/ac diquat in 100 gal. water at the onset of lower leaf senescence. Before spraying, plants were either adequately watered or had been subjected to drought sufficient to induce moderate wilting. After spraying, plants received either a low or high humidity for 8 hours. Tubers were harvested for examination and chemical analysis two weeks after treatment.

TABLE 5

The effect of atmospheric and soil moisture on the residues of diquat in potato tubers and the extent of stem-end rot

Experiment	Soil	% RH after spraying	% Damaged tubers				Diquat residues (ppm fresh weight)	
			King Edward		Majestic		King Edward	Majestic
			slight	moderate	slight	moderate		
1	Dry	79	7	13	17	6	0·21	0·14
	Wet	79	4	0	0	0	0·01	0·01
	Dry	38	0	0	0	0	0·01	0·01
	Wet	38	0	0	0	0	0·01	0·01
2	Dry	98	-	-	19	4	-	0·13
	Wet	98	-	-	0	0	-	0·04
	Dry	58	-	-	9	0	-	0·07
	Wet	58	-	-	0	0	-	0·00

Such experimental information together with the field evidence from recorded cases has led to the formulation of recommendations based on weather data to overcome this practical problem.

Environment in the field.

Potatoes. Results in Tables 4 and 5 indicate how water stress influences the movement of diquat and paraquat. But no evidence has been reported on the effect of different light regimes on the desiccation of potato haulm by diquat and on the residues in the tubers.

Therefore a field trial with Majestic and King Edward potatoes was carried out in which diquat was used to desiccate the haulm in various light intensities and with treatments at different times of day. Residues in the tubers were also assessed.

Light intensities were varied by hanging hessian sheets of different densities over the plots but allowing free circulation of air.

Figures 1 and 2 show the effect on leaf and haulm desiccation of periods of reduced light intensity before and after spraying Majestic and King Edward potatoes (Brian and Ward 1967).

It was found that light intensities below 5,000 lux following treatment increased both leaf and haulm desiccation. (Reduced light intensities before treatment had no effect on activity). It was concluded that evening treatments would be most effective. However, potatoes were sprayed at different times of day and with the exception of one trial, evening sprays were not more effective than those earlier in the day. The trials were carried out after heavy rains, the soil was wet and

hence it is unlikely that water stress was influenced much by changes in the air humidity at different times of day.

It was observed that heavy rain which fell less than $\frac{1}{2}$ hour after spraying, did not impair the efficiency of diquat.

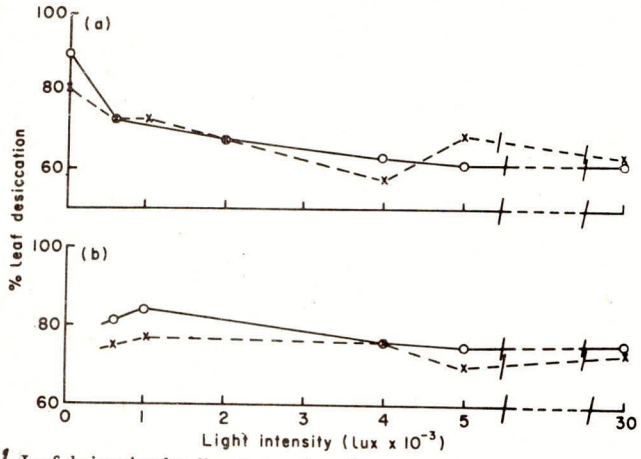

FIG. 1 Leaf desiccation by diquat at various light intensities before (b) and after (a) spraying King Edward (×) and Majestic (○) potatoes. Significant difference (5% level) = 14·0 (Majestic), 13·0 (King Edward).

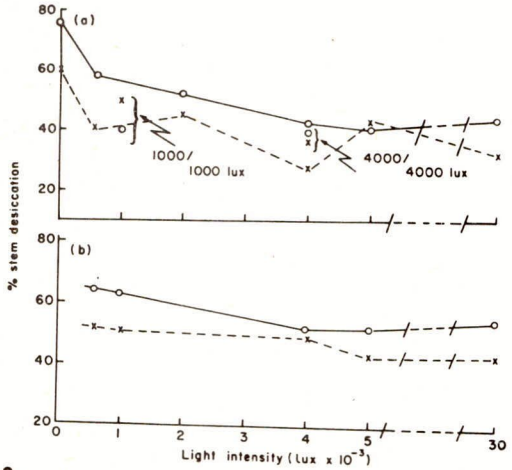

FIG. 2 Stem desiccation by diquat at various light intensities before (b) and after (a) spraying King Edward (×) and Majestic (○) potatoes. Significant difference (5% level) = 16·0 (Majestic), 15·0 (King Edward).

The residues in the tubers presented in Fig. 3 are in ppm fresh weight

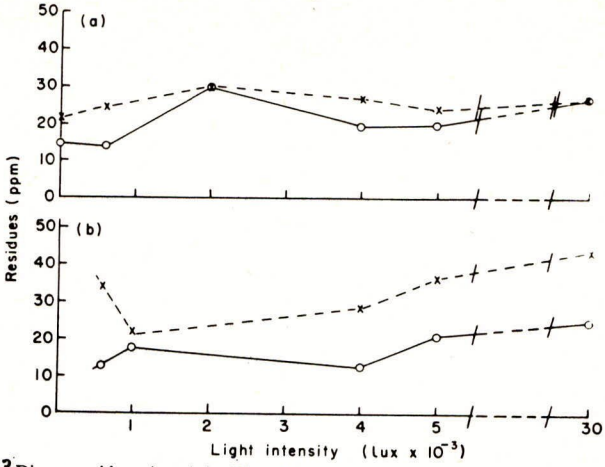

FIG. 3 Diquat residues (ppm) in King Edward (×) and Majestic (○) potato tubers resulting from various intensities before (b) and after (a) spraying. Significant difference (5% level) = 0·017 (Majestic), 0·018 (King Edward).

There was a small but progressive increase in residues with increasing light intensities before and after treatment. Residues in King Edwards exceeded those in Majestics. This reflects glasshouse results where diquat moved more freely from the leaves to haulm of King Edward potatoes.

It is concluded that in these conditions of wet soil, differences in light intensity in the field are unlikely to influence significantly the efficiency of diquat for potato haulm desiccation. Evening treatments moreover were not more effective but this is not true for all plant species because considerable improvement in the control of perennial grasses has been demonstrated in the tropics by late evening applications of paraquat or diquat.

Perennial Grasses. The stoloniferous grass Paspalum conjugatum is one of the most troublesome weed species in Malaysian plantation crops. In young rubber and oil palm, with little shade, the initial desiccation of the weed with paraquat is very rapid but so too is the recovery from new shoots. The results of a field trial in which a range of doses of paraquat was applied either mid-morning (10 a.m.) in bright sunlight or at 5 p.m. (about one hour before sunset) on the same day are shown in Table 6.

TABLE 6

The influence of time of day on the duration of control* (wk) of P. conjugatum with paraquat

Time of spraying	Dose (lb/ac)			
	0·125	0·25	0·5	1·0
10 a.m.	0	2·5	3·5	3·5
5 p.m.	2	5·5	7·5	7·8

* Duration of control is the time between spraying (at 100% ground cover) and regeneration to 50% ground cover.

It is evident that in this situation a considerable improvement in weed control is possible by evening compared with morning application, or, considered in another way, that less chemical need be used to achieve equivalent weed control. Similar results have been reported by Sheldrick (1967) using diquat on Axonopus compressus in Nigeria and by Raybone (pers. comm.) using paraquat on Echinochloa crus-galli in Australia.

CONCLUSIONS

Environmental factors influence the uptake, movement and activity of diquat and paraquat. Of the factors, light quality and intensity, time of day of spraying, humidity of air and soil, it was found that only the conditions of humid air combined with dry soil produced a water stress which greatly increased downward movement of diquat and paraquat, with a consequent increase in activity.

The results in the glasshouse indicate that evening sprays should be most effective. Although this was not found with potatoes in the U.K. there has been greatly increased activity from evening sprays on perennial grasses in the tropics.

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INVESTIGATIONS ON THE DISAPPEARANCE OF SIMAZINE FROM LIGHT SOIL

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Summary Investigations were carried out on the disappearance of simazine from light soil under field conditions. The herbicide was applied at 1.5, 5.0, 10.0 and 25.0 kg/ha. The disappearance rate of the herbicide was followed on sub plots which were sown with maize or uncropped. Soil samples from the 0-10 and 10-20 cm layers were taken monthly during the growing season. Quantitative determination of the simazine residue was made using an oat bioassay. Simazine applied at 1.5 kg/ha was found to disappear within one growing season, while the higher doses persisted into the second and third year. The disappearance of simazine was more rapid on plots sown with maize than on uncropped ones.

INTRODUCTION

Triazines are amongst the most widely used weedkillers in agricultural practice (Crafts 1964, Van Overbeek 1964). However, the extensive application of these herbicides creates the problem of their residues in the soil which may have harmful effects on following crops (Becker 1964, Kolesnikov and Zeltakova 1967). Triazine residues remain in the soil for considerable periods, their persistence depending on the dose applied, soil properties, rainfall and other environmental factors. The organic matter, and to a lesser extent, the clay fractions of the soil adsorb simazine and reduce the amount available to plants (Frissell 1961, Gast 1962 and Grover 1966).

The object of the experiments reported below was to follow the rate of disappearance of simazine from a light soil of low adsorptive capacity, where residues would be available to succeeding crops. In addition the influence of a maize crop on the rate of loss of simazine was determined. The doses of simazine applied ranged from those used in agricultural practice to those used for total weed control on uncropped land.

METHOD AND MATERIALS

The experiments were conducted at the Experimental Station, Laskowice from 1965 to 1967.

The light loamy sand contained:- sand 61%, fine sand 28%, silt and clay 11%, organic carbon 0.6%. The pH of the soil was 6.0.

Simazine (from J. R. Geigy A.G., Basel, Switzerland) formulated as a 50% wettable powder was applied as an aqueous suspension at 1.5, 5.0, 10.0 and 25.0 kg/ha a.i. to plots which were sown with maize or uncropped. Unsprayed plots were used as controls. The herbicide was applied after sowing, but before emergence of the maize. Three replicates of each treatment were laid out in randomized blocks.

In the 1965 experiment, plots with maize were not included.

During the growing seasons of 1965 to 1967 soil samples were taken monthly from the 0-10 and 10-20 cm layers of the experimental plots.

The simazine residue in the soil was determined quantitatively by an oat bio-assay developed by Swietochowski et al (1965). The results are presented as kg/ha of simazine remaining in the soil.

Table 1

The disappearance of simazine from uncropped light soil

Time of spraying - May 1965. Results in kg/ha

Time of sampling	Applied doses of simazine kg/ha							
	1,5		5,0		10,0		25,0	
	Depth of sampling in cm							
	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
1965								
June	1,47	0,00	4,50	0,40	9,60	0,00	21,25	1,00
July	1,42	0,00	3,90	0,75	8,20	1,00	18,50	1,25
August	1,35	0,00	3,10	0,80	6,50	0,50	15,00	1,00
September	0,75	0,25	1,70	0,45	5,00	0,30	11,37	1,00
October	0,50	0,25	1,10	0,25	2,40	0,20	6,75	0,50
1966								
June	0,00	0,00	0,30	0,00	0,60	0,40	1,75	2,25
July			0,00	0,00	0,40	0,40	1,00	1,75
August					0,15	0,10	0,60	1,00
September					0,00	0,00	0,50	1,00
1967								
July							0,40	0,70
September							0,00	0,00

RESULTS AND DISCUSSION

Table 1 shows the loss from uncropped plots of simazine applied in May 1965. 1.5 kg/ha disappeared within the first season, while 5 kg/ha persisted until June 1966 and 10 kg/ha until August 1966. Following the 25 kg/ha dose phytotoxicity lasted until July 1967.

Only small quantities of simazine penetrated into the10-20 cm layer following normal agricultural doses. This agrees with the results of Aelbers and Homburg (1959) who found that simazine was strongly adsorbed in the surface layers of the soil.

Similar rates of simazine loss and distribution in the soil profile of uncropped plots were recorded in the experiment set up in April 1966 (table 2). However, the disappearance rate of simazine was more rapid from plots sown with maize and the quantities of simazine detected were lower. The results of this experiment indicate that tolerant crop plants may play an important role in removing herbicide residues from the soil.

Table 2

Influence of maize on disappearance of simazine from light soil

Time of spraying - April 1966. Results in kg/ha

Time of sampling	Applied doses of simazine kg/ha							
	1,5		5		10		25	
	Depth of sampling in cm							
	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
1966	uncropped plots							
May	1,45	0,00	4,90	0,00	9,80	0,00	23,50	0,00
June	1,11	0,00	4,10	0,50	8,75	0,65	21,25	1,25
July	0,87	0,00	3,60	0,70	7,50	1,00	18,00	3,00
August	0,70	0,07	2,50	0,30	6,40	0,90	14,25	1,50
September	0,45	0,04	1,55	0,20	4,20	0,30	11,25	1,75
October	0,26	0,02	0,80	0,10	2,60	0,00	7,50	0,75
1967								
July	0,00	0,00	0,10	0,40	0,90	0,75	3,00	1,60
September			0,00	0,00	0,50	0,40	2,25	1,25
1966	Plots sown with maize							
May	1,33	0,00	4,70	0,05	9,30	0,20	21,25	1,00
June	0,92	0,04	3,70	0,25	8,25	0,50	18,60	1,50
July	0,72	0,03	3,00	0,40	6,75	1,00	16,00	2,00
August	0,41	0,09	2,20	0,25	5,20	1,20	12,50	0,75
September	0,15	0,02	1,00	0,10	3,00	0,20	9,25	1,50
October	0,00	0,00	0,30	0,05	1,60	0,00	4,50	1,00
1967								
July			0,00	0,00	0,60	0,40	1,75	1,25
September					0,20	0,25	0,80	0,60

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PRELIMINARY STUDIES OF GERMINATION AND SEEDLING BEHAVIOUR IN AGROPYRON REPENS (L.) BEAUV. AND AGROSTIS GIGANTEA ROTH.

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Summary The germination of seeds and the emergence and growth of seedlings of Agropyron repens (L.) Beauv. and Agrostis gigantea Roth. were studied in the laboratory and glasshouse. A large percentage of seeds of both species germinated under alternating temperatures, but their response to light was small. Neither species exhibited natural dormancy, but dormancy could be induced in A. gigantea. When seeds were sown at various depths in pots, seedlings emerged from 4% of A. repens seed sown 4" deep and 1% of A. gigantea sown 2" deep. In fertile soil A. gigantea grew faster than A. repens and was slower to initiate rhizomes. At the beginning of August, A. repens seedlings, planted in February, had produced more ears and a greater rhizome dry weight but fewer shoots than A. gigantea.

INTRODUCTION

The two rhizomatous perennial grasses, Agropyron repens (L.) Beauv. and Agrostis gigantea Roth. are well known as serious weeds of arable land. It is generally considered, once they are established, that rhizome multiplication is the main form of reproduction, but the importance of seed production and seedling behaviour in the two species has received little attention. More knowledge of this could lead to more efficient control of these weeds. Seed production, and consequent seedling establishment, could make eradication more difficult, introduce the weeds to clean areas and create new genetic variability (MacKay, 1964) with new patterns of behaviour and possibly changing response to herbicides. Beddows (1931) and Hitchings (1960) give some data on seed production in A. repens and Sagar (1960b) has discussed the importance of this as a means of spreading this species. Various workers, mainly in other countries, have investigated the germination requirements of A. repens e.g. Dahlberg (1916) and Everson (1954) and Agrostis species e.g. Thygeson (1929). To assess the importance of seed production in A. repens and A. gigantea we need to know more about the occurrence and behaviour of seeds and seedlings of the two species. This report deals with the germination of seeds and the emergence and growth of seedlings in the laboratory and glasshouse.

MATERIALS, METHODS AND RESULTS

(1) Laboratory germination (Tables 1 and 2)

The germination of seeds of A. repens and A. gigantea was tested in incubators under the following conditions :

A. 20°C and darkness.
B. 30°C and light (200 f.c.) for 8 hours; 25°C and darkness for 16 hours. The transition from 30° to 25° and from 25° to 30° took two hours.
C. 30°C and light for 8 hours; 20°C and dark for 16 hours.
D. 20°C for 8 hours; 25°C for 16 hours, both with continuous dark.

Seeds of both species were placed on moist filter paper in glass germinators using three replicates for each treatment. The effect of hulling (h) A. repens

seeds was also investigated. The effect of light on both species was tested in another experiment by giving the same temperature and light treatment as in C to half the germinators and covering the other half with aluminium foil.

Table 1.

Effect of environmental conditions and hulling on A. repens seed germination (%). (Means for each treatment)

Treatment	Time in weeks from start of test. 1	2	3	4	8	12	18
A	3	3	3	3	4	4	4
Ah	16	25	25	26	31	31	31
B	0	3	4	4	24	32	53
Bh	5	15	27	33	58	68	75
C	11	82	95	96	97	98	98
Ch	56	83	86	87	87	87	87
D	7	54	77	81	89	93	93
Dh	31	67	73	75	80	81	81
S.E.	2.8	4.1	3.7	3.8	4.6	4.8	3.7

Table 2.

Effect of environmental conditions on A. gigantea seed germination (%). (Means for each treatment)

Treatment	Time in days from start of test. 4	6	10	19
A	49	54	57	58
B	44	86	94	95
C	50	92	98	98
D	54	93	97	97
S.E.	2.7	1.6	1.7	1.7

After 18 weeks, when no more seeds of A. repens germinated, seeds from treatment A and B were given treatment C. 81% more seeds originally given treatment A and 54% more Ah germinated after a further 45 and 30 days respectively. A further 39% of seeds from treatment B and a further 6% from Bh germinated after 9 more days. A. gigantea seeds, which had been given treatment A for 19 days were transferred to C; 38% more seeds then germinated after a further 21 days. A. repens seeds were more sensitive to the different treatments than A. gigantea. Hulling accelerated germination but decreased the percentage which germinated.

With 30°C for 8 hours and 20°C for 16 hours light promoted A. gigantea germination, 86% germinating in the dark and 96% in the light (S.E.± 1.2) but had little effect on A. repens, of which 93% germinated in the dark and 91% in the light (S.E.± 0.8).

(2) Germination in soil

A. repens and A. gigantea seeds from different areas were sown in shallow pans of silty loam soil in the glasshouse on 25 September 1967 and 20 October 1967 respectively, and also on 12 February 1968. Emerged seedlings were recorded weekly and removed monthly when the soil was cultivated. One replicate of the A. gigantea autumn sowing was not cultivated until April. On 12 February A. gigantea seeds were also sown on the soil surface and not covered.

Germination of the September-sown A. repens seed ranged from 55-82% and was similar for that sown in February; all seeds that germinated did so within a month of sowing. Table 3 shows results with October-sown A. gigantea seed. Seeds from

the different areas behaved similarly and their mean is given, but because of an unequal number of replicates for the two treatments standard errors cannot be given.

Table 3.

Germination (%) of Agrostis seed sown in soil in October

	Date											
	17.11	15.12	16.1	12.2	11.3	8.4	6.5	4.6	1.7	29.7	26.8	23.9
Cultivated monthly	18	24	28	30	37	58	61	63	64	65	66	66
Uncultivated until April	17	21	21	22	22	25	35	39	44	47	49	52

Cultivation evidently facilitated A. gigantea germination. Seventy-five per cent of A. gigantea seed sown in February on the soil surface and 44% of seeds covered lightly with soil germinated within two months. At the end of September a further 15% of the covered seeds had germinated but no more of the uncovered.

(3) Depth of burying and seedling emergence (Tables 4 and 5).

On 12 March 1968 seeds of A. repens and A. gigantea were sown at various depths (see tables) in Kettering medium loam soil in 8" pots and seedlings were counted weekly and removed monthly.

Table 4.

% emergence of A. repens from seeds sown at various depths in pots in a cool glasshouse

	Time (weeks from sowing) and date of assessment				
	3	4	8	12	16
Depth (in.)	1 April	8 April	6 May	3 June	1 July
0	26	52	74	80	85
1	84	92	96	96	96
2	68	84	99	99	99
3	6	29	50	51	51
4	0	2	4	4	4

No seedlings emerged from 5 and 6 in.

Table 5.

% emergence of A. gigantea from seeds sown at various depths in pots in a cool glasshouse

	Time (weeks from sowing) and date of assessment			
	2	3	4	8
Depth (in.)	25 March	1 April	8 April	6 May
0	67	89	93	100
$\frac{1}{4}$	32	45	48	49
$\frac{1}{2}$	18	41	44	46
1	1	29	33	36
$1\frac{1}{2}$	0	3	4	4
2	0	1	1	1

No seedlings emerged from 3 in. depth

Standard errors, based on angular transformations, indicate that for A. repens at 16 weeks differences between all treatments except 1 and 2 in. were statistically significant and for A. gigantea at 8 weeks neither the differences between $\frac{1}{4}$, $\frac{1}{2}$ and 1 in. nor between $1\frac{1}{2}$ and 2 in. were significant.

(4) Seedling growth (Tables 6-10)

The growth of seedlings, in relation to crop growth, was studied by taking 8 periodical samples from 8 in. pots which contained four seedlings of either A. gigantea, A. repens or spring wheat (Kloka). The plants, sown on 22 February, were grown in Kettering loam with adequate fertiliser. A total of 96 pots was arranged in 4 randomised blocks of 24 pots. Shoots were counted and dry weights of plant parts determined at each sampling. Relative growth rates (R.G.R.) were calculated.

Table 6.

Total dry weights (g.) of A. gigantea, A. repens and wheat

	Time (weeks from sowing) and date of sampling							
	Seed weight	4	7	9	11	13	16	19	24*
Species	22.2	21.3	9.4	25.4	9.5	23.5	13.6	4.7	8.8
A. gigantea	0.0001	0.0012	0.014	0.097	0.59	1.95	11.4	24.3	28.9
A. repens	0.0020	0.0066	0.052	0.217	1.14	3.29	13.6	27.0	28.1
Wheat	0.0392	0.0704	0.515	2.798	7.59	14.61	26.4	35.5	35.6

* top dry weights only

The dates of sampling given above also apply to Tables 7-10.

As might be expected, the species dry weights differed significantly. A. gigantea started smaller, but grew faster than A. repens and wheat and by 8 August there was little difference between A. gigantea and A. repens top dry weight (Tables 6 and 7).

Table 7.

The relative growth rates, per cent/week

	Time (weeks from sowing)						
Species	0-4	4-7	7-9	9-11	11-13	13-16	16-19
A. gigantea	64	90	84	92	58	60	25
A. repens	30	76	61	84	52	48	23
Wheat	14	73	74	50	33	20	10
S.E.	1.6	2.6	6.5	5.5	8.8	4.4	2.9

Wheat began to tiller at the end of March (5 weeks) and A. repens and A. gigantea a week later.

Table 8.

Number of shoots at sampling

	Time (weeks from sowing)							
Species	4	7	9	11	13	16	19	24
A. gigantea	1.0	2.4	7.8	14.8	22	44	40	50
A. repens	1.0	2.3	7.4	12.8	20	28	22	26
Wheat	1.0	3.4	9.4	13.6	13	8	8	8
S.E.	-	0.13	0.39	1.08	1.3	1.4	0.9	1.2

By the second sampling A. repens seedlings, which were at the 4-leaf stage, had buds at the base of the main shoot which were growing horizontally or slightly downwards; at the third sampling 50% of the A. repens seedlings had short rhizomes and at the fourth, 12% of the A. gigantea seedlings which were at the 6-leaf stage, had initiated rhizomes. The dry weights of the rhizomes are in Table 9 and their R.G.R. in Table 10.

Table 9.
Dry weights (g.) of rhizomes at sampling

Species	Time (weeks from sowing) 11	13	16	19	24
A. gigantea	0.0016	0.009	0.53	2.55	7.18
A. repens	0.0588	0.223	1.83	5.73	10.40

Table 10.
Relative growth rate of rhizomes, per cent/week

Species	Time (weeks from sowing) 11-13	13-16	16-19	19-24
A. gigantea	88	137	54	21
A. repens	73	71	38	12
S.E.	18.5	8.4	6.7	3.4

Between 13 and 16 weeks A. gigantea increased its rhizome dry weight sixty-fold.

Ears emerged during mid-June for wheat, from late June to late July for A. repens and throughout July for A. gigantea. Approximately 100%, 75% and 25% of the shoots of the three species produced ears.

DISCUSSION

The results indicate that most seeds of both A. repens and A. gigantea are viable. Their germination behaviour, however, differed greatly. A. repens was more sensitive to the different environmental conditions in incubators than A. gigantea, although slightly more A. gigantea seeds germinated in the light than in the dark. A. repens, and probably A. gigantea, as many other species (Warington, 1936) required alternating temperatures for optimum germination. The variability in the behaviour of seeds given the same treatment is of considerable interest: although a few A. repens seeds germinated after a week at a constant 20°C in the dark some did not germinate until they had received 5 weeks with alternating temperature. Such variability could lead to a spread of germination in the field. The tests were made with mature seed kept dry in the laboratory for several months and resembled that contaminating seed-corn rather than seed shed directly into soil. Response to different environmental conditions may vary with age; also there may be an interaction between light sensitivity and temperature (Baar, 1912). Germination, therefore, needs to be tested at different ages and under other environmental conditions. A. gigantea and A. repens also behaved differently in soil. When the seeds were covered lightly with soil A. repens germinated readily, but only a small fraction of A. gigantea germinated under such conditions and germination continued slowly throughout the year. A. gigantea seeds sown on the soil surface behaved like those of A. repens covered lightly with soil.

There was no evidence of natural dormancy in seeds of either species but some evidence of induced dormancy in A. gigantea: although more seeds germinated quickly on the soil surface, and many fewer when covered with soil, covered seeds germinated later when cultivation brought them to or near the surface. Kephart (1923) states that A. repens seeds buried deeper than 3 in. may persist in the soil for at least 5 years and grow when brought to the surface. Chepil (1946) lists A. repens as a species having long dormancy and Dunham et al (1956) state that A. repens seed can remain viable for at least four years in soil or in storage.

The emergence of A.repens seedlings from seeds buried at different depths is in accord with the results of Kephart (1923) and Sagar (1960a). Similar work has

not been reported for A. gigantea. Variability within treatments is again of interest as well as between treatments.

Because A. gigantea was not sown until late autumn the results do not provide information on its periodicity of germination. However, they do suggest that, lacking natural dormancy, the seeds of A. repens and probably A. gigantea, will germinate when the environmental conditions allow, i.e. in autumn and spring. Kephart (1923) reports similar findings for A. repens in North America. Work in Sweden by Håkansson, (1967), Canada (Chepil, 1946) and Russia (Solov'eva, 1958) indicates that in those countries A. repens germinates mainly in the spring. In the United Kingdom, with a longer and milder autumn, Sagar (1960b) has reported autumn germination of A. repens.

Seedlings were grown in pots to supply basic information on some of their characteristics. Findings from such studies will not be directly applicable to conditions in the field. However, growth during the early stages in pots may be an indication of the potential performance of the seedlings. Despite its extremely small seed, A. gigantea has great potential for surviving because the seedlings grow quickly. The time of rhizome initiation is important because the plants can then become perennial (Håkansson, 1967) and be less easily eradicated. Under the conditions of the experiment rhizome initiation was earlier in A. repens than in A. gigantea, but the rhizomes of A. gigantea grew faster than those of A. repens.

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THE OCCURRENCE AND GROWTH OF RE-INHIBITED SHOOTS AND DORMANT BUDS ON FRAGMENTED RHIZOMES OF AGROPYRON REPENS (L.) BEAUV.

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Summary Earlier work with Agropyron repens has shown that re-assertion of dominance (correlative inhibition) is not complete amongst shoots from rhizome fragments for 10 - 20 days after fragmentation: during this time many of the shoots make limited growth. The influence of various conditions upon the length of these re-inhibited shoots was investigated and their growth potential tested by planting them in soil individually attached to 1-node fragments of the parent rhizome. Re-inhibited shoots arising from parent fragments of 2-or 3-nodes were longer than those from 7-and 15-node ones. Fewer of the shortest re-inhibited shoots (5 mm or less) grew than longer ones. Longer shoots tended to start growth quicker than shorter ones, but this advantage was soon lost and they are deemed more vulnerable to damage by cultivation. Disease was not apparently a major cause of failure to grow.

INTRODUCTION

The importance of Agropyron repens in agriculture is due in part to its ability to grow new plants rapidly from small fragments of rhizome. New shoots arise from dormant lateral buds which occur one to a node along the whole length of the rhizomes. In complete plants these buds remain dormant through apical dominance (correlative inhibition) exerted by the main rhizome apex. It has been estimated (Johnson & Buchholtz, 1962) that 95% of these buds remain permanently dormant if the plant is not disturbed. In arable land, however, the rhizomes are frequently cut up into short lengths and because dominance by the apex is broken thereby these dormant buds give rise to new aerial shoots.

Research on the development of shoots from rhizome buds (Chancellor, unpublished) has shown that on average 70 - 80% of buds on 7-and 15-node fragments make detectable growth during the period immediately following fragmentation. These studies have shown that dominance, usually by only one of the new shoots, is not fully re-asserted until about 10 - 20 days after fragmentation. During this period many of the hitherto dormant buds make variable amounts of growth and are then re-inhibited once again by the new dominant shoot. These shoots do not grow anymore provided the new dominant remains alive and attached to the rhizome fragment. A similar type of shoot behaviour has been described for the potato (Goodwin & Cansfield, 1967). These re-inhibited shoots should be capable of yet further growth and are therefore potentially of importance as reserve shoots for regrowth from the fragments. This paper records their lengths under various conditions and reports tests on their ability to make further growth.

METHODS AND MATERIALS

The plant used in all the experiments here was Agropyron repens clone no. 31 (the Headington clone) of the Weed Research Organization Couch-grass collection. The plant material was always obtained either from 1 year-old rhizomes or from rhizomes of the current year, all were grown in the field and were freshly dug-up for each experiment. Before use the rhizomes were carefully washed and all roots and scale-leaves removed by hand. The fragments (2,3,7 or 15-nodes) were always selected from the centre of long lengths in order to avoid short internodes near the base or immature buds close behind the main rhizome apex. At each end a length

of internode was left beyond each terminal bud. Fragments were not selected for length or diameter, but unusally thin or short ones were not used.

The fragments selected were grown in conditions of high humidity in sealed perspex boxes, which had been specially developed for the study of dominance re-assertion. The boxes being transparent allow each root and shoot to be continuously observed and measured day by day without disturbance. The external dimensions of the boxes are 11 x 11 x 1 in. for 7-node or smaller fragments and 11 x 19.5 x 1 for 15-node ones: all the walls are $\frac{1}{4}$ in. thick perspex. Their internal capacities are approximately 850 and 1600 ml.

In each box were placed 3 rhizome fragments, which were sewn horizontally onto black photographic mounting paper cut to fit the boxes exactly. After the rhizomes on the sheet of paper were put into the box it was filled with distilled water or nutrient solution as required and left for about 5 minutes to allow the paper to become fully charged with liquid. It was then emptied and the open top end sealed with 1 in. wide PVC self-adhesive tape. The boxes were placed upright in an incubator. To investigate the effects of light and dark the boxes were wrapped in envelopes of clear or black polythene sheeting. The dark treatments were set up in a photographic dark room and for assessment infra-red photographs of 1/400 sec. exposure were made there. These were later projected onto a screen for measurements to be made.

Assessments were usually made every 2 - 3 days and for them the boxes were filled with water or nutrient solution, which charges the whole sheet of paper fully, cleans off condensation inside the boxes and flushes out all the air which is then replaced when the box is emptied. Shoots were then measured individually with a ruler to the nearest mm.

To test the ability of re-inhibited shoots to grow, the rhizomes were taken out of the perspex boxes, after dominance had been re-asserted, cut up into 1-node fragments and planted $\frac{1}{2}$-1 cm. deep in sieved light sandy soil in 7 in. polythene pots. Only buds and shoots that had stopped growing were planted: the still-growing dominant shoots were discarded. Assessments of growth were made after various intervals. In the first of these experiments only buds and shoots up to 15 mm were tested, but in the second all shoots up to the maximum length obtainable were planted.

RESULTS

(a) The occurrence of different shoot lengths under various conditions

A number of experiments (Chancellor, unpublished) were carried out in 1967 on the re-assertion of dominance among lateral shoots from rhizome fragments under various conditions and data from these experiments have been summarised to give the results shown in Tables 1 and 2. These show the effects of various conditions upon the lengths of re-inhibited shoots and buds.

There is little difference in Table 1 between shoots grown in the dark and in the light apart from 4 longer shoots (out of a total of 110) which occurred on rhizomes grown in the dark. Similarly there was no apparent difference between re-inhibited shoot lengths from rhizomes with added potassium nitrate and those with only distilled water. This conflicts with the report (McIntyre, 1965) that shoot inhibition through dominance can be prevented by adding potassium nitrate to the substrate. In Table 2, however, there is a noticeable difference between shoots from various fragment sizes. Shoots from 2-and 3-node lengths of rhizome (these are combined because relatively few were investigated) were on average very much longer than those from 7-and 15-node lengths. There was no apparent difference between 1 year old rhizomes and those from the current year.

Table 1.

The lengths* of re-inhibited shoots and dormant buds occurring on 7-node rhizome fragments under various conditions
(The number and percentage in 10 mm size groups)

size groups (mm)	Rhizomes grown with distilled water in LIGHT No of shoots	% of Total	DARK No of shoots	% of Total	Rhizomes grown in light with 200 ppm KNO_3 No of shoots	% of Total	Dist. water No of shoots	% of Total
1-10	83	65	70	63	56	42	58	44
11-20	27	21	21	19	32	24	29	22
21-30	6	5	5	5	12	9	18	13
31-40	7	5	11	10	10	7	13	10
41-50	4	4	2	2	11	9	7	5
51-60			0	0	6	5	4	3
61-70			1	1	4	3	1	1
71-80			1	1	1	1	2	1
81-90			1	1	1	1	0	0
91-100			1	1			1	1

* Dormant buds usually measure 1-3 mm in length: The still-growing dominant shoots are not included.

Table 2.

The lengths of re-inhibited shoots and dormant buds occurring on different-lengthed rhizome fragments
(The number and percentage in 10 mm size groups)

size groups (mm)	No. of nodes per fragment: 2 or 3-nodes No of shoots	% of Total	7-nodes No of shoots	% of Total	15-nodes No of shoots	% of Total	Age of 7-node fragments: 1 year old No of shoots	% of Total	Current Year's No of shoots	% of Total
1-10	9	14	350	55	273	57	107	54	243	55
11-20	5	8	109	17	97	20	38	19	71	16
21-30	4	6	65	11	35	8	20	10	45	10
31-40	9	14	56	8	22	5	17	9	39	9
41-50	6	10	32	5	20	5	11	6	21	5
51-60	6	10	13	2	11	2	2	1	11	2
61-70	6	10	9	1	4	1	2	1	7	2
71-80	2	3	4	1	2	1			4	1
81-90	4	6	1		1	0			1	
91-100	4	6	1		3	1			1	
101-110	0	0	0		0				0	
111-120	2	3	0		2				0	
121-130	3	5	0		1				0	
131-140	1	2	0		1				0	
141-150	0	0	1		1				1	
151-160	2	3			0					
161-170					1					
171-180					2					
181-190					1					
191-200					0					
201-210					2					

(b) The ability of re-inhibited shoots and dormant buds to grow

Having investigated the occurrence of different shoot lengths it remained next to see if they differed in their ability to resume growth. In January 1968 115 buds and shoots of 15 mm or less in height were cut off with 1-node parent rhizome fragments attached and planted individually in pots of soil. The results of this are given in Table 3.

Table 3.

The growth behaviour of short re-inhibited shoots or buds from rhizome fragments
(The percentage making new growth or no growth by certain dates)

Bud or shoot lengths (mm)	No of pieces planted	Percentage making new growth by 18 days	33 days	50 days	Percentage making no growth
1-5	56	43	55	59	41
6-10	41	69	86	91	9
11-15	18	78	89	89	11

It is interesting to note that 41% of the 1-5 mm group did not produce new growth even after 50 days whereas only about 10% of longer shoots made no new growth.

The second experiment was planted in August 1968 to obtain a maximum contrast in the condition of the rhizomes to those in the first experiment. In this test shoots of all lengths were used. The results are given in Table 4.

Table 4.

The growth behaviour of re-inhibited shoots of all lengths from rhizome fragments
(The percentage making new growth or no growth by certain dates)

Bud or shoot lengths (mm)	No of pieces planted	Percentage making new growth by 14 days	21 days	31 days	Percentage making no growth
1-5	35	17	49	57	43
6-10	14	65	93	100	0
11-15	19	52	73	84	16
16-50	94	79	84	86	14
51-100	34	85	94	94	6
more than 100	10	90	100	100	0

It is noticeable that 43% of the 1-5 mm group made no growth at all, while smaller proportions of longer shoots made no growth as in the first experiment. More longer shoots made new growth by the first assessment than shorter ones.

At the end of 31 days all fragments failing to grow were carefully dug up to see if they had died. Of 15 fragments with shoots between 1-5 mm, 5 were obviously dead and rotting while of the 16-50 mm group 6 out of 13 were dead and of the 51-100 mm group 1 was dead and 1 alive. Proportionally then there is no definite tendency for fragments with a particular shoot length to die and rot more than others.

Finally a check was made to see whether the rhizome fragments attached to non-growing shoots were themselves shorter or smaller than ones with shoots that did grow. No evidence of this was found.

DISCUSSION

Tables 1 and 2 show that the growth of re-inhibited shoots is not influenced by light, nitrate or rhizome age, but it is apparently by fragment size. This effect is thought to be due at least in part to the relatively slow basipetal movement of the inhibitor responsible for the dominance system. In long rhizome fragments basal buds often remain inhibited until the new dominant shoots produce fresh inhibitor so that these buds apparently remain permanently dormant. The practical importance of this difference between rhizome fragment sizes is likely to be that as shorter fragments give rise to longer shoots they will be more vulnerable to subsequent cultivation or herbicidal treatment. Fail (1956) found the mean length of fragments after 1 rotary cultivation to be 3.44 in. (8.7 cm) with a maximum of 7 in. (17.8 cm), after 2 cultivations 2.22 in. (5.6 cm) with a maximum of 6 in. (15.2 cm) and after 3 cultivations 1.53 in. (3.9 cm) with a maximum of 4 in. (10.2 cm). A photograph in Fail's paper suggests a possible maximum of 6-nodes per fragment. Such a small number of buds implies that on the longer fragments only a few could still remain dormant after one or two rotary cultivations, but most if not all buds would make considerable growth on shorter ones. The recent trend of substituting herbicidal treatments for some of the rotary cultivations should result in similar growth patterns. Other cultivations such as mouldboard or chisel ploughing would of course result in greater fragment lengths and a larger proportion of dormant buds.

There is apparently no effect of time of year on the ability to grow, for Tables 3 and 4 both show that over 40% of the 1-5 mm group and lesser percentages of longer shoots failed to grow. For 1-5 mm shoots this failure could be due either to a form of dormancy or to buds being damaged, which effects, as has been noted before (Chancellor, 1967) are difficult to differentiate. These tables also show that the longer the re-inhibited shoot, the greater the proportion growing by the first assessment, but this advantage, if any, is soon lost. In the second experiment the pots were kept for a further 14 days after the last assessment and by then no differences in plant size associated with length of the original shoot could be found.

In the second experiment only 14 of the 33 shoots that made no further growth were dead and rotting, which indicates that disease was not the prime cause of their failure. However, rotting of rhizome fragments has been described as important elsewhere (Fail, 1956).

Rhizomes when cut up by cultivation in the field usually have several nodes, each with one dormant bud. The results given here show that depending on fragment size, a few buds make no growth, most make some growth and then stop, while only one or two grow on indefinitely to become the dominant shoots that give rise to the new plant. Those making limited growth grow to various lengths. Length is important because the longer the shoot the more likely it is to be damaged or destroyed by later cultivations and it is by the systematic destruction of long re-inhibited shoots and still-growing dominants that control by rotary cultivation works. There is apparently no particular length of re-inhibited buds or shoots that is incapable of further growth should the dominant shoot be cut-off or destroyed, but ones less than 5 mm long appear less able to regrow than longer ones. The ubiquity and importance of Agropyron repens in British agriculture surely indicates how well suited this pattern of growth is to overcome the difficulties of the habitats in which it lives.

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5

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THE GROWTH AND DEVELOPMENT OF AGROPYRON REPENS (L.) BEAUV. IN COMPETITION WITH CEREALS, FIELD BEANS AND OILSEED RAPE

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Summary An experiment is described in which populations of Agropyron repens were established artificially in plots sown to four spring crops. The growth of the weed was assessed at intervals throughout the life of the crops. A. repens was suppressed to a marked degree by the crops: oilseed rape and barley were most suppressive, wheat was intermediate and field beans offered the least competition. The maximum growth of A. repens was recorded in each case after the period of maximum crop growth. It is suggested that relative speed of establishment and early growth of a crop is important in suppressing this weed and that habit and form of growth are also important.

INTRODUCTION

As a result of the widespread and growing importance of A. repens as a weed of cereal land renewed emphasis has been given to this weed in the programme of work of the Weed Research Organization. One aspect of this work has been a study of the productivity and seasonal pattern of growth of A. repens under a range of conditions.

It seemed inevitable that the seasonal pattern of growth and total production by the plant would be powerfully influenced by competition from crop plants. Mann and Barnes (1948)(1949) working on two other rhizomatous grasses Holcus mollis and Agrostis gigantea had reported that barley had a greater effect on the growth of these grasses than vice versa. Aspinall and Milthorpe (1959) in a study of competition between barley and Polygonum lapathifolium also found the crop to be dominant.

Aspinall and Milthorpe (1959) and Aspinall (1960) suggested that the success of P. lapathifolium could depend on the fact that this plant, although powerfully suppressed by barley in its early stages, retained its ability to make vegetative growth after crop growth has ceased.

This paper presents some results of an experiment carried out to examine the growth of A. repens in the presence of four spring sown crops.

METHOD AND MATERIALS

The experiment was sited at Begbroke Hill Farm, on a sandy loam soil. A randomised block design was used with four replicates. Each main plot was 60 ft long by 9.5 ft wide; the plots were separated by pathways 2.5 ft wide. The main plots were sub-divided into areas 10 ft by 9.5 ft of which the central 4.5 ft by 4.5 ft was planted to A. repens. All assessments were made on the central 3 ft by 3 ft of this area. There were six of these sample plots within each main plot.

The A. repens was planted before the crops were drilled and as nearly as possible to the time of drilling. Rhizome pieces 6 in. long were cut from clonal material obtained from a stock bed maintained at Begbroke. Unbranched and unsprouted pieces were selected and the material was chosen so as to avoid rhizome with damaged buds or which differed markedly from the normal in respect of internode length and diameter.

To plant these rhizome sections shallow furrows were drawn 9 in. apart and 3 in. deep and the rhizome sections were placed in the furrow bottoms at 9 in. intervals. The planted population was therefore sixteen 6 in. rhizome fragments per yd^2 or 5.3 g of rhizome dry matter per yd^2.

The main plots were sown on the 20th March as follows:
Barley (var. Impala) at 160 lb/ac, Wheat (var. Kloka) at 190 lb/ac, Tic beans (var. Maris Bead) at 210 lb/ac and Oilseed rape (var. Nilla) at 95 lb/ac. These seedrates correspond to 12.8, 15.2, 16.8 and 7.6 g/yd^2 of dry matter.

All the crops were planted in rows 6 in. apart and were sown with a conventional seed drill. The excessive seed rate of the Oilseed rape was not intentional, it should have been 9.5 lb/ac. The whole area received on 10th March 2½ cwt/ac of a compound fertilizer containing N.P.K. in the ratio of 13:13:20. All plots except those to be sown to Beans received an additional seedbed application of 2 cwt/ac of an ammonium sulphate/nitrate product containing 26% Nitrogen. A pre-emergence treatment of 4 lb/ac dinoseb amine in 40 gallons of water per acre was applied to the Bean plots on April 7th. Little weed developed on the experiment and no other plots received herbicide treatment. Dimethoate was applied to the Bean plots on the 15th June and 14th July to control Aphis fabae and to the Oilseed Rape plots on the 14th July to control Brevicoryne brassicae L.

Sample plots selected at random were harvested 7, 11, 15, 20 and 24 weeks from planting. At each harvest date the A. repens was completely excavated and assessed, where applicable, for tiller number, leaf number, number of flower heads, number of new rhizomes, and number of upturned rhizome apices. The dry weight of the plants and of newly initiated rhizome was also determined and at two sampling dates the disposition of foliage dry weight in relation to height above ground level was also recorded.

The assessment of the crop species varied somewhat with date. Total dry matter production above ground level was recorded for all species at the first four sampling dates. After this the wheat and oilseed rape plots suffered severely from bird damage and these crops were not assessed on the 4th September.

At the first three sampling dates, plant number per yd^2 was recorded and the numbers of tillers per plant and leaves per plant were also recorded. For this purpose all of the bean plants on a yd^2 sample plot were assessed but a random sample of 50 plants was taken from the other crops.

RESULTS

1. Crop Growth

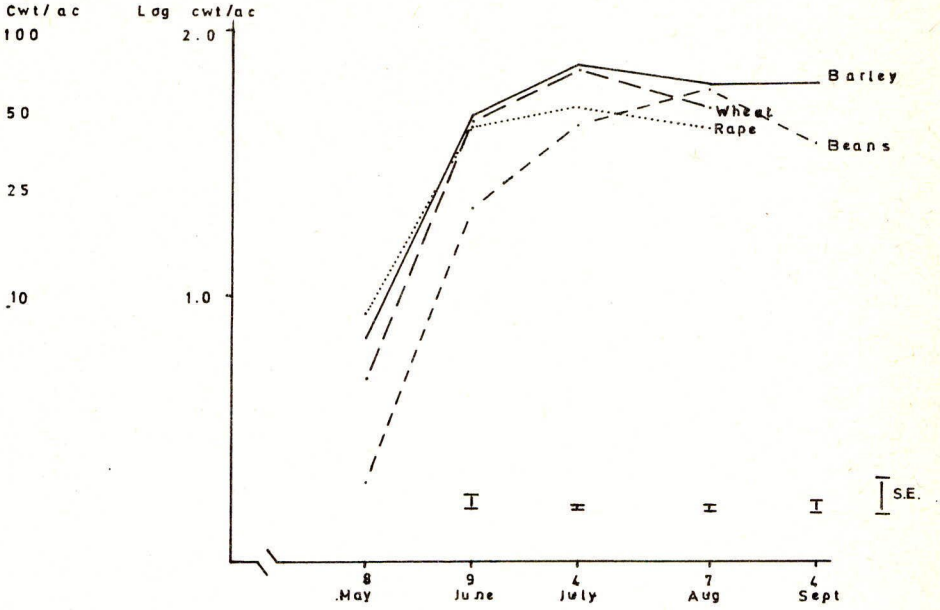
All crops showed the pattern of increasing dry matter yield during the periods of vegetative growth, flowering and seed formation followed by loss of dry matter during the ripening phase. The dry matter yields above ground are shown in Fig. 1.

Barley and oilseed rape produced the highest yield after the first seven weeks and beans by far the lowest. Subsequent dry matter yield values were very much affected by the differing rates of maturation of the crops; the maximum value was recorded for beans at the August harvest but at the July harvest for the other crops.

Yield at this maximum level was highest in the case of barley and wheat and lowest in the case of oilseed rape, with beans being intermediate.

Unfortunately a full comparison of yields at maturity is not possible because of damage to the wheat and oilseed rape plots, by birds.

Fig 1 Dry matter yield of four crops



Tables 1 and 2 illustrate the plant populations and total shoot populations of the four crops for the first three harvest dates.

Table 1

Crop populations, plants/yd^2

Harvest Date	Beans	Barley	Oilseed Rape	Wheat
8th May	39	273	953	292
9th June	40	251	544	222
4th July	37	218	367	228

Table 2

Total shoot numbers/yd^2

Harvest Date	Beans	Barley	Oilseed Rape	Wheat
8th May	39	945	953	695
9th June	44	823	544	559
4th July	39	689	367	479

It will be seen that beans and oilseed rape scarcely tillered at all and barley tillered more profusely than wheat. In all crops there was a tendency for numbers of plants and tillers to rise to a maximum and then fall with the onset of severe competition. This was least marked with beans and most marked with barley and oilseed rape. The latter was of course sown at a grossly excessive seed rate.

2. Growth of Agropyron repens

Table 3 shows the total dry matter yield of the weed. The competitive effect of all crops is demonstrated by the fact that maximum dry matter increase of A. repens took place after the period of maximum crop growth, during the crop ripening phase. This is considerably later than the peak of growth in the absence of the crop.

Table 3

Agropyron repens. Dry matter yield in the presence of four competing crops. Total yield g/planted section - logarithmically transformed values in brackets

Harvest Date	Beans	Barley	Oilseed Rape	Wheat	S.E.
8th May	0.71	0.56	0.53	0.69	
9th June	4.05 (0.607)	1.54 (0.189)	1.17 (0.067)	2.40 (0.380)	(0.0374)
4th July	6.76 (0.830)	2.53 (0.403)	2.16 (0.335)	3.03 (0.482)	(0.0351)
7th August	10.28 (1.012)	3.35 (0.525)	3.07 (0.487)	4.40 (0.732)	(0.0442)
4th Sept.	20.09 (1.303)	6.74 (0.829)	5.14 (0.711)	8.73 (0.941)	(0.0531)

In addition there are considerable differences between the growth of A. repens in the different crops. Beans have consistently provided the poorest competition so that the growth of couch in this crop is at least twice that in any of the other crops. Growth in the presence of the other three crops also showed consistent differences but of a much lower order of magnitude; more couch was present in barley plots than oilseed rape plots and more was present in the wheat plots than either of the others.

Fig 2

Growth of Agropyron repens in competition with two crops

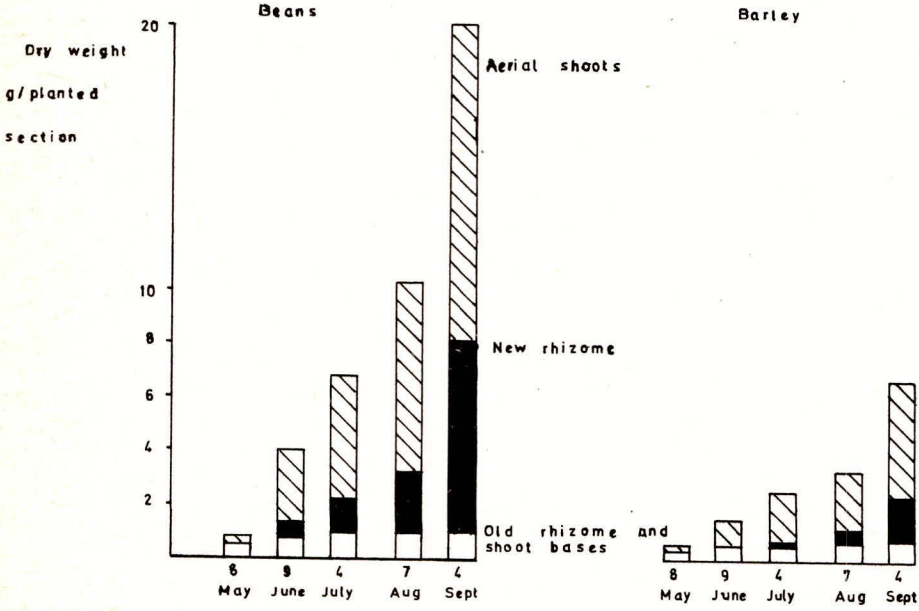


Fig. 2 demonstrates the difference in total yield between A. repens grown in the presence of beans or barley and also shows that new rhizome formed a greater proportion of the total in the bean plots. In the presence of barley there was practically no new rhizome growth for the first 15 weeks.

These results on the gross production by Agropyron repens were closely paralleled by the observations which were made on the morphology of the weed. Table 4 shows the total number of shoots per "plant"; i.e. primary shoots, tillers and upturned rhizome apices.

Table 4

Total no. of shoots per planted section of Agropyron repens - logarithmically transformed values in brackets.

Harvest Date	Beans		Barley		Oilseed Rape		Wheat		S.E.
8th May	3.4		2.8		2.6		3.3		
9th June	9.5	(0.978)	2.9	(0.467)	2.3	(0.367)	5.0	(0.695)	(0.0389)
4th July	8.9	(0.950)	2.7	(0.436)	2.2	(0.343)	2.9	(0.457)	(0.0485)
7th August	25.5	(1.423)	7.7	(0.888)	6.8	(0.833)	10.2	(1.008)	(0.0475)

The number of primary shoots produced by each plant was around 2.6 with no differences observable between plots. These results indicate that by the 8th of May a small number of tillers had been produced by A. repens on all treatments, the total shoot number being greatest in the case of the beans and wheat plots. By June a great deal of tiller formation was recorded on the bean plots and a slight increase had been recorded on the wheat plots, but shoot numbers on the barley and rape plots had remained almost static. By July there had been a reduction in shoot number on all plots; this was least significant in the bean plots. By August all plots showed a great increase in shoot numbers due to tillering and the emergence of some rhizome apices.

It appeared that A. repens had reacted to the low light intensity in the lower levels of the competing crops by growing upwards to produce foliage above the crop canopy. Table 5 illustrates this by showing the distribution of dry matter in relation to ground level.

Table 5

Dry matter yield of aerial shoots of Agropyron repens in relation to height above soil levels (9th June harvest only)

Height above soil level inches	Competing crop: Beans	Barley	Oilseed rape	Wheat
over 30	Nil	0.04	Nil	0.05
24 to 30	0.10	0.17	0.02	0.20
18 to 24	0.29	0.19	0.11	0.32
12 to 18	0.55	0.19	0.17	0.35
6 to 12	0.76	0.21	0.17	0.38
0 to 6	0.97	0.22	0.21	0.44

It was apparent that the height of the tallest shoots of Agropyron was related to the height of the crop in which it was growing. The plants growing in the less competitive bean crop had produced much more foliage at the lowest levels than the others.

Another reaction to competition was a reduced proportion of flowering shoots in relation to those which elongated without producing a flower head. If the number of

spikes produced by the 7th August is expressed as a percentage of the number of shoots present on the 8th May (at around the time of flower initiation) the following figures are obtained.

A. repens grown in:	Beans	92%
	Barley	32%
	Oilseed rape	31%
	Wheat	45%

DISCUSSION

These results represent the effects of competition for light, water and available nutrients, but the importance of each factor cannot be determined from this experiment. However it is suggested that competition for light played an important role in this case. For example, the morphological differences between the different populations of A. repens would seem to be the result of etiolation rather than shortage of water or nutrients. As a further example the differences between A. repens grown in competition with wheat or barley are difficult to explain solely on the basis of dry matter production of these crops. These differences might be more easily explained by the earlier growth of barley and its more profusely tillering habit. Of the two species, barley produced a denser shade earlier in its life. In further contrast the beans provided little shade in the early stages of growth. The production by A. repens was very high on these plots despite the reduced use of nitrogen fertilizer.

The success of a plant as a competitor would seem to depend on its ability for rapid establishment and early growth, allied to an efficient habit of growth in respect of light reception.

Two points of practical relevance emerge from the results of this experiment. First the growth of the weed is very much limited by competition from the crop. Any factor which leads to earlier establishment or better disposition of the crop plants is likely to be beneficial. Conversely, crops which provide poor competition will allow the weed opportunity for growth.

Secondly, a high proportion of the total growth of A. repens during the term of this experiment was made after the competing crop had set seed and commenced ripening. Early crop harvest and early initiation of control measures must enhance the probability of successful control.

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A STUDY OF THE RATES OF SHOOT AND TILLER EMERGENCE OF BARLEY AND AGROPYRON REPENS (L.) BEAUV.

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Summary The emergence and early stages of development of barley and Agropyron repens were observed by making repeated assessments in fixed quadrats. Barley was consistent in emerging more rapidly than A. repens. Early development of A. repens relative to that of barley appeared to be affected little by variations in site and date of drilling. There appeared to be little difference between the performance of artificially established and natural populations of A. repens.

INTRODUCTION

When the rhizome system of A. repens is fragmented by cultivation some of the rhizome buds develop into aerial shoots. These shoots are referred to as primary shoots throughout this paper. The other rhizome buds remain dormant so that there is no further development of primary shoots unless the rhizome system is once more disrupted or until the apices of newly formed rhizomes turn up to produce shoots.

It follows that the emergence of shoots of A. repens in a spring cereal crop is analagous to the emergence of the crop itself. There is a flush of shoot emergence after seedbed preparation and subsequent shoot development takes place by tillering rather than the emergence of fresh primary shoots.

In experiments on artificially established populations of A. repens, it had been observed that this plant tended to be dominated in the early stages by competing crops of barley. Such dominance appeared to depend on the more rapid emergence and early growth of barley relative to that of the weed. It seemed possible that the relative speeds of emergence of crop and weed could vary from field to field and that artificially established populations of A. repens might differ in this respect from natural infestations.

This paper presents the results of a preliminary study of the emergence of barley and A. repens in the Oxford area in the spring of 1968.

METHOD AND MATERIALS

Quadrats 1 ft^2 were fixed on eight sites, the details of which can be seen in Table 1. At sites 1 - 5 inclusive the quadrats were placed on experiments that had been laid down for other purposes and on these, 6 quadrats were used per plot and the plots were replicated 3 or 4 times. The remaining sites were on ordinary fields of barley and on these, 25 quadrats were used at each site. In every case the quadrats were thrown at random and then reoriented so as to lie parallel with the crop rows.

Counts were made of the numbers of primary shoots, tillers and leaves of barley and A. repens. The assessments were terminated when the barley had formed a complete cover and it was felt that the physical interference involved in making these counts was such that the assessment areas could no longer be regarded as completely typical.

Table 1

Site details

Site No.	Location	Soil type	Spring Barley Variety	Spring Barley Drilling Date
1	Begbroke (1)	Light loam with gravel	Impala	27th Feb.
2	" (1)	"	"	23rd April
*3	Begbroke (2)	Sandy loam	Impala	6th March
*4	" (2)	" "	Deba Abed	6th March
5	Elsfield	Loamy sand	Deba Abed	8th March
6	Chipping Norton	Med. loam over limestone brash	Impala	9th March
7	Albury	Clay loam	Zephyr	13th March
8	Bucknell	Clay loam	Impala	15th March

* At the Begbroke (2) site the A. repens was established artificially by planting 6 in. rhizome sections.

Sites 1 to 4 were on two fields at Begbroke Hill and Table 2 gives some meteorological data obtained nearby.

Table 2

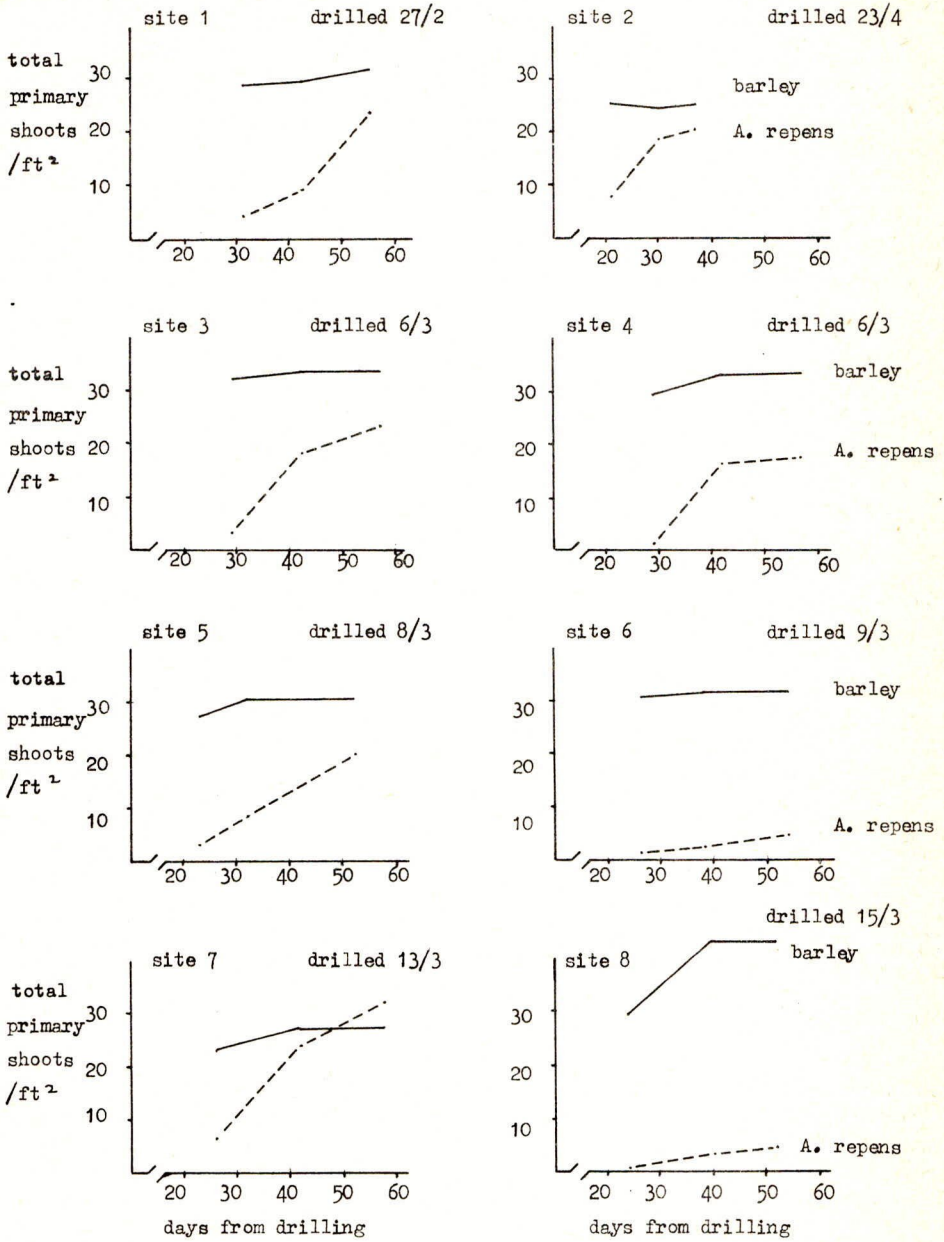
Rainfall and soil temperature at Begbroke Hill

Week Commencing	Total precipitation Weekly totals in mm	Soil temperature at 5.0 cm Means of 7 daily readings: Minimum temperature °C	Soil temperature at 5.0 cm Means of 7 daily readings: Temperature at 0900 GMT in °C
26th Feb.	0.0	- 1.2	0.6
4th March	0.5	0.6	2.3
11th "	3.5	1.7	4.1
18th "	7.8	2.7	5.6
25th "	8.8	1.9	6.3
1st April	5.8	1.0	3.1
8th "	0.0	0.5	4.3
15th "	17.9	9.8	11.4
22nd "	11.7	5.0	10.4
29th "	18.0	3.1	9.7
6th May	15.7	1.3	9.1
13th "	32.3	4.5	11.2

RESULTS

Fig. 1 shows the number of primary shoots of the two species plotted against the time in days from the date of drilling. It can be seen that emergence of barley was generally rapid. In most cases 80 - 90% of the primary shoots present at the final assessment had emerged during the first 20 - 30 days. The exception to this was at Bucknell, at which site the heaviest soil of the series was recorded.

Fig. 1. :- Primary shoot emergence of barley and A. repens at three successive dates.



The emergence of A. repens was much slower and more protracted than that of barley. Of the primary shoots recorded at the final assessment only 10 - 40% had emerged during the first 20 - 30 days compared with 80 - 90% in the case of barley.

The emergence of primary shoots of A. repens continued throughout the period of assessment, whereas there was little or no further emergence of barley after about 40 days from the date of drilling.

Table 3 shows the degree of tillering and the number of main stem leaves of the two species at the time of the final assessment.

Table 3

Stage of development of barley and A. repens

at the time of the final assessment

Site No.	Final assessment		Shoots originating from one primary shoot		Main stem leaves per primary shoot	
	Days from drilling	Date	Barley	A. repens	Barley	A. repens
1	56	23rd April	2.5	1.1	4.7	2.6
2	37	28th May	2.9	1.0	4.9	2.7
3	57	2nd May	2.4	1.0	4.7	3.0
4	57	2nd May	2.8	1.0	4.7	3.0
5	52	29th April	3.9	1.2	6.0	2.6
6	54	2nd May	2.9	1.2	4.9	3.2
7	58	10th May	2.9	1.2	5.0	3.3
8	52	6th May	2.7	1.1	5.0	3.0

Barley was, at all dates of assessment, consistently at a more advanced stage of growth than was the accompanying A. repens. At the final assessment barley was generally at about the 5 leaf stage with 1 to 2 emerged tillers on each primary shoot. A. repens in contrast was at around the 3 leaf stage and less than 20% of the primary shoots had produced tillers.

DISCUSSION

This was a limited study on 6 fields and the results should therefore be interpreted with some caution. The period of assessment terminated at a stage when it seemed certain that seedling emergence of barley was complete. No such conclusion can be drawn on the emergence of A. repens although observations elsewhere have indicated that, in spring, primary shoot emergence is normally complete by 40 to 60 days from the date of the last cultivation.

These results did, however, show that the establishment and early development of barley were consistently more rapid than of A. repens. Although there were differences between the absolute values recorded at the different sites the relative speeds of development of the two species followed the same pattern. The relative speed of emergence of the A. repens that was planted artificially appeared to differ little from that recorded for the natural populations.

Acknowledgements

A number of colleagues from the Weed Research Organization have given helpful advice and criticism. Particular thanks are due to P. D. Smith and J. F. Nash for their help with the assessment programme. Their assistance with the work described elsewhere in these proceedings is also gratefully acknowleged.

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A STUDY OF THE RESPONSE OF FOUR CLONES OF AGROPYRON REPENS (L) BEAUV. TO ROOT AND SHOOT APPLICATION OF AMINOTRIAZOLE AND DALAPON

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Summary Four clones of Agropyron repens were grown under glasshouse conditions and supplied with a range of concentrations of dalapon and aminotriazole. In the first experiment the herbicides were soil applied and uptake was through the roots; in the second the foliage was dipped into the appropriate solutions. Not all clones showed the same dose responses for each chemical but the differences between them were most striking at the lower doses including the control. The order of clone performance was not the same in the two experiments.

INTRODUCTION

There have been many demonstrations of the variability in response to herbicides within species. Some of them have been indirect: failure to explain the variability under field conditions in terms of environmental variations being taken to mean that genetic differences were the cause. Other demonstrations of intra-specific variation have been more firmly established. Hayes et al (1965) for example went as far as producing an explanation of the inheritance of resistance to barban in barley. It is often relatively easy to multiply doses of vegetatively reproducing species and in consequence many perennials have been studied in this context. Varieties of potatoes vary in their response to TCA (Bylterud, 1958) and to 2, 4 - D and MCPA (Berg, 1958). Rochecouste (1962) demonstrated very convincing differences in response to TCA and dalapon of biotypes of Cynodon dactylon (L) Pers and related these to the ploidy of the clones concerned. Holly and Chancellor (1960) showed differences in response of two clones of A. repens to foliage applications of aminotriazole and dalapon. The work to be reported is an extension of their line of investigation.

METHOD AND MATERIALS

Single rhizomes selected from samples of A. repens collected from the College Experimental Station, Pen-y-ffridd (Clone P), from a school garden in Bangor (Clone D), from Headington, Oxford (Clone H) and from Sealand, N. Flint (Clone S) were multiplied using standard techniques to provide abundant experimental material. The clones differed in certain morphological characters (Table I).

Table I

Some morphological characteristics of the four clones

	Clone	Hairiness	Texture	Colour
	P	loosely hairy	soft	dull green
D	D	sparsely hairy	soft	dull green
	H	closely hairy	stiff	glaucous
	S	almost glabrous	soft	glaucous

Experiment I. Root applications

On 12th May 1967 single-node segments each ca 2.5 cm long were cut and planted in trays of sand saturated with Hoagland solution. When leaf 3 was partly emerged the plants were selected for uniformity within clones and five plants from the same clone were transplanted into each of 24 six-inch pots containing washed quarry sand. Ninety-six pots were involved and all were supplied with 200 ml Hoagland solution every other day. All the pots were leached with de-ionised water at weekly intervals. By 14 June 1967 when the fourth leaf was emerging the two herbicides aminotriazole[1] and dalapon[2] were supplied separately and each at six concentrations viz. zero, 0.01, 0.1, 1, 10 and 100 ppm a.i. in 250 ml of culture solution. Care was taken to ensure that the foliage did not come into direct contact with the herbicide solution. One month after the herbicides were supplied the plants were harvested.

Experiment 2. Shoot application

The experimental plants were selected from single-node segments grown in a manner similar to those for Expt. 1. When leaf 3 was partly emerged the segments were transfered to water culture which was aerated daily. The culture vessels were arranged on a glasshouse bench and a minimum 16-hr. day maintained by supplementation (400 watt mercury fluorescent lamps.) When leaf 4 was partly emerged the aerial parts of the plants were dipped into the appropriate herbicide solution. For aminotriazole the doses were zero, 1, 10, 100, 1000 or 10,000 ppm and for dalapon zero, 2, 20, 200, 2000 or 20,000 ppm. The technique was similar to that used by Rochecouste (1962). Following the treatment with herbicide the plants were allowed to continue growth for one month. On 15 Jan 1968 plants in the aminotriazole series were harvested but because of lack of phytotoxic symptoms the plants in the dalapon series were retreated to produce a dose series (the combined doses from the two applications) of 0, 1000, 2000, 3000, 4000 and 20,000 ppm. These plants were allowed to continue growth for a further 15 days before harvest.

General

Both experiments were conducted in a glasshouse. A number of parameters were measured and recorded but only total dry weight and dry weight of new rhizome are presented in the results. At harvest the plants were dissected into fractions which were oven dried at 80°C for four days and subsequently weighed. There were four replicates for every treatment. Layout was of randomised blocks and statistical analysis of the results was by Analysis of Variance and Duncan's Multiple Range Test. The data were not transformed.

1 as Weedazol 2 as Dowpon

RESULTS

Expt. 1. - Root applied herbicides

Total dry weight

The dose responses of the four clones to dalapon and aminotriazole are given in Figs. 1 and 2. The analysis of variance confirmed that aminotriazole was more toxic than dalapon (P = 0.001),

Fig. 1

Expt. 1. Root application
Dalapon

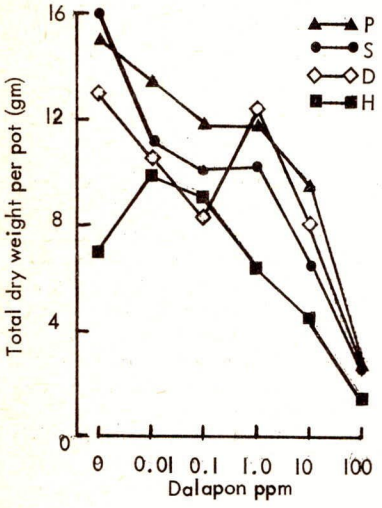
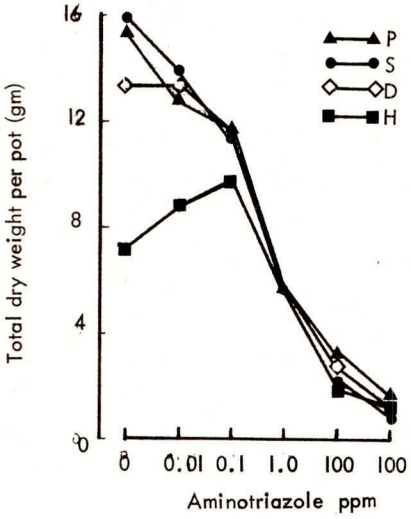


Fig. 2

Expt. 1. Root application
Aminotriazole



that the clones differed (P = 0.001). Herbicide x concentration and clone x concentration interactions were both significant, the former because aminotriazole depressed dry weight more than dalapon at the lower doses and the latter because the differences between the clones were not maintained at all doses. Thus for aminotriazole the H clone produced less dry weight than S, P or D at doses of 0 and 0.01 ppm (P = 0.05) but all the clones were similar following application of higher doses. For dalapon the situation was more complicated with the H clone apparently showing stimulation of growth following treatment with 0.01 and 0.1 ppm (P = 0.05)

New rhizome production

The data are presented in Figs 3 and 4. In the control situation the H clone produced less dry weight of new rhizome than the other three clones (P = 0.05). Overall P grew most. Dose

Fig. 3

Expt. I. Root application.
Dalapon

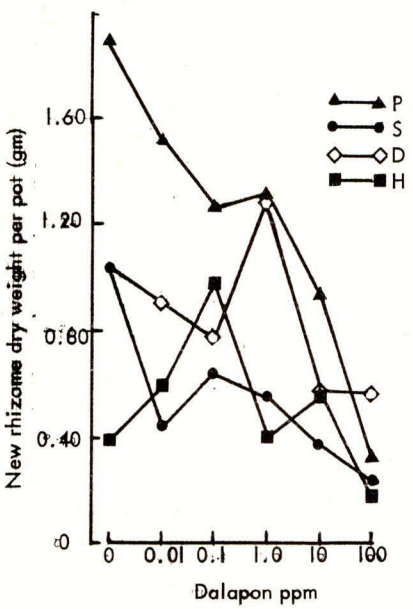
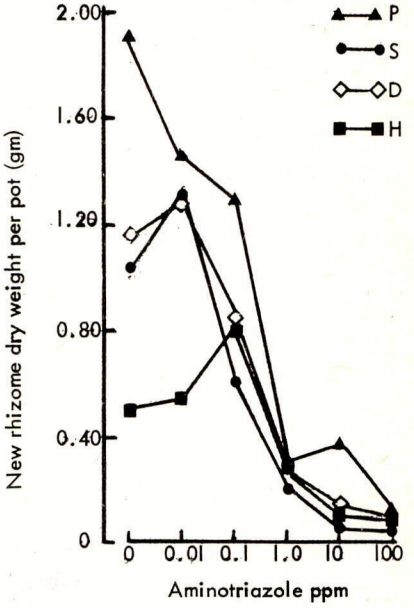


Fig. 4

Expt. I. Root application
Aminotriazole



had a large effect (P = 0.001) and the herbicide x dose interaction was very significant (P = 0.001) for the dose response with dalapon was much less marked than with aminotriazole. The clones differed in the dose required to produce significant reduction from the control values. For dalapon new rhizome production by the S clone was depressed by 0.01 ppm, D required 10 ppm and P 100 ppm. For aminotriazole P required 0.01 ppm, S 0.1, D 1.0 and H 10 ppm before new rhizome production was depressed (all P = 0.05).

Experiment 2. Shoot applied herbicides

Total dry weight

There were overall differences between the clones following application of aminotriazole (Fig. 5), P producing most and D least dry weight (P = 0.05). Although increasing the dose reduced dry weight the response curve for all the clones were very similar, 100 ppm being the

lowest dose which reduced dry weight. The dalapon treated plants were harvested later and hence the dry weight values are higher but the effects of dalapon were relatively slight except at the dose

Fig. 5

Expt. 2. Foliage application
Aminotriazole

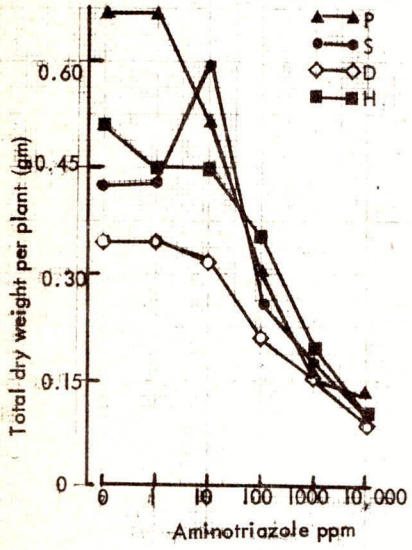
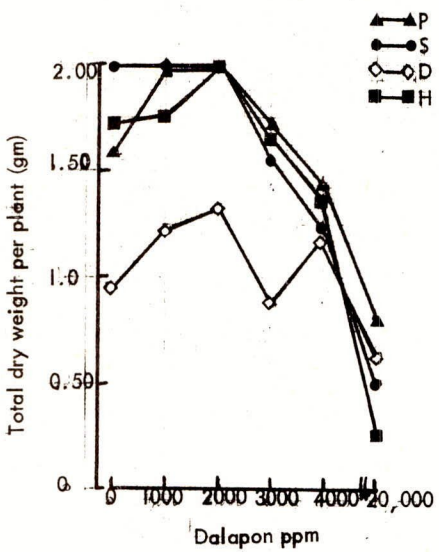


Fig. 6

Expt. 2. Foliage application
Dalapon



of 20,000 ppm in all clones and at 4000 ppm in the S clone (P = 0.05) (Fig. 6). For both chemicals the greatest differences between the clones were recorded in the absence of herbicide.

New rhizome production

New rhizome production was very limited and the results are not presented. The only significant feature was that 1000 ppm aminotriazole inhibited new rhizome production completely.

DISCUSSION

The primary purpose of these experiments was to search for differences between four selected clones of Agropyron repens and in this respect the experiments were reasonably successful. No attempt at field relevance was made and the differences recorded may not have been reproduced if assessments had been extended for a longer period.

The major differences between clones which appeared do not seem to be directly related to performance following herbicide treatment; rather were they biological. From the root treatment experiment clone H emerged as yielding less total dry weight and less new rhizome than the other clones and this was particularly marked in the absence of herbicide treatment. In the second experiment the H clone did not show the same characteristics; the D clone was in this case least productive. There were clear differences between the experiments irrespective of the site of application of the herbicides. The first experiment was made in early summer and the plants were grown in quarry sand culture, the second in winter with the plants in water culture. Under these circumstances it is clearly unwise to compare the responses of the clones to the two methods of supplying the herbicide.

Examination of the results of the first experiment shows that the S clone was the most sensitive to both herbicides, if sensitivity is reflected by the minimum dose required to reduce dry weight production below the value of the control. The S clone was also the most sensitive to dalapon in respect of new rhizome production but the P clone was the most sensitive to aminotriazole. The H clone was the least readily depressed. Sensitivity however is a comparatively unsatisfactory measure of clone response for from the results of the present experiment it can be seen that the overall differences between clones in total yields of dry matter and of new rhizome were by no means maintained at all doses for despite being most sensitive the S clone still produced as much dry weight as the less sensitive D clone following some of the herbicide treatments.

It is clear that the differences between the clones in the control treatments were the most striking. The cause of these differences is not understood but they were reflected also in tiller numbers at harvest (see as example Table 2).

Table 2

Expt. 1. Mean number of tillers per pot at harvest

Clone	Tiller number	
	Control	All treatments
S	25.8a*	24.1a*
D	22.5a	19.4b
P	20.7a	17.7b
H	16.8b	15.1c

* When values within a column share a common letter they do not differ significantly at the 5 per cent level.

Although no relevance to the field situation is claimed it is suggested that more studies of clonal variations are necessary particularly for weeds like A. repens where morphological variability is so evident.

Acknowledgements

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